A STUDY ON THE ENGINEERING AND DURABILITY PROPERTIES OF POLYMER MODIFIED MORTAR (PMM)

WONG WEI KAI

UNIVERSITI TUNKU ABDUL RAHMAN

A STUDY ON THE ENGINEERING AND DURABILITY PROPERTIES OF POLYMER MODIFIED MORTAR (PMM)

WONG WEI KAI

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Science (Hons.) Construction Management

Faculty of Engineering and Green Technology
Universiti Tunku Abdul Rahman

September 2016

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature	:	____________________________
Name	:	WONG WEI KAI
ID No.	:	14AGB00985
Date	:	02 September 2016

APPROVAL FOR SUBMISSION

I certify that this project report entitled "**A STUDY ON THE ENGINEERING AND DURABILITY PROPERTIES OF POLYMER MODIFIED MORTAR (PMM)"** was prepared by **WONG WEI KAI** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Science (Hons.) Construction Management at Universiti Tunku Abdul Rahman.

Approved by,

Signature : _________________________

Supervisor : Dr. Kwan Wai Hoe

Date : _________________________

Specially dedicated to
my beloved parents. Without their support, understanding,
and most of all love, the completion of this work
would not have been possible.

ACKNOWLEDGEMENTS

I would like to take this opportunity to express my gratitude to all parties who had involved throughout the process of completing this research project. First and foremost, I would like to acknowledge the opportunity given by Universiti Tunku Abdul Rahman to conduct this research and given the sufficient access to the facilities in order for me to complete this efficiently.

Next, I would like to express my gratitude to my research supervisor Dr. Kwan Wai Hoe and moderator Mr. Tey Kim Hai for their invaluable advice, guidance and enormous patient given to me throughout the process of this research. Besides, I would like to express my appreciation to Mr. Cheah Chew Keat and Encik Ekhwan Izzadi Bin Mat Saleeh for their advices and technical assistance in completing this research.

In addition, I would also like to express my gratitude to my loving parents for their continuous moral support and my course mate especially Leong Ee Laine who had helped and given me encouragement for me to continuously keep the passion and effort to complete this research.

A STUDY ON THE ENGINEERING AND DURABILITY PROPERTIES OF POLYMER MODIFIED MORTAR (PMM)

ABSTRACT

The performance of mortar can be improved by introducing polymer modified cement additive. People in the industry do not have sufficient knowledge on PMM. Besides, most of the previous research was done in other country but not in Malaysia perspective. This research was carried out to determine the optimum percentage of PMM mixed by SBR-Latex and make comparison with the market available polymer modified cement additive in Malaysia. This research consist of 2 phases, first phases involved determination of Optimum percentage by 3 variable which is 5%, 10% and 15% of SBR-Latex added based on the weight of cement. Water cement ratio applied is 0.4 with cement sand ratio 1:3 in phase 1. After obtaining the optimum percentage, the samples were then compared with the market samples in phase 2. Flow table test was conducted to determine the workability of PMM. Mechanical test include compressive strength test, flexural strength test and UPV test. Intrinsic air permeability test, water absorption test, porosity test and water absorption test were carried out to determine the durability properties of PMM. In the first phase, the optimum percentage obtained is 11.5%. Higher percentage of polymer gain higher workability, lower permeability and lower compressive strength. In phase two, Pentens with 8% polymer added and 0.3 water cement ratio has overall better performance compared with Optimum, CMI and Sika.

Keywords: polymer modified, SBR-Latex, optimum percentage, engineering properties, durability properties, compared market sample.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE	TITLE	PAGE

LIST OF ABBREVATIONS

Hcl	Hydrochloric Acid
H_2O	Water
OPC	Ordinary Portland Cement
PMC	Polymer Modified Concrete
PMM	Polymer Modified Mortar
PVA	Polyvinyl Acetate Emulsion
ASTM	American Society for Testing and Materials
BS	British Standard
P	Maximum load at failure
l	Span length (mm)
d	Depth of beam (mm)
b	Width of the beam (mm)

LIST OF SYMBOLS

°C	Degree Celcius
%	Percentage
g	Gram
kg	Kilogram
Nos	Numbers
m	Meter
m^3	Cubic Meter
mm	Millimeter
µm	Micrometer
mm^2	Millimeter Square
L	Litre
MPa	Megapascal
N	Newton
kN	Kilonewton
s	Seconds
km/s	Kilometer per second

CHAPTER 1

INTRODUCTION

1.1 Research Background

Concrete is the composite material mainly consist of cement, water and aggregate. This composite material had been used for many years in construction. The mixture can be easily shaped and molded and give high compressive strength after go through the hydration and curing process. This technology was invented around 300BC during the Roman Empire, and was developed and improved by the researcher until today. Passing through many years, concrete still the best material to use in construction as it can last long and it strength can meet the desire requirement.

Due to the nature of concrete that transformed from plastic state to solid state through hydration process, some problems occur to affect the final performance of the concrete during the chemical process. Problems such as delay in hardening, low chemical resistance, plastic shrinkage, crazing, scaling and other concrete failure that caused by poor workmanship, weather constraints, and improper planning on pouring concrete, these factors lead to low workability of concrete, rapid loss of water content in concrete and finally lead to poor quality of concrete.

To encounter the problems, cement additive can be used to improve or make the concrete to meet the desire performance when the required performance of concrete unable to achieve caused by the weather constraints or time constraints. Additive is the substance added to the concrete in relatively small amount to improve desirable properties or suppress the undesirable properties. Additive able to modify the properties of hardened concrete, reduce the cost of using concrete, ensure the quality of concrete during mixing, transporting, pouring and curing; and also to encounter or overcome the emergencies problem during concrete operation.

Polymer modified mortar (PMM) uses a polymer binder in place of Portland cement, polymer additive such as thermoplastics, thermosets like epoxy resins which hardens, elastomers or rubbers, naturals polymers cellulose, lignin and proteins are added into the mix to achieve the desired properties (Kardon, 1997).

When certain types of admixtures are blended into Portland cement concrete, the resulting mixes may be called polymer modified concretes. To be able to increase the compressive strength of the concrete, resinous polymers such as epoxy, vinyl ester, and furan types of additive can be added to the mix, as well as increase the resistance to acid due to nonabsorbent properties of the polymers ("Materials of Construction : Polymer Concrete vs. Polymer Modified Concrete," 2008).

Besides, polymer modified concrete have a lower degree of permeability and higher density than the pure Portland cement concrete, but it still dependent on the Portland cement to form it's structure integrity ("Materials of Construction : Polymer Concrete vs. Polymer Modified Concrete," 2008).

The polymer modified additive selected to conduct this research is SBR-Latex. SBR-Latex is an admixture consist of carboxylated styrene butadiene copolymer which integral the adhesive strength for cement bond. The performance of concrete after adding SBR Latex with 5%, 10% and 15% by weight of cement are tested, recorded and analysed on this research, emphasize the advantages of using polymer modified concrete over normal mix concrete.

By increasing the performance of concrete, it able to make full use of resources, leading to material cost saving, and make the project more productivity and efficiency. This research clarifying the use of polymer modified additive and enhance the knowledge on polymer modified concrete.

1.2 Problem Statement

Malaysia is a developing country, where construction industries play an important role in helping the country to become a developed country. Concrete is the main material used in construction industry as it is durable, versatile and cost effective compared with other materials such as wood. Over the years, upon the demand of the market, more durable and high performance concretes are invented. Polymer additive are commonly used in construction industry to increase the performance of concrete and mortar.

Ordinary concrete brings some inconvenience to the industry as once the concrete mixed, the chemical reaction of cement and water reacted immediately and this would affect performance of concrete if the pouring time were delayed. For high-rise building construction, the fresh mixed concrete need to maintain its workability during transporting and pumping up to the concreting area. Failed to do so, the performance of concrete are affected and thus lead to increasing in construction waste. Concrete that fails to meet the designed strength or performance need to be removed and reconstruct.

PMM consist of mining sand bonded together by resin binder instead of water cement alone that used in ordinary mortar. The polymer modified cement additive allows the concrete to achieve the desired performance. The ordinary mortar can be very durable but not as durable as the PMM, the ordinary mortar required longer time to be cured compared to the PMM.

Although it’s mentioned on the package that the additive could increase the performance of concrete, the exact data on performance of polymer modified concrete and ordinary concrete need to be tabulated and clarify. PMM might be high at the initial cost, but when sustainability and durability come into consideration, it is a good choice.

Ordinary concrete is strong in compressive strength but weak in tensile. It is a porous material as it forms pores itself when hardens, as through the hydration process, the reaction between water and cement, the capillary water dries out and leaves interconnected pores (Islam, Rahman, & Ahmed, 2007.). The pores become a bridge for the gases and water vapour to penetrate the concrete or mortar, different chemical content in some gas might damage the mortar or damaged the reinforcement bar in the concrete structure. Due to the weak adhesive strength and poor chemical resistance of ordinary concrete, abrasions occur and weaken down the concrete strength.

Mortar often use as the protective layer or bonding agent in construction industry. The durability properties such as porosity and air permeability are important to maintain a good mortar performance. Poor performance mortar may lead to cracks and make the internal layer unprotected.

Lastly, the local people has insufficient knowledge on PMM which they applying it without understanding its function. Most of the previous has been done in other country but not on local people perspective as the polymer cement additive applied and obtained could be different.

1.3 Aim and Objective of Study

The aim of this study is to determine the performance of polymer modified mortar that made up by mixing SBR-Latex and compare with the market available polymer cement additive. Sometimes due to the nature of project, time limitation and workmanship, it could affect the final mortar performance. Besides, the optimum percentage of PMM mixed by SBR-Latex is determined in this research. The following objective has been conducted to complete this research:-

i. To investigate the workability and mechanical properties of polymer modified mortar (PMM) with 5%, 10% and 15% weight of cement added to the mixture.
ii. To evaluate the durability properties of PMM.
iii. To compare the basic PMM mixed by SBR-Latex with the market polymer additive.

1.4 Scope of Study

The scope of study of this research are focused on laboratory experiments to determine the performance of PMM with different market polymer additive, by analysing the workability, mechanical properties, durability, permeability and chemical resistance of PMM. By adding SBR-Latex to the mixture with 5%, 10% and 15% by weight of cement in phase one.

The water cement ratio is 0.4 in phase one and the cement sand ratio is 1:3. Whereby, the mix proportion of PMM in phase two were mixed with accordance to the guidance on package. All the specimens going through two curing process, 7 days of wet curing process in curing tank and follow by the dry curing process under ambient environment.

Workability of fresh mixed PMM is analysed through flow table test. Compressive strength test, flexural strength test and Ultrasonic Pulse Velocity (UPV) test will we tested on harden PMM to determine the mechanical properties of PMM with comparison to market available polymer modified cement additive.

Durability of polymer modified mortar is analysed by intrinsic air permeability test, water absorption test, porosity test, and acid resistance test. These tests are carried out to determine and analyse the performance of PMM by SBR-Latex in compare PMM by market available polymer modified cement additive upon durability of the mortar in common practice.

1.5 Significant of Study

Polymer modified cement additive are commonly used in the industry to increase the workability and increase the performance of mortar. In Malaysia, construction industry practice used polymer modified cement additive to increase the workability of fresh mixed mortar without knowing how it could affect the performance of hardened mortar. Besides, polymer modified mortar are rarely applying in Malaysia as the conventional mortar are more preferable in the industry. Although polymer modified mortar can be very costly but in term of sustainable and durability, it's more cost efficient compared to the conventional mortar.

The performance of polymer modified mortar on its mechanical properties and durability are emphasize on this research to rise the interest of construction industry in Malaysia to apply PMM in certain parts of the project. This research introducing new information on different brand and types of polymer that easily obtained in the industry. Different types of polymer used and mix design will results in different performance of PMM, the application of PMM need to be determined before choosing the right types of polymer cement additive to be used.

1.6 Research Framework

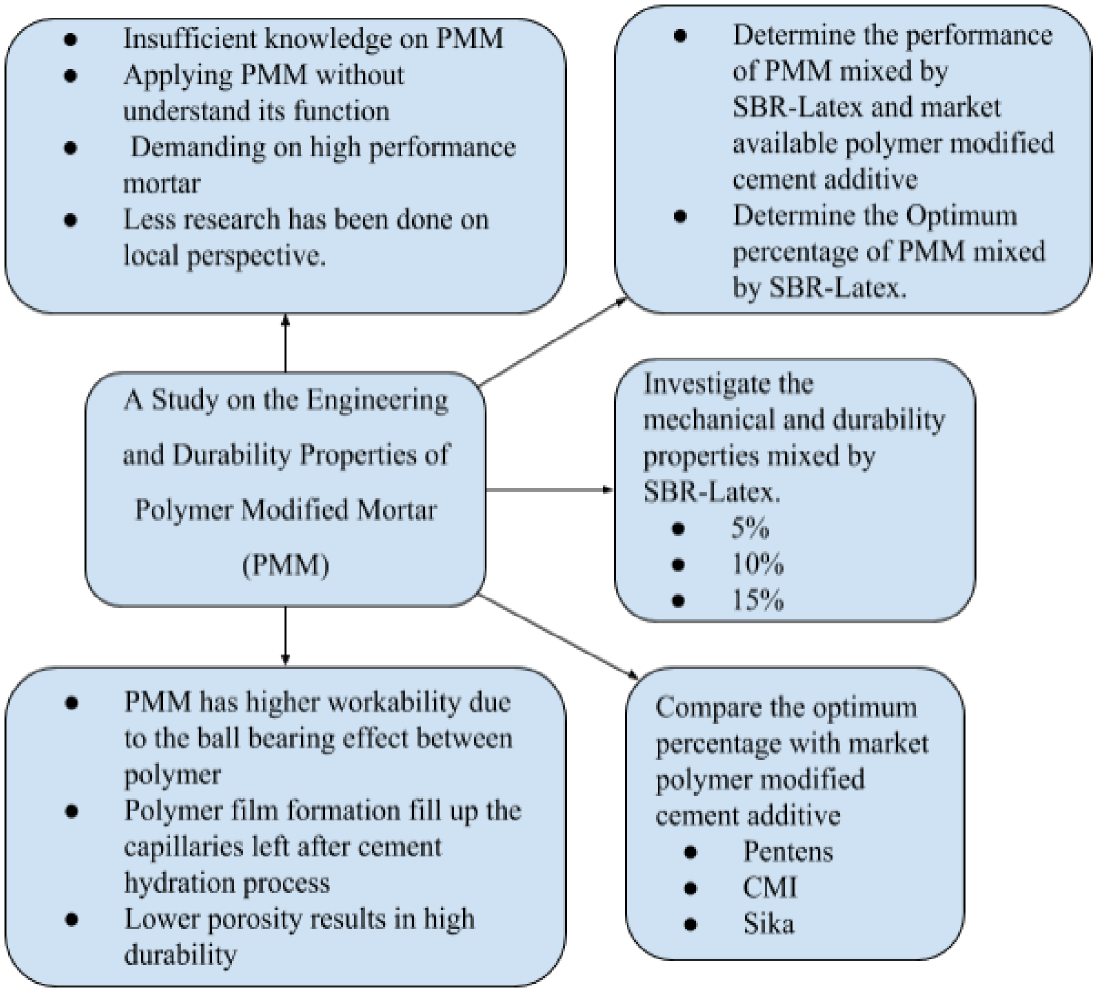


Figure 1.1 Research Framework

CHAPTER 2

LITERATURE REVIEW

Literature review was exercise to study the relevant information related to the research. As a guide to determine the information that need to be collect and analyse in the research topic, to achieve the aim and objective of this research. In this chapter, literature review on additive and admixture for concrete, development of concrete technology is studied. Moreover, composition of concrete, properties of concrete after mixed with additive, content of polymer modified cement and performance of polymer modified mortar and concrete are review based on the previous research related to PMM or PMC. Previous researches that have been done on how different percentage of polymer modified cement additive in weight to cement will affect the performance of PMM or PMC are studied.

2.1 History of concrete

Cement was made up by using gypsum or crushed limestone in the ancient period. They found that, the cement become adhesive and able to bond the stones together when sand and water were added together. In about 1300BC, the Middle Eastern builders accidentally found that the when the burned limestone are used to stick on the walls, chemical reaction occur between limestone, and water and form a hard protective surface. Although it wasn't concrete, but it generated an initiation for the development of cement and concrete (Nick Gromicko, 2014).

The first concrete like structures was built by the Nabataea traders or Bedouins in southern Syria and northern Jorden who own a small empire in around 6500 BC. Besides, they discovered the hydraulic lime which that the cement is hardens underwater. A Kilns were built to supply mortar for their construction work use (Nick Gromicko, 2014).

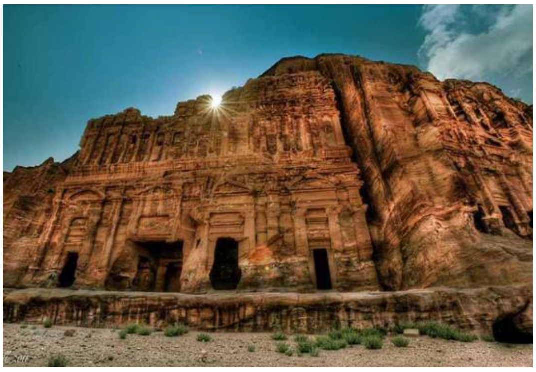


Figure 2.1 Nabataea Concrete Like Structure

Around 3000 BC, the ancient Egyptians developed brick that made mum by mixing stay together with the mud which more like a adobe. They had used gypsum and lime mortar in the construction of their significant building, the pyramids. The Great Pyramid at Giza had used about 500,000 tons of mortar in the construction work, for the finishing of the pyramids and also beefing purpose. This allowed stone masons to be carved and set casing stones with joints open no wider than 1/50-inch (Nick Gromicko, 2014).

In 300BC, the Romans used animal products in their cement as admixture to achieve the desire properties of concrete. The concrete used in Roman are closest to modern cement to build their architectural marvels, such as the Colosseum, and the Pantheon. The admixtures they use are developed as today's admixture. In 1824, Portland cement was invented by Joseph Aspdin in England ("Timeline of Concrete & Cement History," 2010.). Portland cement is the basic ingredient of concrete, it is a closely controlled chemical combination of calcium, silicon, aluminium, iron and small amounts of other ingredients to which gypsum is added in the final grinding process to regulate the setting time of the concrete ("Timeline of Concrete & Cement History," 2010.).

The first compressive strength test and tensile strength test of concrete took place in Germany in 1836. The ability for concrete to resist the compression is the compressive strength, whereby tensile strength refer the ability of concrete to resist tension (“Timeline of Concrete & Cement History,” 2010.). Both of this mechanical properties are important in concrete development, when both properties can be determine, the designed concrete load bearing capacity can be easily achieve. Concrete have high compressive strength but low tensile strength, and thus the reinforced concrete were introduced. In 1889, the fist reinforced concrete bridge was built in San Francisco, and the bridge still last until today named Alvord Lake Bridge (“Timeline of Concrete & Cement History,” 2010.).

In 1891, the first concrete street was built in America in Bellefontaine, Ohio. The concrete used for this street tested at about 8,000 psi, which is about twice the strength of modern concrete used in residential construction (Nick Gromicko, 2014). The first concrete high rise was built in Cincinnati, Ohio, with 16 storey height in 1903 which is the highest concrete building at the time named Ingalls Building (“Timeline of Concrete & Cement History,” 2010.).

The first concrete homes were built in Union, New Jersey in 1908 by Thomas Edison. The design is still exist until today where he hopes that everyone in the America will own a concrete home. His expectation didn't come to real where the concrete homes just become popular now which is one hundred year later (“Timeline of Concrete & Cement History,” 2010.).

Figure 2.2 Hoover Dam

The first load of ready mix was delivered in Baltimore, Maryland in 1913 (“Timeline of Concrete & Cement History,” 2010.). The idea that concrete could be mixed at a central plant, and then delivered by truck to the job site for placement, revolutionized the concrete industry. In 1930, to prevent freezing and thawing, air entraining agent were used for the first time (“Timeline of Concrete & Cement History,” 2010.). The Hoover Dam was built along the Colorado River, bordering Arizona and Nevada (“Timeline of Concrete & Cement History,” 2010.). It was the largest scale concrete project ever completed.

In 1970, fibre reinforced concrete was introduced to strengthen the concrete (“Timeline of Concrete & Cement History,” 2010.). The fibres include glass fibre, synthetic fibre and natural fibre. Fibre reinforced concrete contains short discrete fibre that are uniformly distributed and randomly oriented to increase the structural integrity. A 65 storey tallest concrete building was built in 1992 in Chicago, Illinois (“Timeline of Concrete & Cement History,” 2010.).

Until today, the world’s tallest building the Burj Khalifa in Dubai in the United Arab Emirates (UAE) stands 2,717 feet tall was built in 2011. Construction used 431,600 cubic yards of concrete and 61,000 tons of rebar (Nick Gromicko, 2014).

Figure 2.3 Burj Khalifa in Dubai

From the history of concrete development, people try to make the concrete more and more advance in the form of its mechanical properties, increasing the compressive strength, tensile strength, workability by replacing the aggregates, bonding agent to other alternative. This could maintain or increase the performance of concrete while generate less impact to the environment. Additives and admixture were being used to change the properties of the concrete to encounter the extreme weather and meet the desirable performance.

Over thousand years, as the technology advances, the researcher passes through experiment, again and again until today, the modern concrete. Modern concrete using Portland cement, aggregates, mining sand and water mixed together and chemical reaction occurs between cement and water become a bonding properties through hydration process.

Admixtures are added to the concrete mix to control it setting properties, or used it during extreme weather that will affect the mechanical properties of hardened concrete.

2.2 Cement

Cement is the material that has adhesive properties that able to bond the materials together (Neville, 2011). The main material to produce concrete is by using limestone. Whereby the production of cement brings pollution to the environment as large amount of carbon is emitted during the process.

In construction, cement is used to bond the concrete materials together include coarse aggregates and fine aggregates. Cement becomes a bonding agent when it reacts with water, hydration process of the cement gained adhesive bonding strength.

2.3 Additive and Admixture

Admixture can be defined as a material other than water, aggregates, hydraulic cement and fibre reinforcement, use as an ingredient of a cementitious mixture to modify its freshly mixed, setting or hardened properties and that is added to the batch before or during its mixing ("Concrete Materials & Admixtures," 2008). Additive is a substance added to another in relatively small amount to impart or improve the desirable properties or suppress undesirable properties ("Concrete Materials & Admixtures," 2008).

Concreting is a time sensitive project which unexpected delays may cause major problems to the concrete. Admixtures can enhance the workability and modified concrete's properties to improve the performance of concrete. Besides, fresh concrete that are rejected due to delays or weather constraints, can be restored by admixtures ("Concrete Materials & Admixtures," 2008). Admixture include, accelerating admixtures, air entraining admixtures, retarding admixtures, and water reducing admixtures. Polymer modified cement additive such as polymer emulsion could increase the durability of mortar ("Cement/Polymer Composite Technology," 2015). Figure 2.4 shows the mechanism of cement dispersion in PMM.

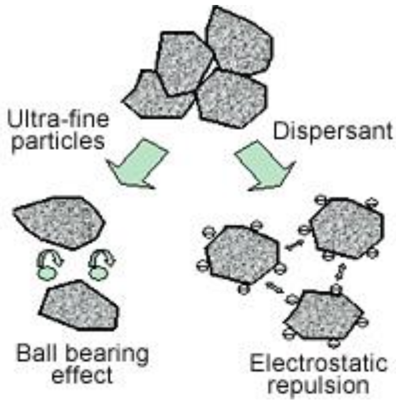


Figure 2.4 Mechanism of Cement Dispersion in PMM ("Cement/Polymer Composite Technology," 2015)

2.4 Concrete Technology

The stature of concrete as a major construction material has strengthened by the rapid development in the field of concrete technology. Concrete technology has entered into a high technology profession, with a potential utilization far beyond the traditional construction industry (Gjorv, 2012).

Over recent years a rapid development in the field of concrete technology has taken place. By combining new innovations in materials and production technique, provided a new basis for producing high performance concrete structure and concrete products which increasing the challenges in construction industry (Gjorv, 2012).

Today, concrete with high compressive strength, up to 230MPa able to produce by using natural aggregates. If the natural aggregates are replace with some high performance aggregates, up to 500MPa compressive strength concrete can be produced. Lightweight concrete with 1800kg/m^3 density can have compressive strength up to 110MPa. With new production technique such as hot curing and high molding pressure can produce a concrete with compressive strength up to 800MPa (Gjorv, 2012). Although some of the new concrete technology keeps facing failure and poor performance, by the effort and passion of researcher, more and higher performance concrete technology can be invented.

High strength concrete is categorized by a low porosity and more uniform microstructure compared to a normal concrete, “high strength concrete” is much equivalent to “high durability concrete” or “high performance concrete”. Thus, improving the overall performance to achieve greatest potential is more practical then solely increase the compressive strength of the concrete (Gjorv, 2012). A high abrasion resistance and durable concrete is highly demand in current industry, which make the product more durable and environmental friendly.

High strength lightweight concrete with the compressive strength in range 55MPa to 65MPa has been used in the market. Probably not used in Malaysia, it had been used to construct Norwegian bridges, one floating bridge and one offshore floating platform (Gjorv, 2012). Lightweight concrete technology still keep on innovating, modifying by incorporating small amount of lightweight aggregates.

Other new concrete technology such as by adding optical fibre into the concrete mix, translucent concrete can be produced. The reactive powder concrete which is extremely workable, durable and have ultra-high strength without using course aggregates. It can achieve 30,000psi compressive strength, steel and synthetic fibre are introduced to concrete to increase the tensile strength of concrete. Besides, self-consolidating concrete provide a smooth surface with our segregation eliminated the need for mechanical consolidate ("Emerging Trends and Innovations in Concrete," 2015).

2.5 History of Polymers in Concrete and Mortar

Natural polymer such as bitumen, albumen, blood, rice paste and others are being use in construction thousand years ago. The temple of Ur-Nina (King of Lagash), in the city of Kish, had masonry foundations built with mortar made from 25% to 35% bitumen which is the natural polymer mixed with loam, chopped straw or reeds (Kardon, 1997).

In 1909, the earliest indication of using polymers is on Polymer cement concrete (PCC) in United State where the patent for such use was granted to L.H.Blackland. Around 1940s, synthetic polymer was invented due to insufficient supply of natural rubber as being used for war time. In 1950s, incorporate of synthetic polymer with portland cement mortar and concrete (Kardon, 1997).

Different countries conducted different research on development of concrete polymer composites due to different background. Country such as US, UK, Russia, Japan and Germany are very active in development of concrete polymer composites for the past 40 years (Yoshihiko Ohama, 1994). Hence, concrete polymer composites are being developed to high performance concrete, and get the attention of mechanical, electrical and chemical industries (Yoshihiko Ohama, 1994).

Concrete polymer composites are made by replacing a part or all of the cement hydrate binder of mortar or concrete with polymers, by strengthening the cement hydrate binder with polymers. The concrete polymer composites can be classified into Polymer modified mortar (PCM) or concrete (PCC), Polymer Mortar (PM) and Concrete (PC), Polymer Impregnated mortar (PIM) and Concrete (PIC).

2.6 Introduction to Polymers

Polymers are materials with long chain molecules that are composed of large number of repeating units of identical structure (Fried, 1995). There are 3 main structures of polymers named linear polymers, branched polymers and crosslinked polymers. The structures of the polymer are shown in the Figure 2.5.

Linear polymers are formed by a long chain of monomers which the structure cannot turn in any direction. Branched polymers consist of a chain that bonded to the molecular chain, this chain formed with the presence of monomers in the reactive group. Crosslinked polymers are formed by 2 or more molecular chain and linked by a short side chain.

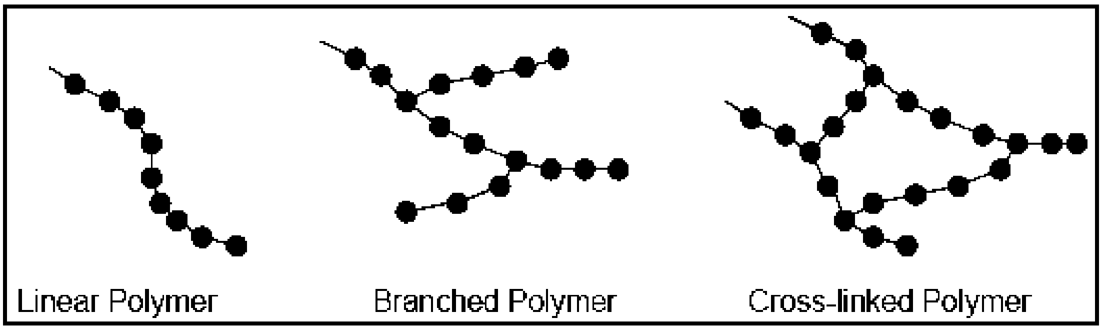


Figure 2.5 Polymer Structure (Fried, 1995)

2.7 Polymer Modified Concrete

PMC are prepared by mixing polymers or monomers in a dispersed liquid or powder form with cement mortar and concrete mixtures (Ohama, 1995). PMC required 2 phases of curing which are wet curing and dry curing (Ohama, 1995). Wet curing happens under high humidity environment for cement hydration process to continue and gaining strength. Dry curing process occurs for polymer film formation to gain more flexural strength and fill up the pores left by hydration process.

PMC generally doesn't increase in compressive strength but it increase in tensile strength (Ohama, 1995). The polymer structure in the concrete increases its workability and flexural strength.

2.8 Mechanism of Polymer-Cement Co-Matrix Formation

The formation of co-matrix by cement and polymers is simplified as shown in the Figure2.6. The steps involved hydration process, formation of polymer film, and combination to form a bonded concrete (Ohama, 1995).

The first step, when the ingredients of concrete first mixed and form fresh concrete, the polymer particles dispersed throughout the cement paste. While hydration process occurs, the cement gel formed and produces ettringite and large CH crystals at the voids between the aggregates.

Polymer particles deposited on the cement gel and on the unhydrated clinker particles. A calcium silicate layer is form when the calcium hydroxide from the hydration process reacts with a silica surface of the aggregates.

The second step is when the water being consumed in hydration process; the polymer particles gradually concentrate in the capillary pores. By the growth of cement gel from the hydration process, the polymer particles flocculate to form a continuous close-packed layer of polymer particles on the gel surfaces, unhydrated cement grains, and on the developing silicate layer over the aggregates. Thus, the larger pores are filled with adhesive polymer particles.

Reactive polymers on the particle surfaces such as polycrylic esters (PAE), poly styrene-acrylic ester (SAE), polyvinylidene chloride-vinyl chloride (PVDC) and chloroprene rubber (CR) latex may react with calcium ions (Ca2+) or calcium hydroxide [Ca (OH)2].

In the third phase, water withdrawal from the hydration process followed by the formation of continuous polymer film or member arranged closely at the surface of hydrated cement. The polymer film or membranes bind the cement hydrates together to form a monolithic network in which the polymer phase interpenetrates throughout the cement hydrate phase. This structure acts as a matrix phase for latex-modified concrete, and the aggregates air bound by the matrix phase to the hardened concrete.

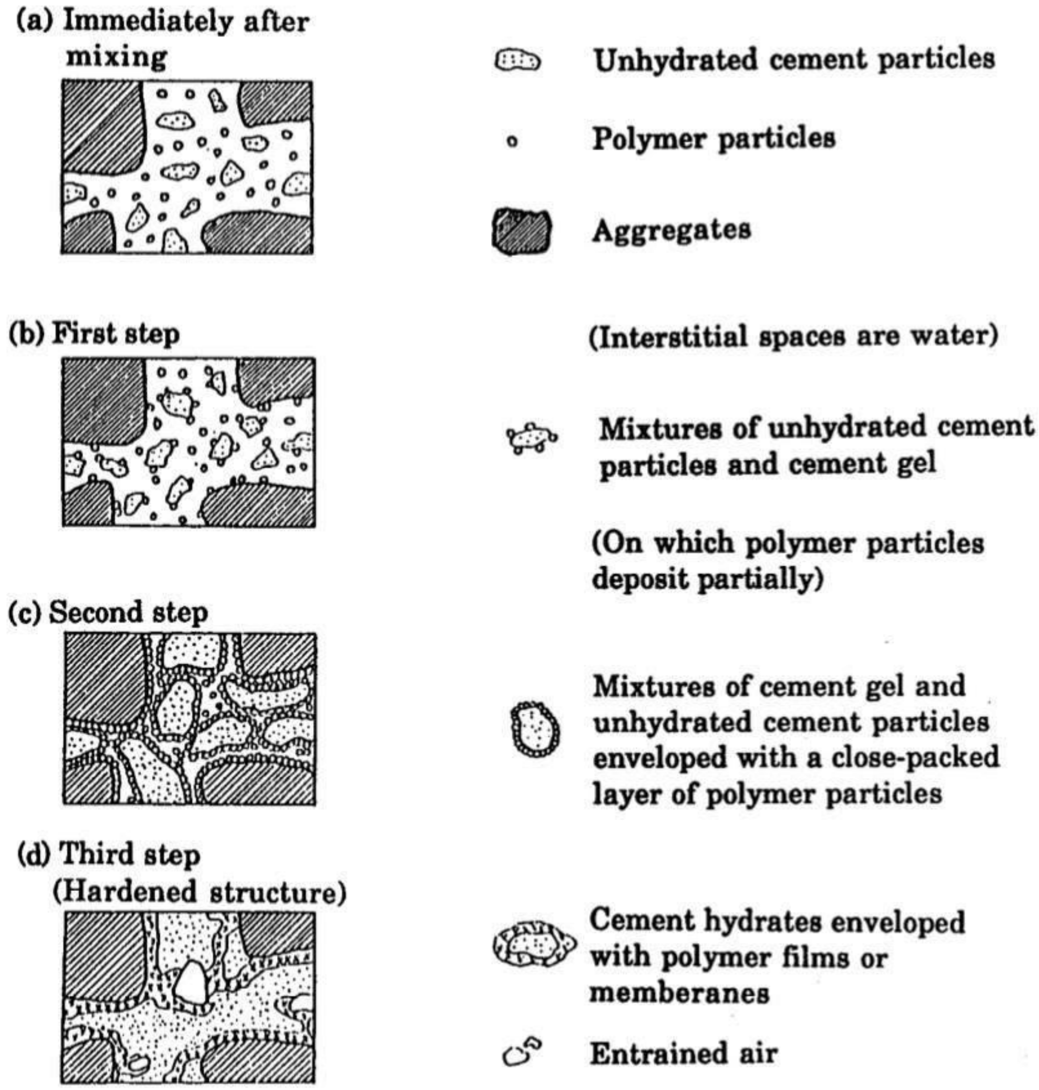


Figure 2.6 Formation of Polymer in Concrete (Ohama, 1995)

2.9 Review on Polymer Modified Concrete

A study was conducted to determine the mechanical properties of polymer modified concrete by polymer cement ratio at 0% to 30% by weight of cement (Aggarwal, Thapliyal, & Karade, 2007).

The compressive strength of ordinary water cured concrete is 39.5 MPa and 45.0MPa at 28 days and 90 days of curing age respectively. When the polymer cement ratio is more than 20% the compressive strength tested on 90 days of curing age is higher than the ordinary water cured concrete. However, at 30% polymer cement ratio, the flexural strength of polymer modified mortar is greater than he ordinary water cured mortar. The results show that, polymer modified by epoxy, flexural strength increased by 10% compared to ordinary water cured mortar.

The findings of this study is that when polymer additive added to the mortar, the workability improved, compressive and flexural strength increased, and water absorption decreased. Moreover, epoxy emulsion showed slightly better properties than acrylic emulsion at the same amount of polymer cement ratio

2.10 Workability of Fresh Mixed Polymer Modified Concrete

The workability of latex- modified mortar and concrete generally will have better workability compared to conventional concrete. The polymer particles in the concrete that gained from latex formed ball bearing action between the particles inside the concrete. Thus latex modified concrete become more fluidity and workable compared to the conventional concrete. The workability is increased by increasing the water cement ratio, same theory apply to the latex modified concrete (Ohama, 1995). However, by increasing the water cement ratio in order to increase the workability of concrete, the strength of the concrete will decreased.

By adding polymers to concrete couldn't increase the compressive strength of the concrete, whereby it increases the workability of concrete as stated in the theory above. When the workability of concrete increase, the water content in the concrete can be reduced, as the water cement ratio decreased, the compressive strength of concrete increase (Ohama, 1995).

2.11 Compressive Strength and Tensile Strength of Polymer Modified Concrete

In general, latex-modified mortar and concrete show a noticeable increase in the tensile and flexural strengths but no improvement in the compressive strength as compared to ordinary cement mortar and concrete. This is interpreted in terms of the contribution of high tensile strength by the polymer itself and an overall improvement in cement-aggregate bond (Ohama, 1995).

A study on compressive strength and tensile strength of Polymer modified concrete (PMC) by replacing part of the cement to Polyvinyl Acetate Emulsion (PVA). It is expected to use high performance polymer modified concrete for repairing work in Pakistan (Arooj, Haydar, & Ahmad, 2011). The research was conducted with mix proportion of 1 : 1.5 : 3 with 0.5 water cement ratio and 7 days curing age. The test were conducted to compare between conventional concrete and polymer modified concrete (PMC) by using Polyvinyl Acetate Emulsion (PVA).

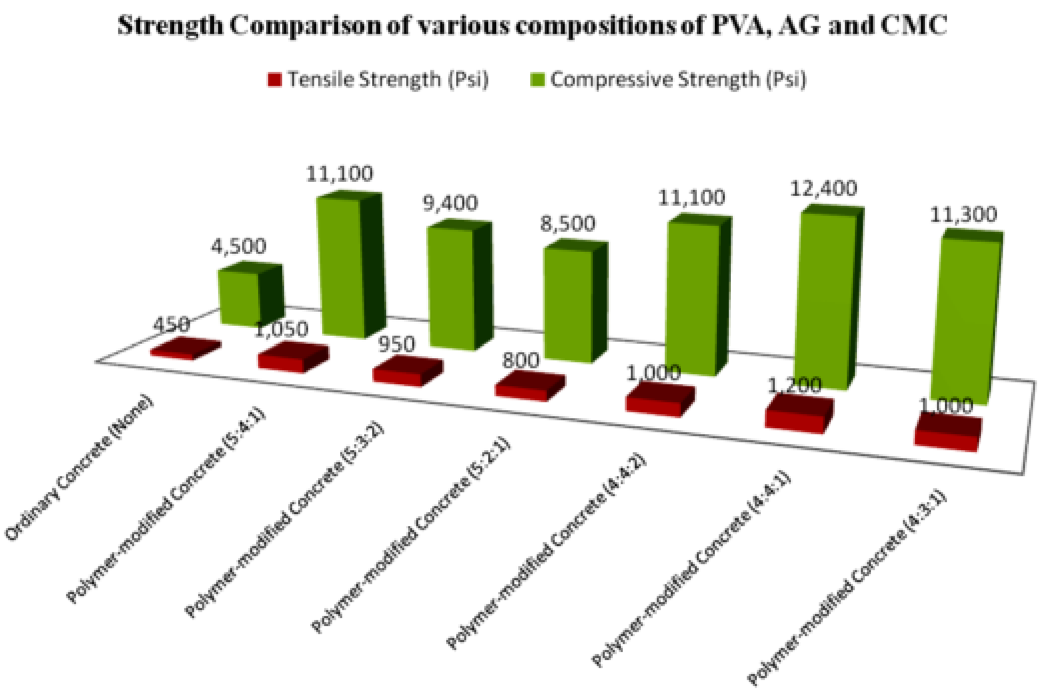


Figure 2.7 Strength comparison between different types of polymer modified concretes (Arooj, Haydar, & Ahmad, 2011)

Concrete cube specimens were then tested for compressive strength test. The highest compressive strength 12,400 Psi was achieved in polymer-modified concrete with the ratio of 4:4:1 by weight of PVA, AG and CMC, respectively. The compressive strength of Polymer Modified concrete is 3 times higher than the ordinary concrete. Where concrete beam specimens were use in flexural test, highest tensile strength was achieve by the same polymer modified concrete with 1,200 Psi. Conclude that with the high performance of polymer modified concrete (PMC) it is suitable to be used for repairing on structural work in Pakistan (Arooj et al., 2011).

As stated in the workability, when the polymer structures are introduced in the concrete, the compressive strength doesn't improve, and probably cause drop of compressive strength. The compressive strength in PMC will increase by reducing the water cement ratio. The compressive strength of PMC is affected by the natural materials used as latexes, cement, and aggregates; water cement ratio and polymer cement ratio; and the curing methods.

2.12 Durability of Polymer Modified Mortar and Concrete

From the study by (Aggarwal, Thapliyal, & Karade, 2007),durability of polymer modified concrete was determined by carbon dioxide penetration and chloride ion penetration. Epoxy based mortar shows greater resistance toward carbon dioxide penetration with comparison to acrylic based mortar and ordinary cement mortar. The result shows that at 10% polymer cement ratio the epoxy emulsion based mortar showed 45% reduction in carbonation, while it was 28% for acrylic based mortar. Whereby for 20% of polymer cement ratio in epoxy based mortar, carbon dioxide penetration greatly decrease by 75%.

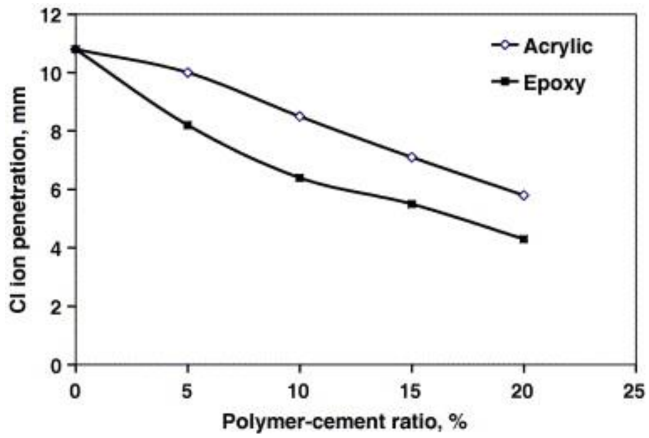


Figure 2.8 Relationship between Cl Ion Penetration and P/C ratio (Arooj, Haydar, & Ahmad, 2011)

In chloride ion penetration, the reduction is up to 60% at 20% epoxy based mortar mix. The reduction in chloride ion penetration is about 40% at 10% and 20% for epoxy and acrylic polymer mixed respectively. This indicates that epoxy emulsion mortar have greater resistant towards chloride ion attack. The result shows that polymer modified mortar has better durability as it has less porosity and chemical resistance.

Study was conducted to determine the durability of polymer modified concrete by F. Giustozzi. 4 types of polymer modified concrete were evaluated in the research, which is Polyvinyl Acetate (PVAC) latex mix, cationic SBR latex mix, Ethylene-Vinyl Acetate (EVA) powder mix and anionic SBR latex mix (Ohama, 1995).

The results show that the void content in the concrete was greatly reduced by polymers. Tested on mortar, with the addition of polymer, regardless of the particular type, generated a reduction of void by 6-12% with respect to control mix. Whereby, the void content of concrete reduced by 21-25% when sand was included. Durability of concrete also affected by tortuosity of the void network. The permeability of concrete was decrease by 21-45% when polymers were added to the concrete.

Durability of concrete is enchanted when polymer is added into the concrete mix. Polymer modified concrete have lower porosity and permeability, less abrasion is occurred and thus become more durable.

2.13 Method of Curing on PMM

There are two phases of curing for PMM. First is the wet curing for cement to cure to the optimum the take place under wet condition. Second, is the dry curing process for polymer particles to develop. Dry curing required a dry or low humidity condition for polymer film formation.

A study was done upon PMM samples under atmospheric surround with different humidity, the result showed reduction in strength of concrete. The properties of dried film are associated with lower temperature. (Ramakrishnana, 1992)

A study was done on PMM under different curing method, procedure 1 with simple wet curing with 95% humidity in ambient temperature; procedure 2 consist of 2 days wet curing and following by ambient temperature curing; procedure 3 involved 2 days steam curing under 60 degree follow by 4 days oven drying at 60 degree and one day cooling under ambient temperature (Ma & Li, 2013). The samples are then compared with the conventional mortar.

The result shows that, on the conventional mortar, the compressive strength reaches a mature level at the early age as by using steam curing, cement going through hydration process in higher temperature which is 60 degree and high humidity environment which increase the rate of reaction. On procedure 1, mortar continuously gain strength by hydration process with continuous 95% humidity environment.

While by using procedure 2, the compressive strength seem to be lower as the cement hydration process with high humidity only stay for 3 days and continue by ambient environment curing which make the conventional mortar's curing process slow down.

Come to the PMM, the overall compressive strength was decreased, the higher the polymer cement ratio, higher reduction of compressive strength with a constant water cement ratio. The results also show that, by using procedure 2, the method fits to requirement for PMM to cure which is combination of wet curing and ambient environment curing for both cement hydration process and polymer film formation process. The study was then compared conventional mortar and PMM by procedure 2.

The overall flexural strength of PMM is higher than the conventional mortar as shows in the results. But for the 3 days age of curing, PMC flexural strength is lower than the conventional mortar and wet curing doesn't form the polymer film. On 28th day, the polymer film had formed and the higher the polymer cement ratio the higher the flexural strength gain.

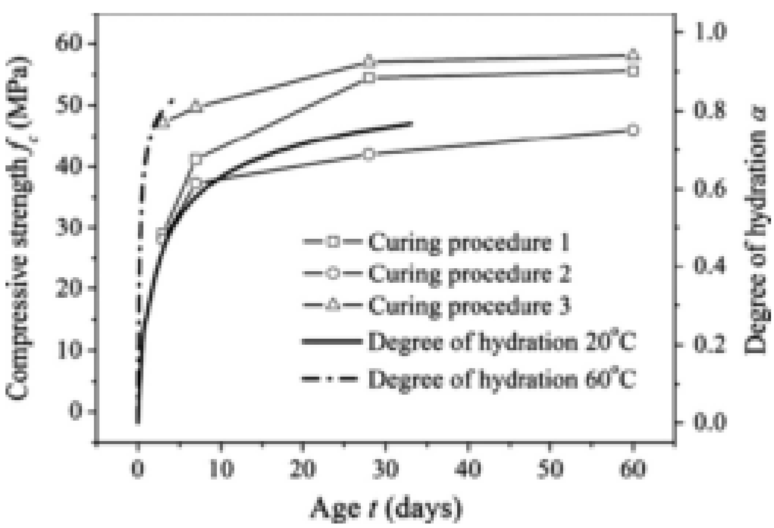
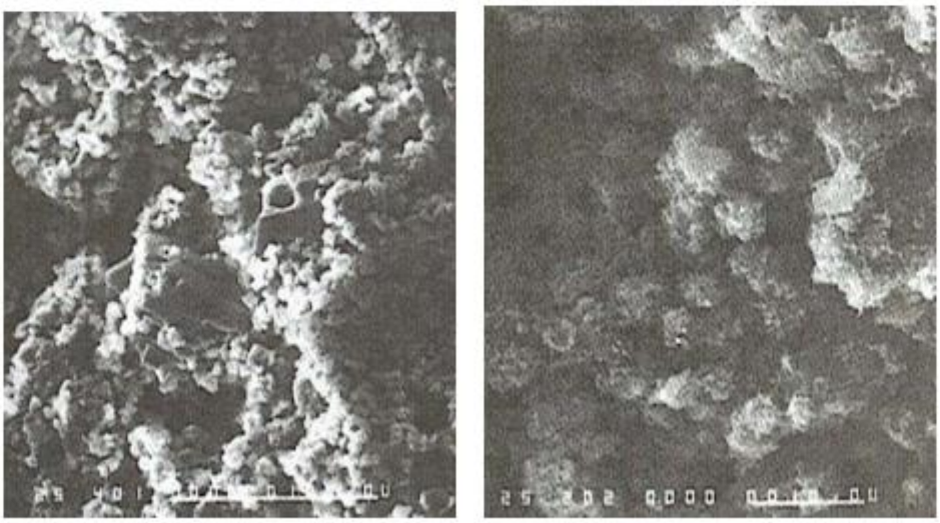


Figure 2.9 Influence of curing method on hydration and compressive strength development of un-modified mortar (Ma & Li, 2013)

2.14 Effect of Polymer on Total Porosity

The durability of mortar is dependent on its porosity. In fresh mixed mortar, the water occupied the available spaces. When the hydration process happen, the water used up the space and the capillaries left become the void (Mindness and Young, 1981).

PMM able to fill up the pores by the polymer film formation from polymer modified cement additive (Chandra, 1994). Hence, increase in polymer cement ratio will results in lower porosity as it had been fill by the polymer film (Ramakrishnan, 1992). Besides, curing length will affect the porosity of PMM, as the curing length increase, the polymer film formation continue developing and thus results in lower porosity (Makhtar, 1997). Porosity will influence the permeability of PMM as well, higher porosity leads to higher permeability and results in lower durability (Ramakrishnan, 1992). Figure 2.10 show the microcraking before and after adding polymer.



(a) (b)

Figure 2.10 (a) without polymer, (b) with polymer (Chandra, 1994)

2.15 Advantages and Application of PMM and PMC

Polymer modified concrete able to improve the workability and durability as the all bearing effect increase the workability and thus, lower water cement ratio can be applied (Ohama, 1995). Due to lower water cement ratio, PMM able to gain more strength and has a significant improvement on effect of freeze-thaw, climate constraint and higher chemical resistance as it has lower porosity (Kardon, 1997).

Currently, PMM is being applied on resurfacing, flooring and patching (Hirde & Dudhal, 2016). Besides, repairing work such as roadway, bridge or swimming pool applied PMM for a better adhesive strength and durability (Hirde & Dudhal, 2016). PMM has higher tensile strength, this characteristic allowed it to reinforced together with fibre to form a better quality concrete or mortar for works that required high tensile strength such as beam structure or bridge construction (Hirde & Dudhal, 2016). Substructure or infrastructure work that required certain resistance on chemical will required PMM or PMC to meet the requirement as PMM or PMC has a higher chemical resistance (Hirde & Dudhal, 2016).

2.16 Summary of Literature Review

From the literature review, PMM has higher workability as the polymer has ball bearing effect. Based on some of the research, the compressive strength of PMM is decreased with the same water cement ratio. PMM allow reducing the water cement ratio which could increase the strength of mortar. Besides, the literature review show that, the performance of PMM highly dependent on several factor which include polymer cement ratio, water cement ratio, types of polymer used, curing procedure and length of curing age.

Higher polymer cement ratio results in lower porosity and increase the impermeability, at the same time, it reduce the strength of PMM. Whereby, the durability of PMM increase as the polymer cements ratio increase. The polymer film formation fill up the capillaries left after cement hydration process, this results in higher durability of PMM compared with ordinary mortar.

As PMM has high bonding strength and durability, it could be used on repairing work and substructure work which required high adhesive strength and high chemical resistance.

Chapter 3

Research Methodology

The methods to establish this research are discussed in this chapter. This research consist of two phases Research methodology involved in this research is mainly laboratory experiments and tests to determine the performance of mortar after adding polymer modified additive with different percentage of weight to cement in the first phase. The optimum percentage of PMM mixed by SBR-Latex is then compared with the market polymer modified additives which include Pentens, CMI and SIKA. Besides, materials and types of test involved in the research are discussed in this chapter with accordance with British Standard and ASTM.

3.1 Materials

The objective of this research is to investigate the performance and durability of PMM mixed by SBR-latex with comparison to the market ready polymer additive. The materials required are ordinary portland cement (ASTM Type III), mining sand as fine aggregate, water and polymer modified cement additive. The polymer modified additive is measured to add 5%, 10% and 15% by weight of cement to obtain the optimum percentage in the first phase. In second phase, the optimum percentage PMM is then compared with market polymer additive with their guidance mix proportion.

3.1.1 Ordinary Portland Cement

Ordinary Portland cement is commonly used in construction for bricklaying, plastering, rendering, concreting, tiling and other construction work. It was used as a binder to produce Polymer modified mortar in this research. The portland cement composite used in this research is Tasek Cement Cap Buaya's Ordinary Portland Cement which is locally produced by Tasek Corporation Berhad. Figure 3.1 shows the package of the portland cement use in this research. Quality assured by the SIRIM (certified to MS 522-1:2007) and BS EN 197-1:2011.

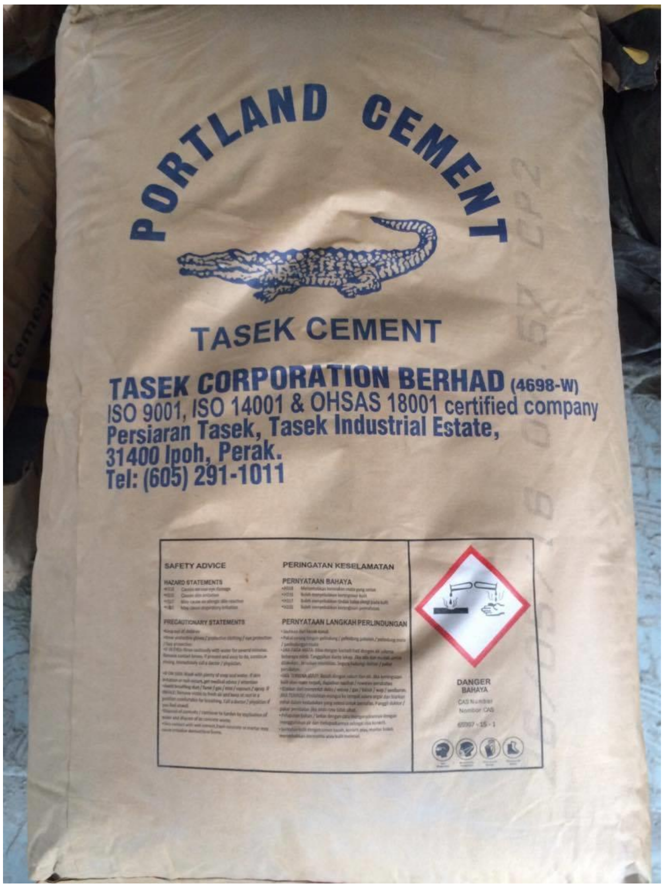


Figure 3.1 Ordinary Portland Cement (Tasek Cement)

3.1.2 Mining Sand

According to CIDB Malaysia (2001), there are two types of fine aggregates used in construction industry, which is mining sand and river sand. Mining sand was chosen to use in this research due to its availability with accordance to British Standard (BS EN 12620:2013). Typically fine aggregates for mortar are below 4.75mm (5mm in British Code). Fine aggregates have particles up to a minimum size of 0.075 mm. Ensure the fine aggregates are free from moisture content to prevent it affect the water cement ratio. Figure 3.2 shows the mining sand that used for this research.

Figure 3.2 Mining Sand

3.1.3 Water

Hydration process occurred when water mixed with the cement powder to form cement paste then bond all the ingredients in the mortar together and gaining strength. Water that suitable to be used for mortar is production at pH 6.9 which is neutral according to CIDB Malaysia (2001). Potable water supply by Lembaga Air Perak for general consumption is used for this research. Figure 3.3 shows the potable water tap for water supply.

Figure 3.3 Potable Water Supplies

3.1.4 Polymer Modified Cement Additive

SBR-Latex additive is used as the polymer modified cement additive in this research. SBR-Latex consist of carboxylated styrene butadiene copolymer latex which designed to increase the adhesive strength and improve chemical resistance (“SBR Latex - Euclid Chemical,” 2016). SBR-Latex is commonly used in construction industry to increase the performance of mortar and concrete. The optimum percentage of polymer cement ratio is determined in phase one of this research. Figure 3.4 show the SBR-Latex that used in this research.

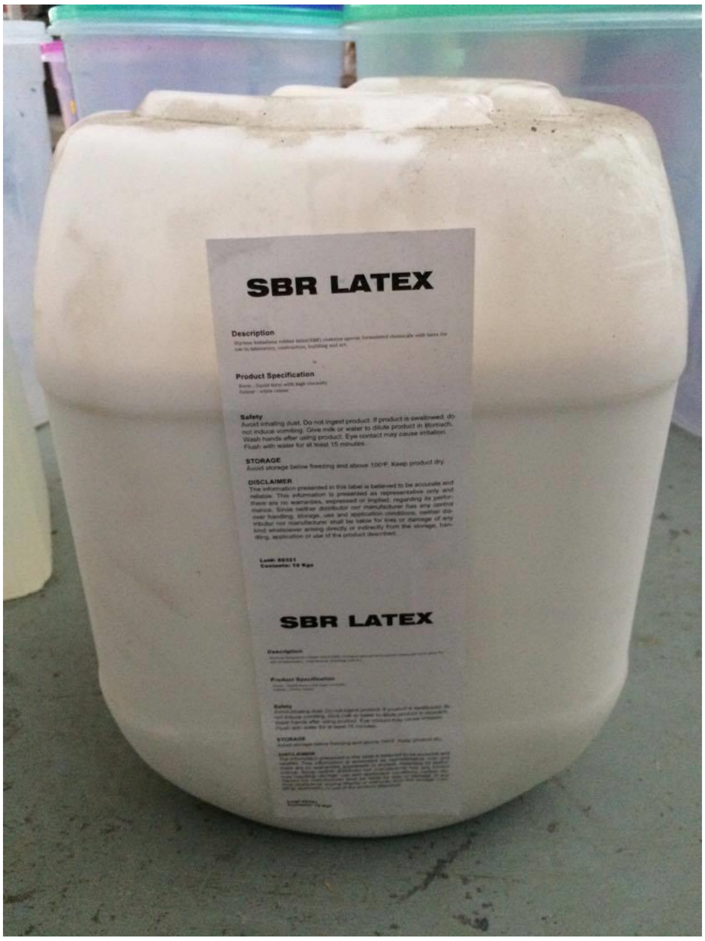


Figure 3.4 SBR-Latex Polymer Modified additives

3.1.5 Pentens

Pentens is one of the market brand that supply polymer modified cement additive. Pentens Latex-108 were chosen to be used to conduct this research. Pentens Latex-108 consist of acrylic based resin as the polymer (“Pentens LATEX-108,” 2014). Petens Latex-108 could improve the water resistance, adhesive strength and improve durability of the mortar based on the information stated on the package (“Pentens LATEX-108,” 2014). The water cement ratio for Pentens is 0.3, and 8% of polymer modified cement additive added by the weight of cement.

Figure 3.5 Pentens Latex-108

3.1.6 CMI

CMI Latex Admix 350 was chosen as one of the market sample to conduct this research in phase two. CMI Late Admix 350 contained high performance latex emulsion admixture which able to improve adhesive strength bond strength and reduce water permeability (“CMI Marketing Sdn. Bhd.,” 2015). Water cement ratio applied is 0.4 and the percentage of polymer is 20% to the weight of cement with accordance to the guide mix on package. Figure 3.6 show the bottle of CMI Latex Admix 350 used in this reseach.

Figure 3.6 CMI Latex Admix 350

3.1.7 Sika

Sika MonoTop-R40 is a polymer modified cementitious patch repair mortar. It comes with a package of 25 kg dry mixed mortar. Sika MonoTop-R40 contain thixotropic, polymer modified, and silica fume ("Product Data Sheet Edition 1105 / 1 Sika ® MonoTop ® -R40," 2010). Sika MonoTop-R40 provide high bond strength and high reduction on permeability upon carbon dioxide and water, improve the resistance to oil and chemical ("Product Data Sheet Edition 1105 / 1 Sika ® MonoTop ® -R40," 2010). The water cement ratio added to 25 kg is 0.14 which is around 3.5L of water. Figure 3.7 show the package and structure of Sika MonoTop-R40 used in this research.

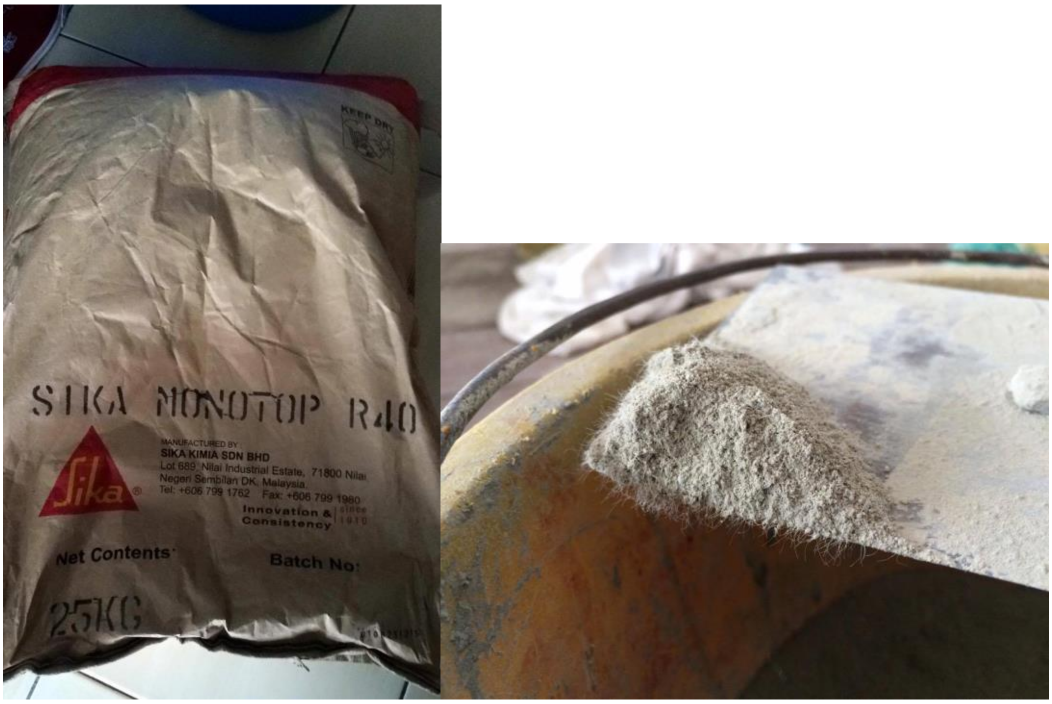


Figure 3.7 Sika MonoTop-R40

3.2 Pre-mixing Experiment

Pre- mixing experiments were carried out to evaluate the characteristic of materials that used in this research. The research involved two phases which is adding polymer modified cement additive by 5%, 10% and 15% to the weight of cement at the first phase, PMM are then compared with conventional mortar on its performance and durability.

In second phase, the optimum percentage obtained from phase one is then compared with the market polymer modified additive. Thus, every materials used must be carefully evaluate to make sure it meet the acceptable level for both PMM and conventional mortar. The experiments include, sieve test to ensure the aggregates used are well graded. With reference on civil engineering portal, the mix design will as table below. Table 3.1 shows the mix design quantity required for 1m^3 of mortar.

Table 3.1 Quantity of Composites for 1m^3 of mortar with 1:3 cement sand ratio

Materials	Conventional Mortar 1:3	PMM 1:3 5%	PMM 1:3 10%	PMM 1:3 15%
Cement	540 kg/m^3	540 kg/m^3	540 kg/m^3	540 kg/m^3
Water	216 kg/m^3	216 kg/m^3	216 kg/m^3	216 kg/m^3
Sand	1620 kg/m^3	1620 kg/m^3	1620 kg/m^3	1620 kg/m^3
Polymer Modified Cement Additive	-	27 kg/m^3	54 kg/m^3	83 kg/m^3

3.2.1 Sieve Analysis

Sieve analysis is carried out to identify the size of the aggregates. In order to get the well graded aggregates, 500g of aggregates are weighted and going through sieve analysis process and fine aggregates that retained below 4.75mm sieve are used for this research with accordance to ASTM C136/C136M – 14.

.

The sieve shaker machine consists of several sieves ranging from 25mm to 0.075mm. The sieves were arranged in descending order with the size of 4.75mm on the top followed by 2.36mm and continue with 1.18mm, 0.60mm, 0.30mm, 0.15mm, 0.075mm and finally a pan at the bottom. The aggregates are placed at the top of the sieve and cover plate was properly covered and tightened before running the machine to prevent the aggregates from fallen out during the test.

During the shaking process, the aggregates will pass through the pores if the size is smaller and finally retained when the sieve fits the aggregate size. The aggregates are identified by the size of sieve that it was retained.

Figure 3.8 Sieve Machine

3.3 Experimental Programme

The experimental programme of this research start with mix design and trail mix of mortar samples for phase one and phase two. The aim of the research is to determine the optimum percentage of PMM mixed by SBR-Latex and determine the performance of PMM. Thus the first objective is to investigate the performance of PMM mixed by 5%, 10% and 15% of SBR-Latex in phase one. Whereby the Optimum percentage obtained are then compared with the market available samples.

The curing process in this research consists of 7 days of wet curing and follows by ambient environment curing. The performance tests are done on the stated length of curing. Figure 3.9 show the flow char of experiment programme.

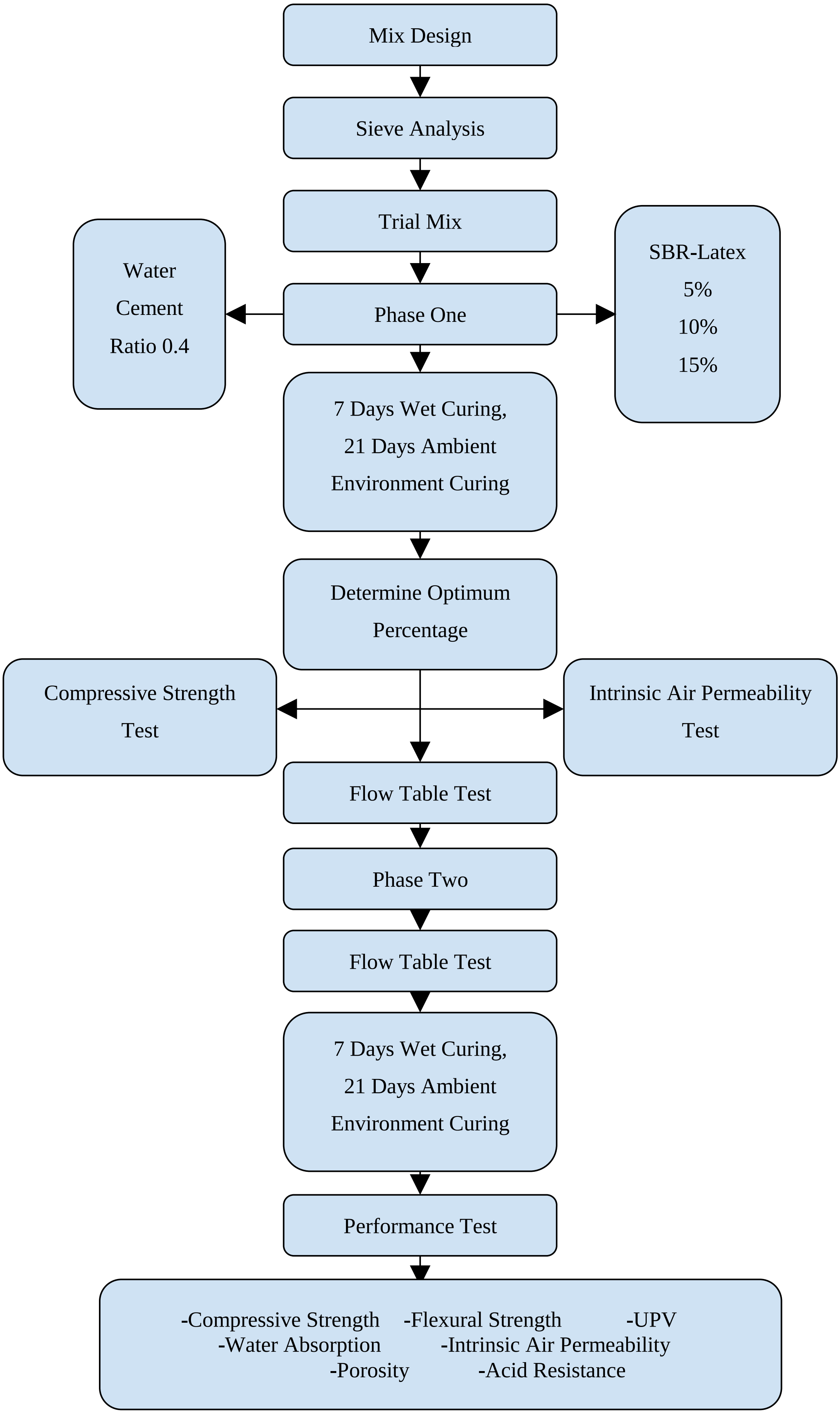


Figure 3.9 Flow Chart of Experimental Programme

3.4 Mix Proportion of Mortar

The mix proportion for mortar used in this research is 1:3 to determine the performance of polymer modified mortar under different percentage of polymer modified additive (5%, 10% and 15%) over conventional mortar in phase one.

To determine the performance of PMM over conventional mortar both with cement sand ratio 1:3, laboratory test is carried out. Mortar specimens are prepared by casting in the mortar cube mould with dimension of 50mm x 50mm x 50mm. Total number of 15 cube specimens and 3 cylinder specimens for each variable are used for compressive strength test and intrinsic air permeability test on first phase.

In second phase of the experiments, after obtained the optimum percentage in the first phase, the optimum percentage is then compared with market polymer modified additive with mix proportion stated on the package.

Several laboratory experiment test are done on second phase which include flow table test, compressive strength test, flexural strength test, UPV test, intrinsic air permeability test, water absorption test, porosity test and acid resistance test.

Total number of 15 cube specimens with dimension 100mm x 100mm x 100mm, 12 beam specimens with dimension of 40mm x 40mm x 160mm and 3 cylinder specimens with diameter 45mm and height 40mm are required to carry out the experiments. Tables 3.2 and 3.3 show the mix proportion and specimens allocation in phase one and two.

Table 3.2 Mix Proportion of Mortar and Specimen's allocation in Phase 1

Specimens	Percentage of Polymer modified cement additive (%)	Percentage of Portland Cement (%)	Mortar Cube Specimens, No	Mortar Beam Specimens, No	Mortar Cylinder Specimens, No
C1 - 0%	-	100	12	-	3
C2 - 5%	5	100	12	-	3
C3 - 10%	10	100	12	-	3
C4 - 15%	15	100	12	-	3

Table 3.3 Mix Proportion of Mortar and Specimen's allocation in Phase 2

Specimens	Percentage of Polymer Modified Cement Additive (%)	Ordinary Portland Cement (%)	Mortar Cube Specimens, No	Mortar Beam Specimens, No	Mortar Cylinder Specimens, No
Optimum	11	100	15	12	3
Pentens	8	100	15	12	3
CMI	20	100	15	12	3
Sika	-	-	15	12	3

3.5 Determination of Mortar Performance

In order to determine the performance of PMM as in the objective of the research, several laboratory test are carried out as in table 3.3 is done to identified the performance of harden PMM with comparison to conventional mortar and market available polymer modified cement additive.

Mechanical properties of harden mortar include compressive strength test, flexural strength test and Ultrasonic Pulse Velocity test is done to determine the performance of PMM.

Durability of mortar is determined through, air penetration test, water absorption test, porosity test and acid resistance test. Whereby, the flow table test is done to determine the workability of fresh mixed mortar for PMM mixed by SBR-Latex, market sample and conventional mortar.

The mortar cube specimens ready for 56 days curing are used for Ultrasonic Pulse Velocity (UPV) test before compressive strength was done. After oven dried, intrinsic air permeability test is carried out, follow by the water absorption test and lead to porosity test. Hence, the same mortar specimens are used. Table 3.4 shows the details of laboratory test for each mortar sample.

Table 3.4 Details of Laboratory Test for Each Mortar Sample

Test	Age of Mortar, Days	Mortar Cube Specimens, No	Mortar Beam Specimens, No	Mortar Cylinder Specimens, No
Compressive Strength Test	3	3	-	-
	7	3	-	-
	28	3	-	-
	56	3	-	-
Flexural test	3	-	3	-
	7	-	3	-
	28	-	3	-
Ultrasonic Pulse Velocity test	3	3	-	-
	7	3	-	-
	28	3	-	-
Air Penetration test	7	-	-	3
	14	-	-	3
	28	-	-	3
	35	-	-	3
Water Absorption test	7	3	-	-
	14	3	-	-
	28	3	-	-
	35	3	-	-
Porosity test	7	-	-	3
	14	-	-	3
	28	-	-	3
	35	-	-	3
Acid Resistance Test	7	3	-	-

3.5.1 Mortar Mixing

Mortar mixing is carried out at Construction Management's workshop under ambient temperature. Materials required for each time of mixing are measured with exact quality with the mix design to prevent material waste. Materials used must be well examined before using.

Hand mix and concrete Mixer are used for mortar mixing in this research for the first phase and second phase respectively. The materials that prepared are then placed near the concrete mixer. First, start the mixer; follow by putting in part of the water. Fine aggregates was poured into the mixer, follow by the cement. Each pour of the materials wait for 60sec buffer time for the materials to mix. Based on the research polymer cement ratio, the polymer modified cement additives are then poured into the mix. Lastly, while the mixer keep mixing, slowly poured the remaining water into the mixer and wait until the mortar was gradually formed. After the fresh mortar formed, flow table need to be carried out immediately. Fresh mixed mortar as shown in Figure 3.10.

Figure 3.10 Freshly Mixed Mortar

3.5.2 Flow Table Test

The freshly mixed mortar is used for flow table test to identify the workability of mortar. Workability is a property of fresh mixed mortar, it is considered as workable if the fresh mix mortar is easily transported, placed and compacted without any segregation. Fresh mixed mortar for PMM, market sample and conventional mortar were determined to make comparison on workability after using polymer modified cement additive.

The test was conducted with accordance to British Standard (BS EN 1015-3:1999). The surface of the round table and the mould were wetted and cleaned before conducting the test. The mould were then firmly held at the middle of the round surface, fill the mould with two layers of mortar, each later were tempted by tempting rod with 25 stroke. After the top layers had been tempted, fill the mortar again and the surface was struck off by a trowel to get a flat surface. The mould were then removed steadily by vertically pull out. The table was then raised and drops repeatedly for 15 times within 15 second. The spread of the mortar were then measured by meter rule and recorded.

Figure 3.11 Flow Table Test Equipment

3.5.3 Moulding and Demoulding

Mortar specimens need to be prepared for laboratory test in order to determine the performance and durability of PMM. Mould with dimension of 50mm x 50mm x 50mm & 100mm x 100mm x100mm is used to cast mortar cube specimens in phase one and phase two respectively, 40mm x 40mm x 160mm beam mould is used to cast mortar beam specimens with accordance to British Standard (BS EN 12390-1:2012) for the test in phase two. PVC pipe with internal diameter of 45mm and height 40mm is use as cylinder specimen's mould.

Before casting, the mould needs to be cleaned and a layer of lubricant was applied for easy removal of hardened mortar specimens. For mortar cube specimens, fresh mortar was placed in the mould with 2 layers, each layers are compacted by vibrator. The fresh mortar was then levelled to a smooth surface by using trowel.

In preparation of mortar beam specimens, single layer of fresh mortar was placed into the mould and compacted by vibrator. Surface of the mortar beam specimens were levelled by using trowel. Compaction while placing mortar was done to ensure the mould was fully filled and prevent air voids and air entrained in the mortar.

Every mortar specimens were steel float finished by using trowel and stored under ambient temperature in the workshop. Marked and tabled on every harden mortar specimens to prevent any mistake. Figure 3.12, Figure 3.13 and Figure 3.14 show the moulds that used to cast mortar specimens.

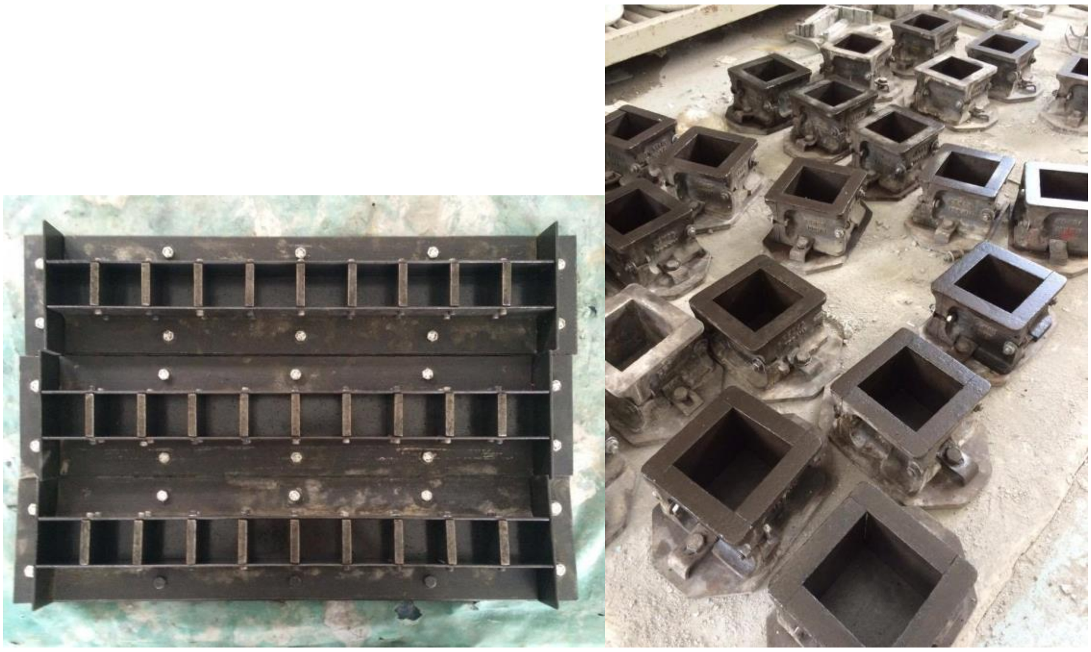


Figure 3.12 Mortar Cube Moulds

Figure 3.13 Mortar Beam Moulds

Figure 3.14 Mortar Cylinder Moulds

3.5.4 Curing of Mortar Specimen

Curing is a procedure for cement in the concrete to enhance the hydration process with control of temperature and moisture movement in and out of the concrete. (Naville, 2011) Curing for mortar specimens is done to ensure the mortar continuing gain strength through hydration process with water movement in and out inside the water tank. With continuing gain strength to the mortar, the performance and durability of mortar is increased and gain resistance to abrasion.

This research consist two stages of curing process, the normal water curing process for 7 days and continue by the ambient environment curing for the following days.

The mortar specimens were cured with accordance to British Standard (BS EN 12390-2:2009) in this research. The mortar specimens were put in the water tank provided at workshop at temperature of 35 ± 2°C for curing purpose. The curing process of PMM consist two stages which is dry and wet curing.

The specimens are cured under wet curing for 7 days and follow by the dry curing which is the ambient environment curing for the followings day. For Ultrasonic Pulse Velocity (UPV) test, compressive strength test, air penetration test, water absorption and porosity test, mortar specimens were cured for 3 days and 7 days under wet curing, 28 days and 56 days under ambient environment curing. After 3 days curing, the first batch of specimens is removed from water tank for laboratory test purpose. On the 7th days, all the mortar specimens are removed from curing tank and wait for further test to be done. Acid resistance test is done on 7th days curing mortar cube specimens. For flexural test, the mortar beam specimens are removed from curing tank on 7th day of curing age, follow by the specimens curing under ambient environment for 28 days and 56 days. Figure 3.15 and figure 3.16 show the curing water tank and ambient environment curing method.

Figure 3.15 Water Curing of Mortar Specimens

Figure 3.16 Ambient Environment Curing

3.5.5 Compressive Strength Test

Compressive strength test was carried out to determine the compressive strength of PMM and conventional mortar. Compressive strength test was carried out on mortar cube specimens with dimension of 50mm x 50mm x 50mm in the first phase that removed from the mould with accordance to British Standard (BS EN 12390-3:2009).

In the second phase, the specimens for compressive strength test is tested on specimens with dimensions of 100mm x 100mm x 100mm. Compressive strength is the main characteristic of mortar that to withstand compressive load by overall structure.

Kenco Compressive strength test machine is used to conduct the compressive strength test on mortar cube specimens. The capacity of this machine is 200kN with the compressive rate of 40kN/s. The compressive strength is calculated from the failure load divided by the cross-sectional area resisting the load and reported in units of pound-force per square inch (psi) in US Customary units or megapascals (MPa) in SI units ("CIP 35 -Testing Compressive Strength of Concrete," 2003).

After curing for 3days, the specimens are removed from the water tank and wiped by using dry cloth, and weight of mortar cube specimens were measured and recorded, then put the specimens one by one to the Kenco Compressive Strength Test Machine. Each type of mortar will have 3 samples and tested for curing age of 3 days, 7 days, 28 days and 56 days respectively. The cubes were tested to fail and the results were recorded. Figure 3.17 shows the Kenco compressive strength testing machine used in this research

Figure 3.17 Kenco Compressive Strength Testing Machine

3.5.6 Flexural Strength Test

The mortar beam specimens for PMM by SBR-Latex and PMM by market polymer modified additive are used for flexural test to determine the tensile strength of the mortar specimens. To evaluate the flexural strength of PMM, non-reinforced mortar beam specimens with dimension of 40mm x 40mm x160mm were prepared for the test with accordance to British Standard (BS EN 12390-5:2009).

Flexural test was carried out by using T-Machine Universal Testing Machine with load capacity of 50kN at the rate of 100mm/s. In order to get an accurate result, three mortar beam specimens for each type of mix are prepared for the test. Mortar beam specimens that undergo 3 days are tested, following by 7 days, and 28 days of curing age. The gauge length using in this test is 150mm.

This test was carried out based on centre point loading system and the length of mortar beam within these three points were marked and recorded. The force was applied from the centre point and both points at the ending are the support fixed point. These specimens were tested to fail, the force applied are recorded. Figure 3.18 shows the T-Machine Universal Testing Machine used for flexural test.

Figure 3.18 T-Machine Universal Testing Machine

3.5.7 Ultrasonic Pulse Velocity Test

Ultrasonic Pulse Velocity test is a non-destructive test in this research. The test was conducted to determine the internal properties of mortar. Any defects inside the mortar, such as honeycomb, decay and other defect can be detected by the speed of the pulse passing through the mortar cube specimens. The destiny of mortar also affected the velocity of the pulse to passing through the mortar. The Ultrasonic Pulse Velocity test was conducted with accordance to British Standard (BS EN 12504-4:2004).

The mortar cube specimens were removed from the water tank after 3 days of curing wiped with cloth and put into oven with 105°C until equilibrium. The mortar cube specimens were then stored under ambient temperature for 24 hours for cooling and meet constant moisture level.

Ultrasonic Pulse Velocity machine is used to conduct this test. Test was conducted on the two opposite sides of the mortar cube to obtain the average reading. The same procedure was done on 7 days and 28 days curing age mortar cube specimens.

Total number of 3 mortar cube specimens are used for Ultrasonic Pulse Velocity test to get more accurate results. The 28 days curing age mortar cube specimens were used in UPV test before going through compressive strength test. Figure 3.19 shows the Ultrasonic Pulse Velocity machine used.

Figure 3.19 Ultrasonic Pulse Velocity Test Equipment

3.5.8 Intrinsic Air Permeability Test

Intrinsic air permeability test were carried out to investigate the permeability of PMM. High permeability mortar will lead to defects, water penetrated through mortar will affects the durability of mortar and affect the bricks wall or other components. This test was carried with accordance to method provided by Lysdale and Cabrera (1988) with cross reference to (Talah & Kharchi 2013).

Mortar cylinder specimens with diameter of 45mm and height of 45mm were used to conduct this test. The test consists of maintaining the mortar specimen at a constant pressure of Nitrogen gas. Intrinsic permeability is defined by Klinkenberg as the y-intercept of the line connecting the permeability and the inverse of the average pressure.

After the mortar cylinder specimens were cured for 7 days, the specimens were removed from curing tank and dried in oven with 105°C and being cooled in ambient temperature for 24 hours. The mortar specimens were ready for intrinsic air permeability test, measure the height and average diameter of every mortar specimens and record the data. The mortar cylinder specimens were then put into oven with 60°C for 2 hours.

The mortar specimens were then surrounded by a thin layer of silicon rubber and put into the permeability cell, 2 bars of gas pressure was applied. Ensure that there was no leakage happen and allowed the specimens to reach steady state. The time flow of gas was recorded according to appropriate bubble meter used. The measured was repeated for 5 times to get an accurate result. Figure 3.20 shows the Intrinsic Air Permeability Testing Machine.

Figure 3.20 Intrinsic Air Permeability Testing Machine

The gas permeability was calculated by the formula below.

$$K = \frac{2P_2(1.76 \times 10^{-16})\mathrm{VL}}{\mathrm{A}(P_1^2 - P_2^2)}$$

Where,

K = Intrinsic permeability, m^2

P_1 = Absolute applied pressure bars (atmosphere pressure)

P_2 = Pressure at which the flow rate is measured (atmosphere pressure) usually 1 bar

A = Cross sectional areas of specimens, m^2

L = Length of specimen, m

V = Flow rate, m^3/s

$$V = \frac{(\frac{D^2}{4})\pi\mathrm{H}}{\mathrm{T}}$$

Where,

V = Flow Rate

D = Flowmeter diameter

H = Length read on flowmeter

T = Average time

3.5.9 Water Absorption Test

Water absorption test were carried out to determine the water tightness of the mortar specimens. The cylinder mortar specimens were used in this test. The water absorption capacity of the mortar will affect the durability of mortar. Mortar that used for external protection or substructure work will frequently contacted with water content, thus the water absorption capacity of the mortar need to be determine. The test was carried with accordance to British Standard (BS 1881-122:2011).

The mortar cylinder specimens after 7 days of curing were removed from the curing tank and wipe to dry. Specimens for each sample were put into oven with 105°C for drying purpose. The mortar cylinder specimens were cooled and keep art constant moisture level for 24 hours under ambient temperature. The initial weight of mortar specimens was measured before submerge into water. The same procedure applied on the 14, 28 and 35 days of curing age under ambient environment.

Mortar specimens were submerged into water and the weight of mortar specimens were determined after 30 minutes. The specimens were wiped to dry before weight to get the accurate results.

Figure 3.21 Water Absorption Test

3.5.10 Porosity Test

Porosity on the mortar affects the strength and durability of mortar. Porosity test was carried out to determine the durability of mortar. The cylinder specimens used in water absorption test are then continuing using in this test. The specimens need to be dried in oven with 105°C before conduct the test. The test was conducted with accordance to (RILEM Recommendations, 1984).

After the dry weight had been recorded, the specimens were then put into the desiccator. Fill the desiccator with water that enough to cover 1cm above the specimens. When the specimens were fully covered by water, the cover and edges of desiccator need to be fully sealed by high vacuum grease to make sure the desiccator was air tight. Switch on the vacuum pump to allow it run for 15 minutes. Allow the vacuum pump to rest for 2 hours, switch on the vacuum pump again for 10 minutes to make sure the air inside desiccator is being removed as much as possible.

Porosity of the mortar defines as the ratio between void's volume and total volume of the specimen. The following formula was used to determine the porosity of PMM by percentage.

Figure 3.22 Apparatus for Porosity Test

3.5.11 Acid Resistance Test

The mortar cube specimens for both PMM by SBR-Latex and PMM by market polymer modified cement additive are used to determine the acid resistance of mortar. One of the properties by using polymer modified additive is that it could increase the chemical resistance of the hardened mortar or concrete. Thus the chemical resistance of PMM was determined.

The mortar cube specimens were removed from water curing tank after 7 days of curing and put into 1 mol concentration of Hydrochloric Acid (HCL) solution. Mortar cube specimens were then dried by cloth and the weight of specimens were measured and recorded. The container must be sealed to prevent evaporation of the solution. Specimens are then removed from the solution and rinsed with water. Measured the weight of mortar cube specimens and make comparison before and after submerge in acid solutions. The procedure repeated on 7 days, 14 days and 28 days submerge in HCL solution.

Compressive strength test was carried out on all the specimens and record the data. Lastly, after all the data collected, comparison between PMM by SBR-Latex and market polymer modified cement additive were conducted.

Figure 3.23 Acid Resistance Test

CHAPTER 4

RESULTS AND DISCUSSIONS

The results obtained from the laboratory experiments are analysed and discussed in this chapter. The performance of PMM mixed by SBR-Latex and PMM mixed by market available polymer modified cement additive were evaluated and comparison between them were made. The laboratory experiments consist of 2 phases, the fist phase was obtaining the optimum percentage from 5%, 10% and 15% of SBR-Latex mix. The second phase was compared the performance of the optimum percentage with the market available polymer modified cement additive. The performance evaluated include workability the flow table test, mechanical properties the compressive strength test, UPV test and flexural strength test. Lastly, durability of PMM by the intrinsic air permeability test, water absorption test, porosity test and acid resistance test.

4.1 Determination of PMM's Performance

In order to achieve the objective of the research, which is to determine the mechanical and durability properties of PMM under 5% 10% and 15% addition of SBR-Latex in phase one; and to compare the optimum percentage of PMM casted by SBR-Latex with the market available polymer modified cement additive which include Pentens, CMI and Sika in phase two.

Various laboratory experiments were conducted to determine that, which include flow table test, UPV test, compressive strength test, flexural strength test, intrinsic air permeability test, water absorption test, porosity test and acid resistance test.

This research consist of two phases, determination of optimum percentage of PMM casted by SBR-Latex in phase one and make comparison with the market available polymer modified cement additive in phase 2. Both phases going through pre-mixing test and performance test. Premixing test involved sieve analysis and trial mix; performance test include the all tests listed previously.

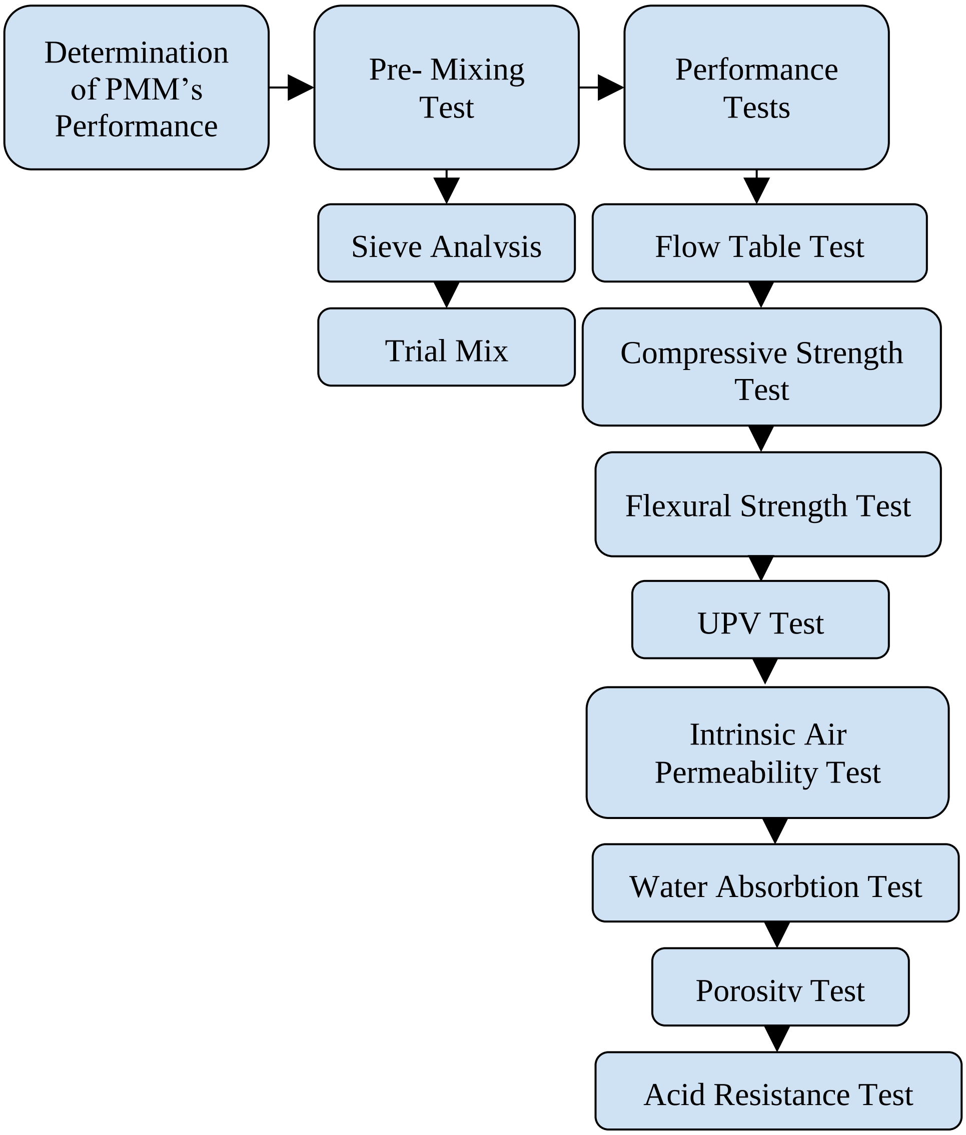


Figure 4.1 Flowchart on Determination of PMM's Performance

4.2 Pre Mixing Test

4.2.1 Sieve Analysis

Sieve analysis was carried out to determine the size distribution and define the nominal size of fine aggregates that used in this research. The nominal size of the sand used will affect the workability of the mortar. Thus sieve analysis need to be done to determine the performance of PMM.

Table 4.1 shows the results of sieve analysis done on the fine aggregates that used in the research which is the mining sand. From the literature review, the size of fine aggregates need to be less than 4.75mm in order to get the good performance of mortar. Thus the sieve pans with size from 4.75mm to 0.075mm were used in sieve analysis.

From the results, it can be observed that 89.2% of the sands were retained in between 1.18mm to 0.15mm, where the nominal size is on sieve size 0.30mm with 37% of sands retained. Very minimal percentage of the sands were retained on sieve size 4.75mm and below 0.075mm, this could shows that the fine aggregates used in this research are well graded as it is well distributed.

Table 4.1 Sieve Analysis Test on Fine Aggregates

Sieve Size (mm)	Weight Retained (g)	Percentage Retained (%)	Cumulative Percentage Passing (%)	Cumulative Percentage Retained (%)
5.00	0	0	100.0	0
4.75	4	0.8	99.2	0.8
2.36	24	4.8	94.4	5.6
1.18	92	18.4	76.0	24.0
0.60	91	18.2	57.8	42.2
0.30	185	37.0	20.8	79.2
0.15	78	15.6	5.2	94.8
0.075	19	3.8	1.4	98.6
Pan	7	1.4	0.0	100.0
Total	500			

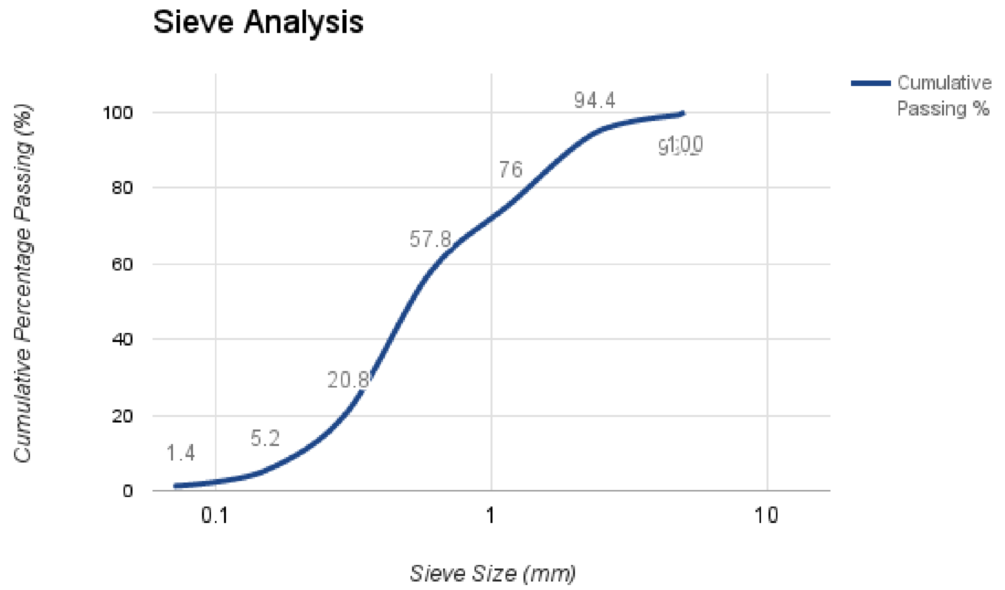


Figure 4.2 Fine Aggregates Sieve Analysis Results

Figure 4.2 shows the curve for aggregates cumulative percentage of passing under different sieve size. The graph shows that at the sieve size of 0.3mm to 2.36 had retained most of the fine aggregates which around 94.4%. Besides, the results indicate that the mining sands that used in this research contained more sands with size 0.3mm. The mining sands used are suitable for mortar mixing as it is well distributed.

4.3 Mortar Performance in Phase 1

4.3.1 Workability Test by Flow Table Test

Flow table tests were carried out at the end of the mixing stage of the fresh mortar. Flow table test is essential to determine the workability of the fresh mortar. One of the functions of polymer modified cement additive is to increase the workability of fresh mixed mortar. The flow percentage are determined from (Suryakanta 2013).

Table 4.2 Flow Table Test in Phase One

Variable	Water/ Cement Ratio	Flow Diameter (cm)	Flow (%)
0%	0.4	12.4	24%
5%	0.4	13.8	38%
10%	0.4	14.7	47%
15%	0.4	17.5	75%

Table 4.2 shows the results of fresh mixed PMM mixed by SBR-Latex with 5%, 10% and 15%. From the results shows that the higher the percentage of polymer modified additive added, the higher the workability of mortar.

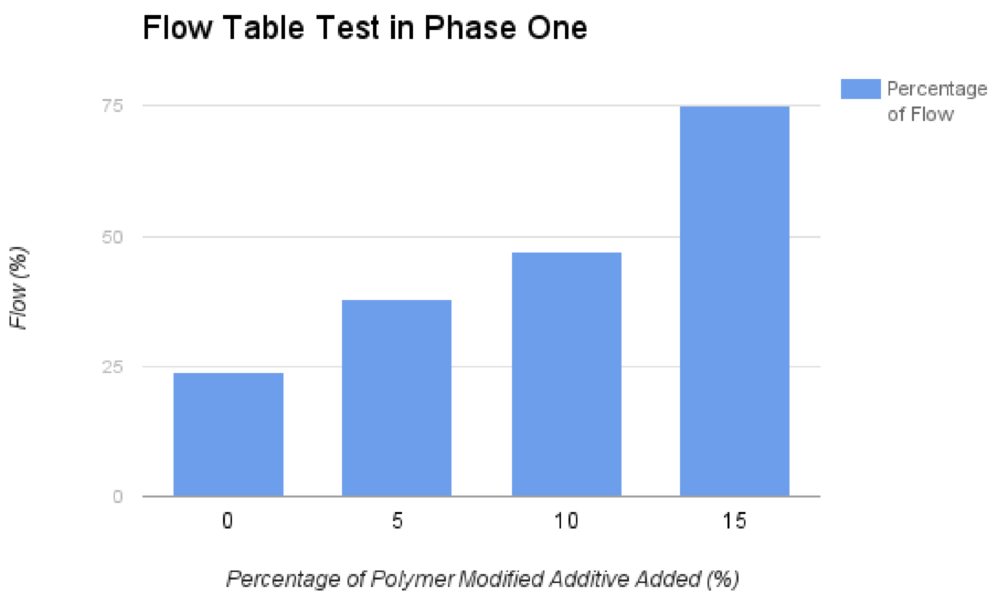


Figure 4.3 Flow Table Test Results in Phase One

Figure 4.3 shows the result of flow table test done on PMM mixed by SBR-Latex with 5%, 10% and 15%. From the results it shows that the highest flow on the 15% of SBR-Latex added and the lowest flow on the control. The results indicate that polymer modified cement additive could increase the workability of mortar. The higher the percentage of polymer modified additive, the higher the workability of mortar (Ohama, 1995).

4.3.2 Compressive Strength Test

Compressive strength test is one of the main mechanical properties of mortar. It is essential to find out how the polymer modified additive could affect the compressive strength of the mortar. In phase one, mortar cube specimens with dimensions of 50mm x 50mm x50mm were used for compressive strength test.

The specimens are tested on 3 days and 7 days of water curing, follow by 28 days and 56 days of curing age under ambient environment. Total number of 3 specimens are tested on each of the determination day.

Table 4.3, 4.4, 4.5 and 4.6 shows the results of compressive strength test in phase one with different percentage of SBR-Latex added to the mortar mix on 3, 7, 28 and 56 days of curing age respectively.

Table 4.3 Compressive Strength in Phase One at 3 Days

Variables	Weight (g)			Compressive Strength (N/mm^2)			Average Strength (N/mm^2)
	A	B	C	A	B	C	
0%	282	281	280	22.05	24.66	30.24	25.65
5%	271	275	267	16.02	14.69	13.80	14.84
10%	272	259	273	11.34	11.52	14.7	12.52
15%	250	255	250	14.67	11.72	11.36	12.58

From Table 4.3, observed that the higher the percentage of polymer modified additive added, the lower the compressive strength at 3 days of water curing. By comparing with the control, the strength of 15% SBR-Latex is about 50.96% lower than the control. Besides, the strength of 10% and 15% SBR-Latex added are almost same.

Table 4.4 Compressive Strength in Phase One at 7 Days

Variables	Weight (g)			Compressive Strength (N/mm^2)			Average Strength (N/mm^2)
	A	B	C	A	B	C	
0%	284	282	279	27.24	36.05	35.14	32.81
5%	277	276	274	16.80	29.03	27.74	24.52
10%	257	267	271	14.50	18.23	16.42	16.38
15%	254	241	257	9.32	12.54	11.53	11.13

Table 4.4 shows the results of compressive strength test on 7 days of water curing which is the last day of water curing. The early strength development of control increased from 25.65 N/mm^2 to 32.81 N/mm^2 with 27.91% of strength increase where the strength of 10% SBR-Latex added increased from 12.52 N/mm^2 to 16.38 N/mm^2 with 30.83% of strength increase. The strength of 15% SBR-Latex is slightly lower compared to the 3 days, this could be some error happened on compacting the specimens.

Table 4.5 Compressive Strength in Phase One at 28 Days

Variables	Weight (g)			Compressive Strength (N/mm^2)			Average Strength (N/mm^2)
	A	B	C	A	B	C	
0%	274	271	274	51.76	43.6	51.22	48.86
5%	267	268	266	31.43	31.05	32.06	31.51
10%	250	260	260	30.36	33.91	26.80	30.36
15%	245	250	250	30.24	27.29	28.10	28.54

On Table 4.5, compressive strength of control increased from 32.81 N/mm^2 to 48.86 N/mm^2 which is 48.92% of strength increase. Whereby, compressive strength of PMM with 15% SBR-Latex added increased from 11.13 N/mm^2 to 28.54 N/mm^2 which is 120.49% increased. These results proved that the formation of polymer happens when the mortar is curing under ambient environment (Ma & Li, 2013).

Table 4.6 Compressive Strength in Phase One at 56 Days

Variables	Weight (g)			Compressive Strength (N/mm^2)			Average Strength (N/mm^2)
	A	B	C	A	B	C	
0%	274	269	274	52.43	48.75	45.37	48.85
5%	261	259	268	30.29	31.71	34.69	32.23
10%	258	261	256	35.75	28.64	27.71	30.70
15%	238	243	242	30.5	28.02	27.62	28.71

Compressive strength test results on 56 days curing age shown in table 4.6. The results followed the trends in 28 days curing age which the highest compressive strength is the control and the lowest compressive strength on 15% SBR-Latex added.

Table 4.7 Summaries of Compressive Strength in Phase One

Variables	Compressive Strength (N/mm^2)			
	3 Days	7 Days	28 Days	56 Days
0%	25.65	32.81	48.86	48.85
5%	14.84	24.52	31.51	32.23
10%	12.52	16.38	30.36	30.70
15%	12.58	11.13	28.54	28.71

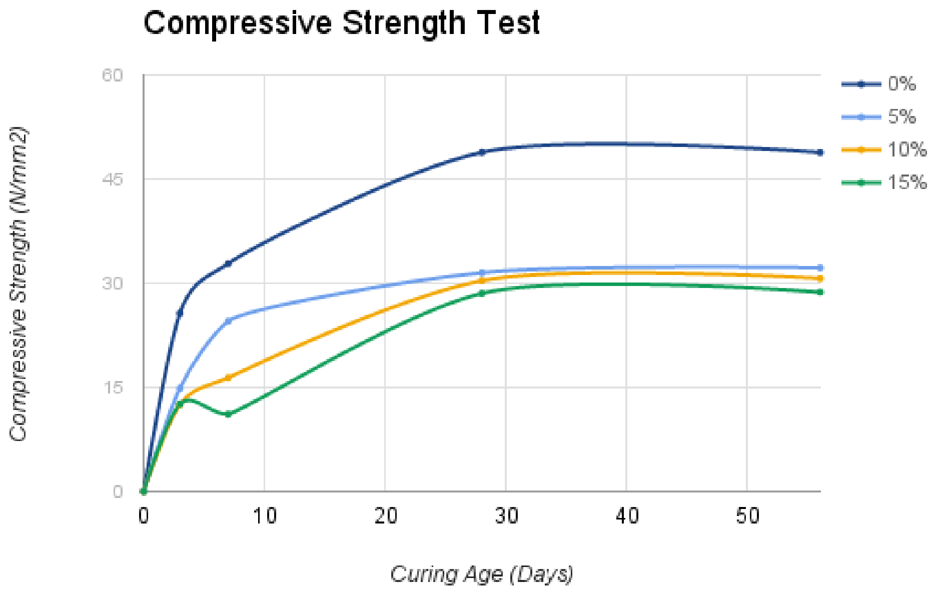


Figure 4.4 Summaries of Compressive Strength Test Results

Table 4.7 illustrate the compressive strength results in phase one from 7 days curing to 56 days curing age. As the percentage of polymer modified additive increased, the strength of mortar dropped with the same water cement ratio. The compressive strength development of PMM is slower under water curing, the higher the percentage of SBR-Latex, the slower the rate of strength development under water curing (Ohama, 1995).

There are samples error occurs on the 15% SBR-Latex 7 days curing age, suppose the strength of specimens are increase but it drops to 11.13 N/mm^2. Error occurs due to poor workmanship upon compaction.

4.3.3 Intrinsic Air Permeability in Phase One

Intrinsic air permeability test was carried out to determine the durability properties of the PMM mixed by SBR-Latex. The higher the permeability of mortar specimens, the lower its durability (Ramakrishnan, 1992). Mortar required high impermeability to prevent water penetration and prevent cracks. Mortar cylinder specimens with diameter of 0.045mm and height of 0.04mm were used in this test. The test was conducted on 28 days age of curing in phase one.

Table 4.8 Intrinsic Air Permeability Test in Phase One at 28 Days

Variables	Average Time (s)	Pressure 1 (Bar)	Pressure 2 (Bar)	Flow rate (cm/s)	Flowmeter Diameter (mm)	Permeability x10^{-16} , K (m^2)
0%	4.17	2	1	0.4709	5	13.90
5%	6.10	2	1	0.3220	5	9.50
10%	3.57	2	1	0.1980	3	6.58
15%	10.44	2	1	0.0677	3	2.00

Table 4.8 shows the results of intrinsic air permeability test. The result shows that, the higher the percentage of SBR-Latex added, the lower the permeability of the mortar. These results proved that polymer modified additive could fill up the capillaries left after the cement hydration process (Chandra, 1994) Control has the highest permeability which is 13.90 x 10^{-16} where the lowest permeability is 15% SBR-Latex specimen with 2.00 x 10^{-16} permeability.

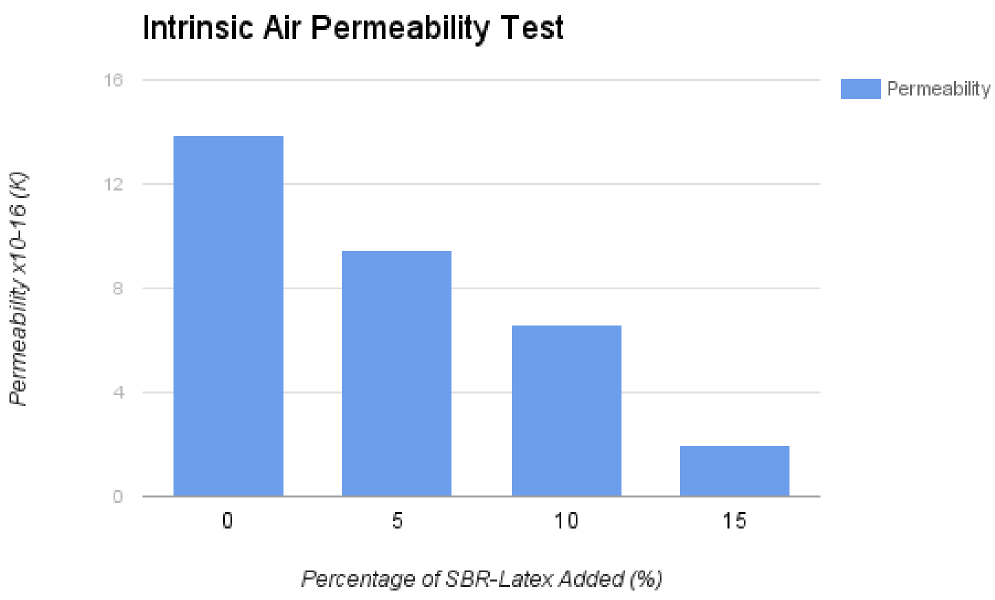


Figure 4.5 Results of Intrinsic Air Permeability Test

The impermeability of mortar increase almost constantly from 0% to 15% of SBR-Latex added as shown in Figure 4.5. Although at 15% of SBR-Latex added have the highest impermeability, but it has the lowest compressive strength. Thus the optimum percentage need to be evaluated based on the compressive strength and air permeability.

4.3.4 Optimum Percentage of SBR-Latex for PMM.

After the compressive strength test and intrinsic air permeability test in phase one, the data need to be evaluated in order to determine the optimum percentage for SBR-Latex added into PMM. The highest compressive strength specimens have the lowest impermeability and vice versa. Hence, the optimum percentage was determined by the method shown in Figure 4.6.

The permeability data added negative sign that will convert it to become the impermeability, the circle line indicate the compressive strength and the triangle line indicate the impermeability. The cross sectional point is the optimum percentage which is 11.50%.

As the relationship between compressive strength and impermeability based on the percentage of polymer modified additive added is inversely, this method of determination is done to obtain the balanced of both variables to fix it as the optimum percentage for SBR-Latex.

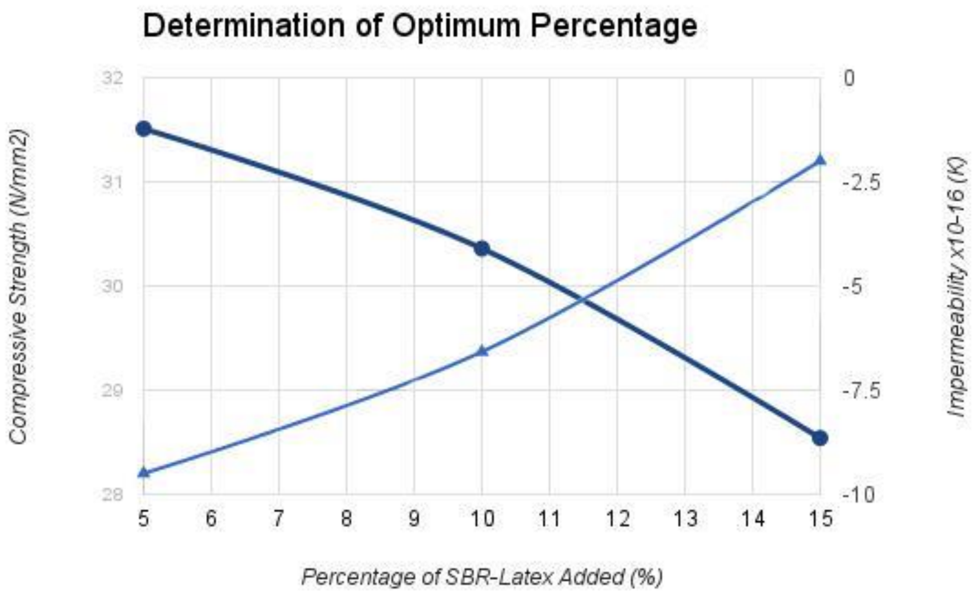


Figure 4.6 Determination of Optimum Percentage

4.4 Mortar Performance in Phase 2

After obtaining the optimum percentage from phase one, the optimum percentage was then compared with the PMM casted by market package or market polymer modified additive; the sample include Pentens, CMI and Sika. The following discussion shows the results from comparing the optimum percentage obtained from SBR-Latex with the market sample.

4.4.1 Workability by Flow Table Test

Flow table test was conducted to determine the workability of mortar under different market sample with different mix design. Cement sand ratio for all samples is 1:3 except Sika as its ready mixed.

Table 4.9 Flow Table Test Results in Phase 2

Variable	Water/ Cement Ratio	Flow Diameter (cm)	Flow (%)
Optimum	0.4	17.00	70.0
Pentens	0.3	14.17	41.7
CMI	0.4	13.23	32.3
Sika	0.2	15.33	53.3

Table 4.9 shows the flow table test results on different market sample in comparison with Optimum. The results show that Optimum have the highest workability which is 70% flow; follow by the Sika, Pentens and CMI.

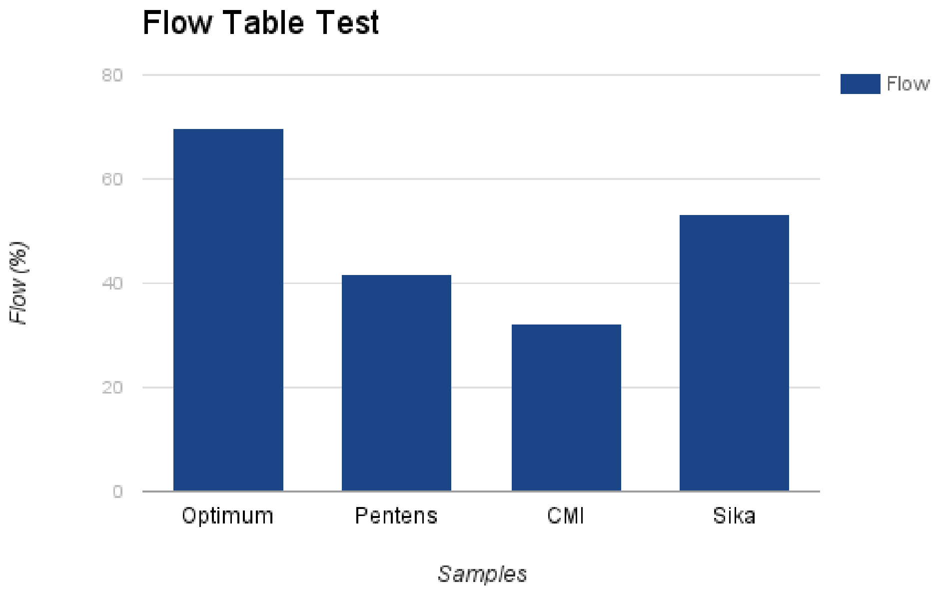


Figure 4.7 Results of Flow Table Test in Phase Two

4.4.2 Compressive Strength Test

The compressive strength test in phase two was determined by 100mm x 100mm x 100mm mortar cube specimens. The test was carried out on the specimens with 3 days and 7 days of water cured, follow by 28 days of ambient environment cured. Compressive strength determines the mechanical properties of the mortar, by making comparison between different market samples, the highest compressive strength of PMM can be evaluated.

Table 4.10 Compressive Strength Test Results at 3 Days

Specimens	Weight (kg)			Compressive Strength (N/mm^2)			Average Strength (N/mm^2)
	A	B	C	A	B	C	
Optimum	2.005	1.934	1.899	7.34	7.11	8.48	7.64
Pentens	2.308	2.367	2.335	22.73	22.86	19.94	21.84
CMI	2.086	2.104	2.086	9.64	11.29	13.05	11.33
Sika	2.102	2.045	2.097	17.32	11.37	14.89	14.53

Table 4.10 shows the results of compressive strength test with different samples. Among them, Pentens have the highest early strength with 3 days of water cured with 21.84 N/mm^2 of compressive strength. This could be caused by higher water content in the polymer modified additive itself compared with other samples.

Table 4.11 Compressive Strength Test Results at 7 Days

Specimens	Weight (kg)			Compressive Strength (N/mm^2)			Average Strength (N/mm^2)
	A	B	C	A	B	C	
Optimum	22.058	1.883	1.870	11.14	10.83	11.43	11.13
Pentens	2.275	2.400	2.321	33.45	36.96	31.56	33.99
CMI	2.217	2.211	2.171	16.83	13.86	14.35	15.01
Sika	2.184	2.175	2.062	22.84	17.09	17.26	19.06

Table 4.11 tabulated the results on 7 days water cured for all samples. The result shows the development of strength under water curing. For pentens, it developed from 21.84 N/mm^2 to 33.99 N/mm^2 with 55.63% of strength increased. The smallest strength development is on Sika which from 14.53 N/mm^2 to 19.06 N/mm^2 with only 31.18% increased. The compressive strength of Optimum stills the lowest among all samples with only 11.13 N/mm^2.

Table 4.12 Compressive Strength Test Results at 28 Days

Specimens	Weight (kg)			Compressive Strength (N/mm^2)			Average Strength (N/mm^2)
	A	B	C	A	B	C	
Optimum	1.833	1.779	2.100	23.04	19.92	30.92	23.54
Pentens	2.251	2.356	2.277	42.61	36.92	42.10	40.54
CMI	2.078	2.137	2.190	24.92	19.93	24.55	23.13
Sika	2.026	2.041	2.110	30.78	26.51	33.23	30.17

After 7 days of water cured, the following days are cured under ambient environment until 28 days. Table 4.12 shows the result of compressive strength test on 28 days of curing age. The compressive strength of Optimum developed rapidly from 11.13 N/mm^2 to 23.54 N/mm^2 under ambient environment curing which the strength almost same with CMI specimens.

Table 4.13 Summaries of Compressive Strength Test Results

Specimens	Compressive Strength (N/mm^2)		
	3 Days	7 Days	28 Days
Optimum	7.64	11.33	23.54
Pentens	21.84	33.99	40.54
CMI	11.33	15.01	23.13
Sika	14.53	19.06	30.17

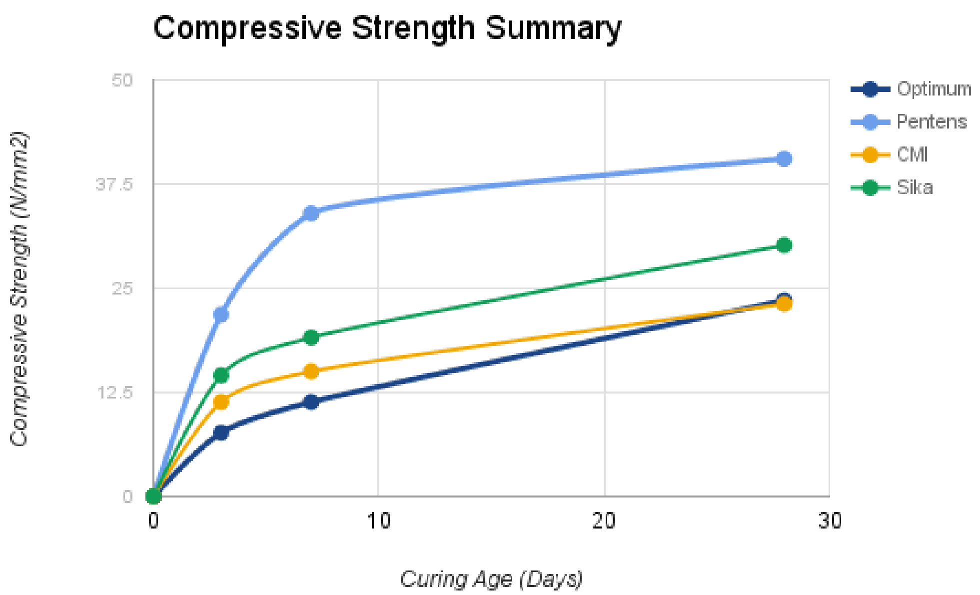


Figure 4.8 Summary of Compressive Strength Test in Phase Two

After 28 days of curing, Pentens developed the highest compressive strength among the market samples, followed by the Sika, Optimum and CMI. Table 4.13 shows the summary of compressive strength development from 3 days curing until 28 days curing for all the samples.

Pentens contained acrylic based liquid resin which developed the polymer chain inside the mortar. With a proper mix proportion guide, it allows the PMM mixed by Pentens to developed to a desire strength with a suitable polymer content. From the result, Pentens developed the highest compressive strength among all samples with 40.54 N/mm^2 on 28 days.

CMI contained modified synthetic latex with higher polymer content, this could increase the adhesive strength but it reduced the compressive strength of PMM. CMI has the compressive strength of 23.13 N/mm^2 which slightly lower than the Optimum samples. As stated in the polymer modified concrete handbook written by Ohama, and some research done by previous researcher, increased in polymer content will decrease the compressive strength of concrete, same thing applied on the PMM.

Sika is the ready mixed PMM, it comes with a 25kg package, no mixing is required. PMM formed after around 3.4L of water added into 25kg package. The package itself contained thixotropic, polymer modified and silica fume. The compressive strength of Sika on 28 days is 30.17 N/mm^2 which allocated second place among the samples.

4.4.3 Flexural Strength Test

Flexural strength was carried out to determine the mechanical properties of PMM. To evaluate the flexural strength of PMM, rectangular mortar specimens with 40mm x 40mm x 160mm were used to determine the flexural strength of PMM with 3 days, 7 days and 28 days of curing age. The test was carried out with accordance to BS EN 12390-5: 2000; the centre point loading method.

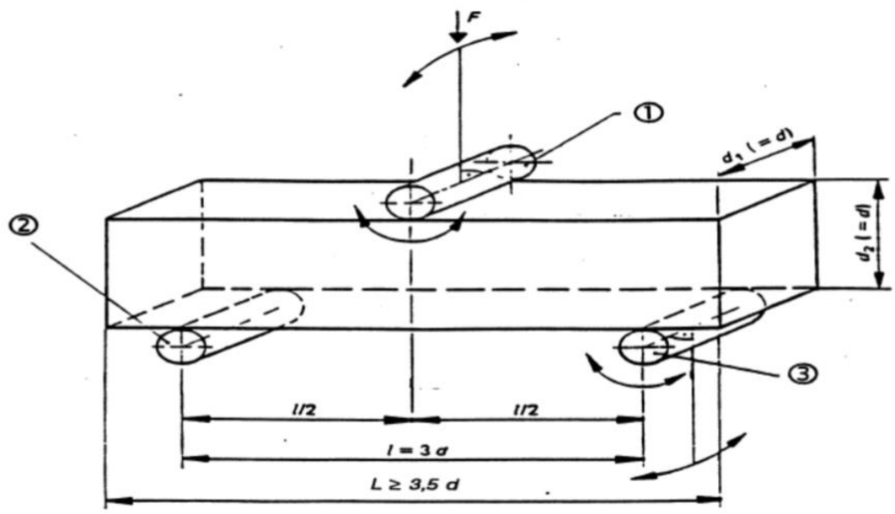


Figure 4.9 Arrangement of Flexural Strength Test on Specimens

To calculate the flexural strength of specimens based on the load applied, the following formula was applied.

$$Flexural\ Strength = \frac{3FL}{2d_1 d_2^2}$$

Where,

F = Maximum load at failure, N

L = Gauge length, mm

d_1 = Width of Specimens, mm

d_2 = Height of Specimens, mm

Table 4.14 Flexural Strength Test at 3 Days

Specimens		Load (N)	Flexural Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
Optimum	1	1523.0	5.354	5.357
	2	1499.0	5.270	
	3	1549.6	5.448	
Pentens	1	1543.2	5.425	5.922
	2	1809.2	6.360	
	3	1701.0	5.980	
CMI	1	1523.0	5.354	5.554
	2	1734.9	6.099	
	3	1481.7	5.209	
Sika	1	1320.2	4.641	4.687
	2	1197.3	4.209	
	3	1482.6	5.212	

Table 4.15 Flexural Strength Test at 7 Days

Specimens		Load (N)	Flexural Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
Optimum	1	1607.4	5.651	6.075
	2	1847.8	6.496	
	3	1728.5	6.077	
Pentens	1	2093.7	7.361	7.447
	2	2257.9	7.938	
	3	2002.8	7.041	
CMI	1	1720.3	6.048	6.310
	2	2057.0	7.232	
	3	1607.4	5.651	
Sika	1	1545.9	5.435	5.626
	2	1656.0	5.822	
	3	1599.1	5.622	

Table 4.14 and 4.15 shows the results of flexural strength test on 3 days and 7 days of water curing. The results show that Pentens has the highest flexural strength with 5.922 N/mm^2 and the lowest flexural strength on Sika with 4.687 N/mm^2 of flexural strength. The flexural strength of Optimum is in between of CMI and Sika with 5.357 N/mm^2 of strength. The flexural strength of 7 days curing developed under water curing from cement hydration process

Table 4.16 Flexural Strength Test at 28 Days

Specimens		Load (N)	Flexural Strength (N/mm^2)	Average Flexural Strength (N/mm^2)
Optimum	1	1694.6	5.958	6.526
	2	1934.9	6.802	
	3	1939.5	6.819	
Pentens	1	2322.1	8.164	8.295
	2	2483.6	8.731	
	3	2272.3	7.989	
CMI	1	2013.8	7.080	6.852
	2	2221.2	7.809	
	3	1612.0	5.667	
Sika	1	1842.3	6.477	6.626
	2	2291.8	8.057	
	3	1520.2	5.344	

After 7 days of water curing, the specimens were cured under ambient environment until 28 days. The flexural strength of PMM developed from the formation of polymer under ambient environment curing. Pentens developed its flexural strength by polymer formation process from 7.447 N/mm^2 to 8.295 N/mm^2. Whereby, the others PMM samples continue developed its flexural strength as well.

Table 4.17 Summaries of Flexural Strength Test Results

Specimens	Flexural Strength (N/mm^2)		
	3 Days	7 Days	28 Days
Optimum	5.357	6.075	6.526
Pentens	5.922	7.447	8.295
CMI	5.554	6.310	6.852
Sika	4.687	5.626	6.626

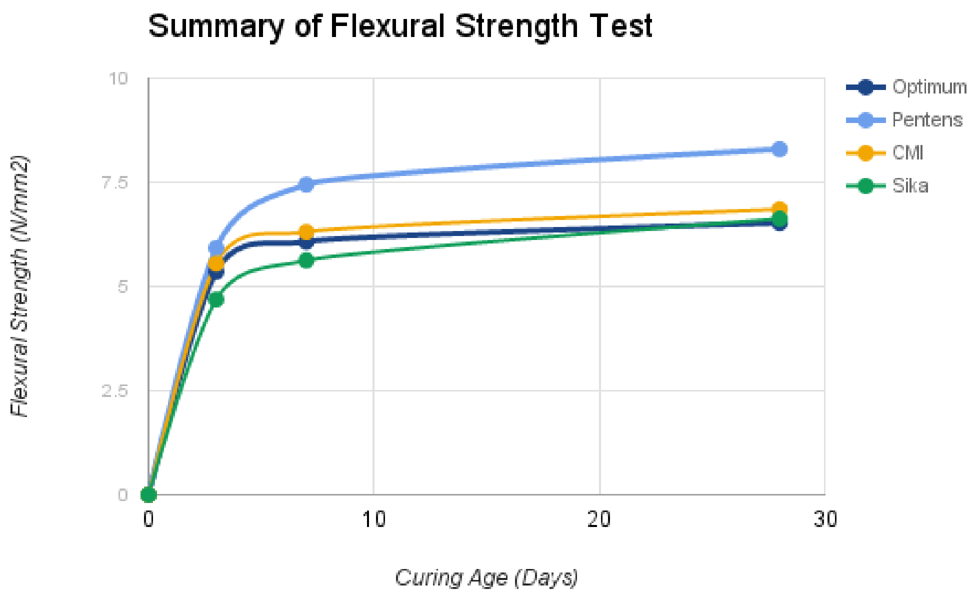


Figure 4.10 Summaries of Flexural Strength Test Results

Table 4.17 concludes the results of flexural strength test on all the PMM samples. Figure 4.10 shows the curve of flexural strength development under different PMM samples. By adding polymer inside the mortar or concrete, it could increase the flexural strength of the PMM (Ohama, 1995).

Based on the different samples obtained from the market, Pentens has the highest flexural strength. The appliance guide given allows PMM mixed by Pentens to develop its flexural strength to an optimum strength. It's about 2.00 N/mm^2 higher compared with other samples.

CMI has the lowest compressive strength, but it has a slightly higher flexural strength compared with the Optimum sample. Sika contained some solid fibres in the mix which supposed to have a higher flexural strength as the fibre could holds the mortar together. But the results show that, modified latex could obtain better flexural strength compared to the solid fibre.

4.4.4 Ultrasonic Pulse Velocity Test (UPV)

UPV test is one of the non-destructive test to determine the mechanical properties of mortar. Mortar cube specimens with dimension of 100mm x 100mm x 100mm were used to conduct this test. Test was conducted on PMM cube specimens with water cured 3 days and 7 days; ambient environment cured 28 days with accordance to BS EN 12502-4: 2004.

UPV machines show the time taken for the pulse to travel through a distance; the following formula was applied to determine the pulse velocity in kilo meter per second.

$$Pulse\ Velocity = \frac{L}{T}$$

Where,

L = Distance traveled, mm

T = Time taken to travel, μ sec

Table 4.18 Results of UPV Test at 3 Days

Specimens	UPV Reading (µ sec)	Pulse Velocity (km/sec)	Average Pulse Velocity (km/sec)
Optimum	39.5	2.532	2.579
	39.2	2.551	
	37.7	2.653	
Pentens	32.6	3.067	3.022
	33.8	2.959	
	32.9	3.040	
CMI	34.3	2.915	2.949
	34.7	2.882	
	32.8	3.049	
Sika	35.2	2.841	2.816
	36.7	2.725	
	34.7	2.882	

Table 4.19 Results of UPV Test at 7 Days

Specimens	UPV Reading (µ sec)	Pulse Velocity (km/sec)	Average Pulse Velocity (km/sec)
Optimum	34.3	2.915	2.993
	30.0	3.333	
	36.6	2.732	
Pentens	28.4	3.521	3.551
	28.6	3.497	
	27.5	3.636	
CMI	30.6	3.268	3.309
	29.4	3.401	
	30.7	3.257	
Sika	31.1	3.215	3.216
	31.8	3.145	
	30.4	3.289	

Table 4.20 Results of UPV Test at 28 Days

Specimens	UPV Reading (µ sec)	Pulse Velocity (km/sec)	Average Pulse Velocity (km/sec)
Optimum	34.9	2.865	2.996
	31.6	3.165	
	33.80	2.959	
Pentens	24.9	4.016	4.016
	24.6	4.065	
	25.2	3.968	
CMI	28.8	3.472	3.595
	27.5	3.636	
	27.2	3.676	
Sika	29.6	3.378	3.417
	29.1	3.436	
	29.1	3.436	

Table 4.18, 4.19 and 4.20 shows the UPV test results on 3 days, 7 days and 28 days of curing age. The higher the pulse velocity indicates the higher quality of the mortar specimens. The results show that in early development under water curing, Pentens has the highest pulse velocity with 3.022 km/s. Optimum sample developed only 2.579 km/s the lowest among all the samples.

As the curing process goes on, going through cement hydration process and polymer formation process, the pulse velocity increased. The results indicate that Optimum has the lowest quality among the PMM samples. The higher the pulse velocity the lesser defects or pores inside the mortar.

Table 4.21 shows the indicator obtained from Civil Engineering Portal (2014) which used to interpret to quality concrete in term of homogeneity, internal defect such as crack and segregation. This can be used to indicate the quality and grading of harden mortar based on the pulse velocity results.

Table 4.21 Assessment on Quality of Concrete (Civil Engineering Portal, 2014)

Pulse Velocity, km/sec	Concrete Quality, Grading
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful

Table 4.22 Summaries of UPV Test Results

Specimens	Pulse Velocity (km/sec)		
	3 Days	7 Days	28 Days
Optimum	2.579	2.993	2.996
Pentens	3.022	3.551	4.016
CMI	2.949	3.309	3.595
Sika	2.816	3.216	3.417

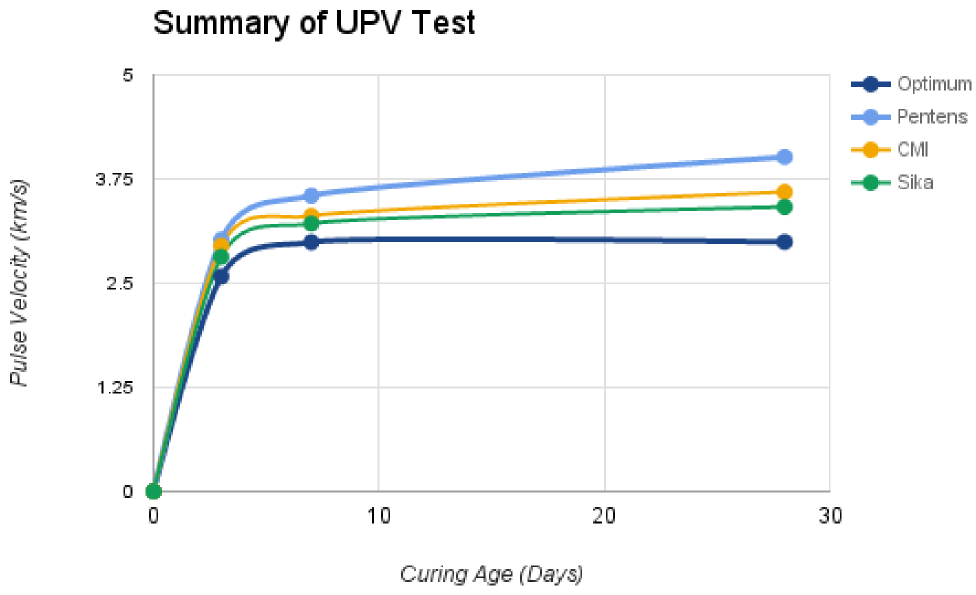


Figure 4.11 Summaries of UPV Test Results

Table 4.22 and Figure 4.11 show the summary of UPV test results. The highest pulse velocity developed on 28 days is on Pentens, follow by CMI, Sika and Optimum with 4.016 km/s, 3.595 km/s, 3.417 km/s and 2.996 km/s respectively. Besides, for Optimum sample, the pulse velocity stays constant after 7 days of curing. Based on the results, the higher pulse velocity could obtained more compressive strength and vice versa.

Based on the indicators show in Table 4.21, none of the PMM has an excellent quality from the results of pulse velocity. Whereby, Pentens and CMI has a grade of good based on the indicator. Sika has a medium grade and Optimum has a doubtful and close to medium grade. Based on the observation, the freshly mixed mortar mixed by SBR-Latex seems to be easily entrained by air. The cement hardly combine with the polymer as when cleaning the concrete mixer, some of the cement paste sticks on the wall of concrete mixer, this does not happen on other market samples. This also results in lower quality of PMM mixed by SBR-Latex.

4.4.5 Intrinsic Air Permeability Test

Intrinsic air permeability test was carried out to determine the durability properties of PMM. High permeability will lead to mortar defects such as shrinkage cracks and weken down the strength. PMM cylinder specimens with diameter of 0.045m and 0.04m height were used in this test.

One of the essential properties of PMM is that it could reduce the permeability of mortar (Aggarwal, 2007). The test was conducted on 7 days of water cured, 14 days, 28 days and 35 days of ambient environment cured.

Table 4.23 Intrinsic Air Permeability Test Results at 7 Days

Variables	Average Time (s)	Pressure 1 (Bar)	Pressure 2 (Bar)	Flow Rate (cm/s)	Flowmeter Diameter (mm)	Permeability $x10^{-16}$, K (m^2)
Optimum	2.821	3	2	0.2506	3	8.8766
Pentens	3.750	3	2	0.1885	3	6.6769
CMI	3.358	3	2	0.2105	3	7.4562
Sika	4.047	4	3	0.1747	3	6.6301

Table 4.23 shows the air permeability test on 7 days of curing age which right after end of wet curing process. Optimum has the highest permeability which is 8.8766 x 10^{-16} where Sika has the lowest permeability with 6.6301 x 10^{-16}. Cement hydration process fill up the pores inside PMM to increase the impermeability. Where there are capillaries pore left by cement hydration process (Ohama, 1995).

Table 4.24 Intrinsic Air Permeability Test Results at 14 Days

Variables	Average Time (s)	Pressure 1 (Bar)	Pressure 2 (Bar)	Flow Rate (cm/s)	Flowmeter Diameter (mm)	Permeability $x10^{-16}$, K (m^2)
Optimum	3.984	3	2	0.1774	3	6.2838
Pentens	6.442	3	2	0.1097	3	3.8857
CMI	4.109	3	2	0.1720	3	6.0925
Sika	5.014	4	3	0.1410	3	5.3512

Table 4.25 Intrinsic Air Permeability Test Results at 28 Days

Variables	Average Time (s)	Pressure 1 (Bar)	Pressure 2 (Bar)	Flow Rate (cm/s)	Flowmeter Diameter (mm)	Permeability $x10^{-16}$, K (m^2)
Optimum	4.387	3	2	0.1611	3	5.7064
Pentens	6.472	3	2	0.1092	3	3.8680
CMI	4.431	3	2	0.1595	3	5.6497
Sika	5.197	4	3	0.1360	3	5.1614

Table 4.26 Intrinsic Air Permeability Test Results at 35 Days

Specimens	Average Time (s)	Pressure 1 (Bar)	Pressure 2 (Bar)	Flow Rate (cm/s)	Flowmeter Diameter (mm)	Permeability $x10^{-16}$, K (m^2)
Optimum	4.815	3	2	0.1468	3	5.2015
Pentens	6.964	3	2	0.1015	3	3.5953
CMI	4.806	3	2	0.1471	3	5.2105
Sika	5.649	4	3	0.1251	3	4.7477

Table 4.24, 4.25 and 4.26 shows the results of air permeability test after ambient environment curing with age of 14 days, 28 days and 35 days. After 7 days of wet curing, follow by the 7 days ambient environment curing, the 14 days curing age specimens tested under intrinsic air permeability test shows the polymer formation developed under dry curing.

Pentens has the significant decrease in air permeability with 3.8857 x 10^{-16} permeability, which means the acrylic based resin had formed polymer chain to fill up the capillaries left by cement hydration process (Chandra, 1994).

Other market sample developed the formation of polymer as well, but does not perform as well as Pentens. The air permeability of all samples decreased as the polymer formation going on.

Table 4.27 Summaries of Intrinsic Air Permeability Result

Specimens	Permeability x10^{-16} , K (m^2)			
	7 Days	14 Days	28 Days	35 Days
Optimum	8.8766	6.2838	5.7064	5.2015
Pentens	6.6769	3.8857	3.8680	3.5953
CMI	7.4562	6.0925	5.6493	5.2105
Sika	6.6310	5.3512	5.1614	4.7477

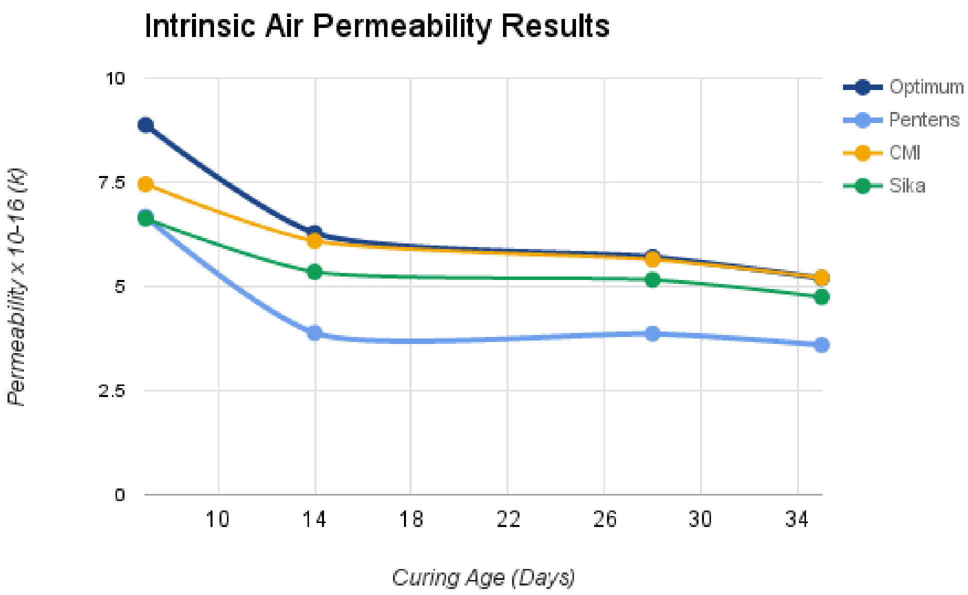


Figure 4.12 Summaries of Intrinsic Air Permeability Test

The summary of intrinsic air permeability test is shown in table 4.27 and figure 4.12. From the curve, observed that the permeability of Optimum samples and CMI samples developed to almost the same permeability on 14 days of curing age which around 6.100 x10^{-16} permeability. Pentens has the lowest permeability as it has a lower water cement ratio and probably the sufficient amount of polymer cement ratio to fill up the capillaries pore (Chandra, 1994).

Sika has the second low permeability right after Pentens. Sika contained polymer modified, and silica fume and some disclosed materials that could decrease the permeability of mortar. Whereby Optimum mixed by SBR-Latex and CMI samples has a higher water cement ratio, which probably the 7 days cement hydration process is too short for cement hydration process to fill up the capillaries pore. Hence, the polymer formed is insufficient to fill up the pores left by cement hydration process .

4.4.6 Water Absorption Test

Water absorption test was carried out to determine the durability properties of PMM. The same specimens that used for Intrinsic air permeability test were used to conduct this test. One of the main purposes of using PMM is that it could increase the water resistance (Ohama, 1995).

Table 4.28 illustrate the results of water absorption test after 7 days of water curing, observed that optimum have the lowest water absorption compared to the other samples with only 2.827% of water absorption. Optimum has a better water tightness after cement hydration process.

Table 4.28 Results of Water Absorption Test at 7 Days

Specimens	Dry Weight (A) (g)	Wet Weight (B) (g)	Water Absorption [(B-A)/A] x 100% (%)	Average Water Absorption (%)
Optimum	0.142	0.147	3.521	2.827
	0.137	0.141	2.920	
	0.147	0.150	2.041	
Pentens	0.146	0.150	2.740	3.414
	0.148	0.154	4.054	
	0.145	0.150	3.448	
CMI	0.144	0.151	4.861	5.078
	0.141	0.149	5.674	
	0.149	0.156	4.698	
Sika	0.131	0.136	3.817	4.170
	0.126	0.131	3.968	
	0.127	0.133	4.724	

Table 4.29 Results of Water Absorption Test at 14 Days

Specimens	Dry Weight (A) (g)	Wet Weight (B) (g)	Water Absorption [(B-A)/A] x 100% (%)	Average Water Absorption (%)
Optimum	0.142	0.146	2.817	2.123
	0.137	0.140	2.190	
	0.147	0.149	1.361	
Pentens	0.147	0.151	2.721	2.715
	0.149	0.153	2.685	
	0.146	0.150	2.740	
CMI	0.144	0.150	4.167	4.375
	0.142	0.149	4.930	
	0.149	0.155	4.027	
Sika	0.132	0.136	3.030	3.362
	0.128	0.133	3.906	
	0.127	0.131	3.150	

In table 4.29, it present the results of water absorption test with 14 days of specimens curing age which include 7 days of wet cure and 7 days of dry cure. The results show that, the water tightness of all samples developed rapidly in 14 days of curing age which increased about 0.7%.

The polymer formation process could increase the water tightness of PMM results in a better water resistance (Ohama, 1995). Pentens consist of acrylic based resin which results in excellent water resistance (“Pentens LATEX-108,” 2014).

Table 4.30 Results of Water Absorption Test at 28 Days

Specimens	Dry Weight (A) (g)	Wet Weight (B) (g)	Water Absorption [(B-A)/A] x 100% (%)	Average Water Absorption (%)
Optimum	0.142	0.145	2.113	1.888
	0.137	0.140	2.190	
	0.147	0.149	1.361	
Pentens	0.148	0.151	2.027	2.023
	0.150	0.153	2.000	
	0.147	0.150	2.041	
CMI	0.146	0.152	4.110	4.335
	0.143	0.140	4.895	
	0.150	0.156	4.000	
Sika	0.132	0.137	3.788	3.330
	0.129	0.134	3.876	
	0.130	0.132	2.326	

Table 4.31 Results of Water Absorption Test at 35 Days

Specimens	Dry Weight (A) (g)	Wet Weight (B) (g)	Water Absorption [(B-A)/A] x 100% (%)	Average Water Absorption (%)
Optimum	0.142	0.145	2.113	1.645
	0.137	0.139	1.460	
	0.147	0.149	1.361	
Pentens	0.149	0.152	2.012	1.778
	0.153	0.155	1.307	
	0.149	0.152	2.013	
CMI	0.146	0.152	4.110	4.315
	0.144	0.151	4.861	
	0.151	0.157	3.974	
Sika	0.137	0.141	2.920	3.231
	0.132	0.137	3.788	
	0.134	0.138	2.985	

Tables 4.30 and 4.31 show the water absorption test results on 28 days and 35 days of curing age. The polymer formation continues developed under ambient environment and results in reduction of water absorption (Ohama, 1995). From the results, observed that CMI and Sika almost meet the optimum water tightness with less than 0.1% development in water tightness.

Table 4.32 Summaries of Water Absorption Test Results

Specimens	Average Water Absorption (%)			
	7 Days	14 Days	28 Days	35 Days
Optimum	2.827	2.123	1.888	1.645
Pentens	3.414	2.715	2.023	1.778
CMI	5.078	4.375	4.335	4.315
Sika	4.170	3.362	3.330	3.231

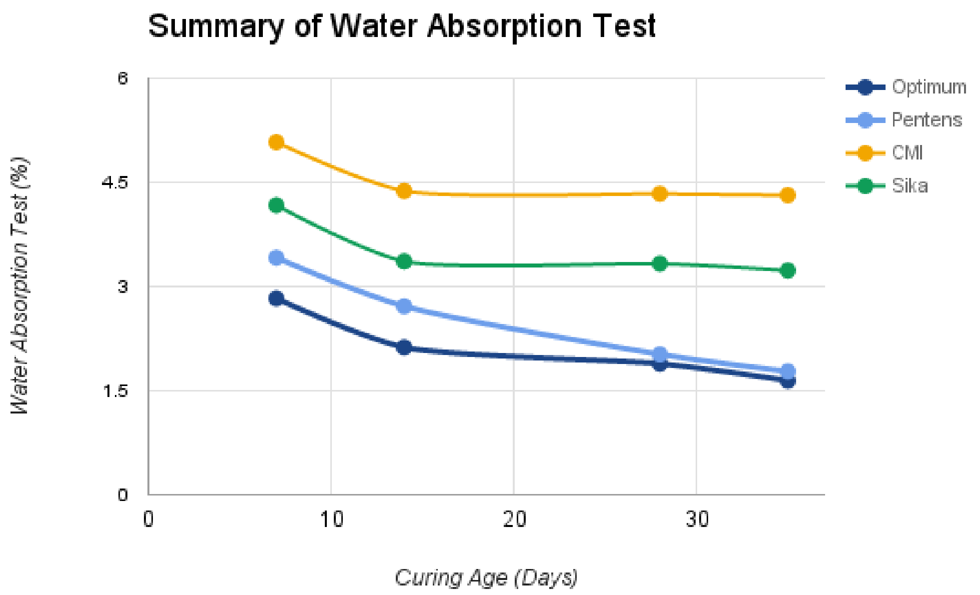


Figure 4.13 Summaries of Water Absorption Test Results

Table 4.32 and Figure 4.13 show the summary of water absorption test for all the samples. The graph presents that both Optimum and Pentens still continue develop the water tightness to increase water resistance, where CMI and Sika almost remain constant in water absorption.

Based on the Optimum, the water absorption of CMI is 162.31% higher which mean the surface of CMI is much easier to absorb water. Sika has a 96.4% higher water absorption compared to Optimum, and the lowest percentage increase is Pentens which is 8.09% of water absorption increased. As the curing length increased, the percentage of water absorption decreased this show that the polymer film formation developing will decrease the water absorption of PMM (Makhtar, 1997).

Besides, Optimum has the best water resistance compared to other specimens. Optimum and Pentens both consist of SBR-Latex and acrylic based resin, these two types of polymer gained water tightness throughout polymer formation process and obtained the lowest water absorption compared with synthetic latex (Aggarwal, 2007).

4.4.7 Porosity Test

Porosity test were carried out to determine the durability properties of PMM. Higher porosity results in lower performance (Ohama, 1995). Tables 4.33, 4.34, 4.35 and 4.36 illustrate the results from porosity test for 7, 14, 28 and 35 days of curing age respectively.

The results show that Optimum has the lowest porosity among all samples with only 11.64% pores. Whereby, Sika has the highest porosity percentage, Sika contained parts of the polymer modifier and some solid fibre. Besides, the results also going with a decreasing trend, which mean as the curing length increase, the porosity decreased.

Table 4.33 Results of Porosity Test at 7 Days

Specimens		Dry Weight (kg)	Wet Weight (kg)	Weight in Water (kg)	Porosity (%)	Average Porosity (%)
Optimum	1	0.148	0.159	0.073	12.79	11.64
	2	0.148	0.157	0.069	10.23	
	3	0.148	0.158	0.074	11.90	
Pentens	1	0.146	0.156	0.077	12.66	12.24
	2	0.148	0.157	0.078	11.39	
	3	0.145	0.155	0.076	12.66	
CMI	1	0.144	0.155	0.075	13.75	14.11
	2	0.141	0.153	0.073	15.00	
	3	0.149	0.160	0.079	13.58	
Sika	1	0.131	0.144	0.065	16.46	17.40
	2	0.126	0.139	0.064	17.33	
	3	0.127	0.141	0.065	18.42	

Table 4.34 Results of Porosity Test at 14 Days

Specimens		Dry Weight (kg)	Wet Weight (kg)	Weight in Water (kg)	Porosity (%)	Average Porosity (%)
Optimum	1	0.142	0.152	0.073	12.66	10.61
	2	0.137	0.146	0.065	11.11	
	3	0.147	0.154	0.067	8.05	
Pentens	1	0.147	0.156	0.078	11.54	11.54
	2	0.149	0.158	0.080	11.54	
	3	0.146	0.155	0.077	11.54	
CMI	1	0.144	0.157	0.076	16.05	14.63
	2	0.142	0.153	0.075	14.10	
	3	0.149	0.160	0.080	13.75	
Sika	1	0.132	0.144	0.065	15.19	16.91
	2	0.128	0.140	0.064	15.79	
	3	0.127	0.142	0.066	19.74	

Table 4.35 Results of Porosity Test at 28 Days

Specimens		Dry Weight (kg)	Wet Weight (kg)	Weight in Water (kg)	Porosity (%)	Average Porosity (%)
Optimum	1	0.142	0.152	0.070	12.2	10.45
	2	0.137	0.146	0.065	11.11	
	3	0.147	0.154	0.067	8.05	
Pentens	1	0.148	0.157	0.075	10.98	11.11
	2	0.150	0.159	0.078	11.11	
	3	0.147	0.156	0.076	11.25	
CMI	1	0.146	0.155	0.074	11.11	12.65
	2	0.143	0.154	0.073	13.58	
	3	0.150	0.161	0.078	13.25	
Sika	1	0.132	0.145	0.065	16.25	14.99
	2	0.129	0.140	0.061	13.92	
	3	0.130	0.142	0.061	14.81	

Table 4.36 Results of Porosity Test at 35 Days

Specimens		Dry Weight (kg)	Wet Weight (kg)	Weight in Water (kg)	Porosity (%)	Average Porosity (%)
Optimum	1	0.142	0.151	0.069	10.98	10.05
	2	0.137	0.146	0.065	11.11	
	3	0.147	0.154	0.067	8.05	
Pentens	1	0.149	0.157	0.075	9.76	8.64
	2	0.153	0.159	0.078	7.41	
	3	0.149	0.156	0.076	8.75	
CMI	1	0.146	0.155	0.074	11.11	11.84
	2	0.144	0.154	0.073	12.35	
	3	0.151	0.161	0.078	12.05	
Sika	1	0.137	0.146	0.067	11.39	10.72
	2	0.132	0.140	0.063	10.39	
	3	0.134	0.142	0.065	10.39	

Table 4.37 Summaries of Porosity Test Results

Specimens	Average Porosity (%)			
	7 Days	14 Days	28 Days	35 Days
Optimum	11.64	10.61	10.45	10.05
Pentens	12.24	11.54	11.11	8.64
CMI	14.11	14.63	12.65	11.84
Sika	17.40	16.91	14.99	10.72

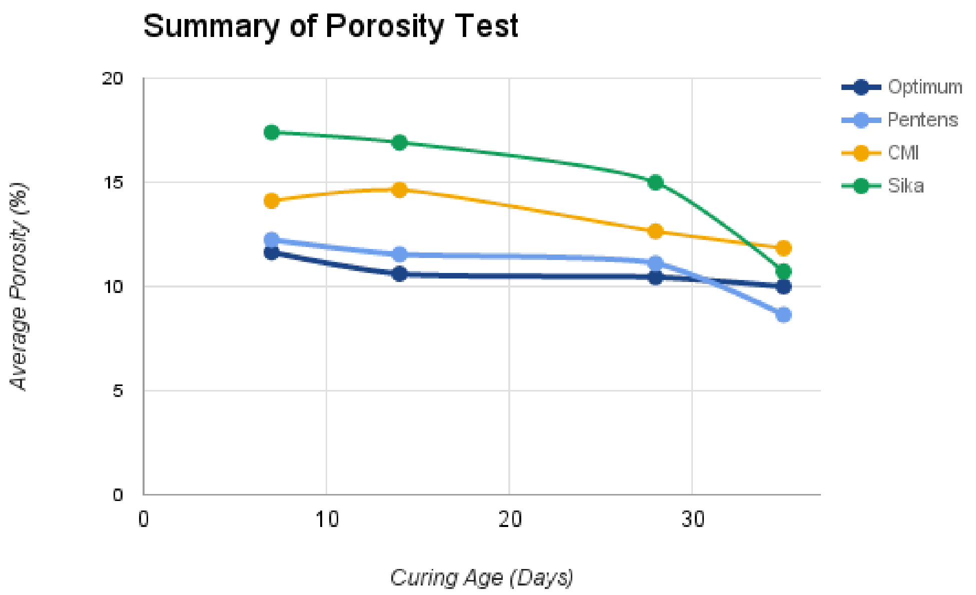


Figure 4.14 Summaries of Porosity Test Results

Figure 4.14 and Table 4.37 show the summary graph for porosity test. Porosity percentage of all sample reduced from 7 days of curing age to 35 days of curing age. Whereby from 28 days to 35 days of curing age, Sika has a significant reduction in porosity which become lesser than CMI.

Optimum samples gain the lowest porosity among all specimens from 7 days to 28 days of curing age. The polymer film formation process allow the capillaries left after cement hydration process to be filled with polymer structure and thus reduced the pores inside PMM (Ohama, 1995).

Besides, the results illustrate that acrylic based resin developed the lowest porosity among all sample in 35 days of curing age follow by Optimum, Sika and CMI. The particles of SBR-Latex stick together to form a flexible network and blocks the pores and capillaries to certain extend (Chemgeek, 2006). The results also indicate that porosity of PMM is dependent on the curing length, as the curing length increase the porosity decrease as polymer film formation developing.

4.4.8 Acid Resistance Test

Table 4.38 Acid Resistance Test Results after 7 Days Curing Age.

Specimens	Compressive Strength (N/mm^2)			
	0 Days	7 Days	14 Days	28 Days
Optimum	11.13	10.50	6.12	5.32
Pentens	33.99	28.95	29.26	27.60
CMI	15.02	14.70	13.52	12.34
Sika	19.06	18.40	17.88	16.23

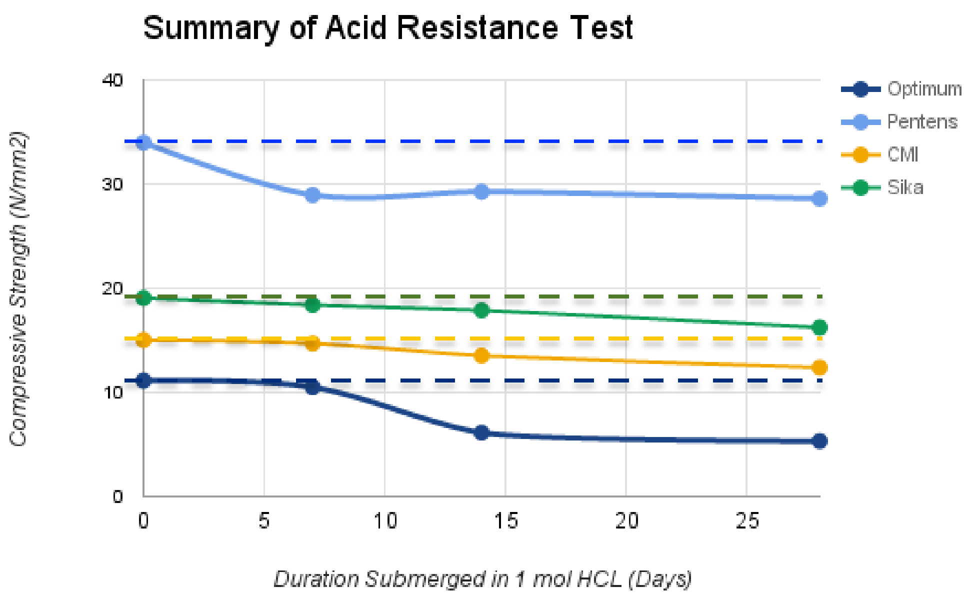


Figure 4.15 Graph Summary of Acid Resistance Test

Table 4.38 present the results of acid resistant test based on 7 days of curing age. Based on the percentage of strength drop, Optimum has the highest percentage of strength drop which is decreased from 11.13 N/mm^2 to 5.32 N/mm^2 with 61.19% of strength drop. The other 3 samples have lower percentage of strength drop with less than 20%.

Pentens, CMI and Sika has 18.8%, 17.58% and 14.85% of strength drop respectively. Based on the graph shown in figure 4.15, Pentens seem to have the highest strength drop, as it gained highest compressive strength in 7 days of curing, thus the percentage of strength drop is low. Whereby Optimum sample has the lowest strength among 4 samples, hence it has the highest percentage of strength drop although it looks similar strength drop with Pentens.

4.5 Correlation between Porosity and Permeability

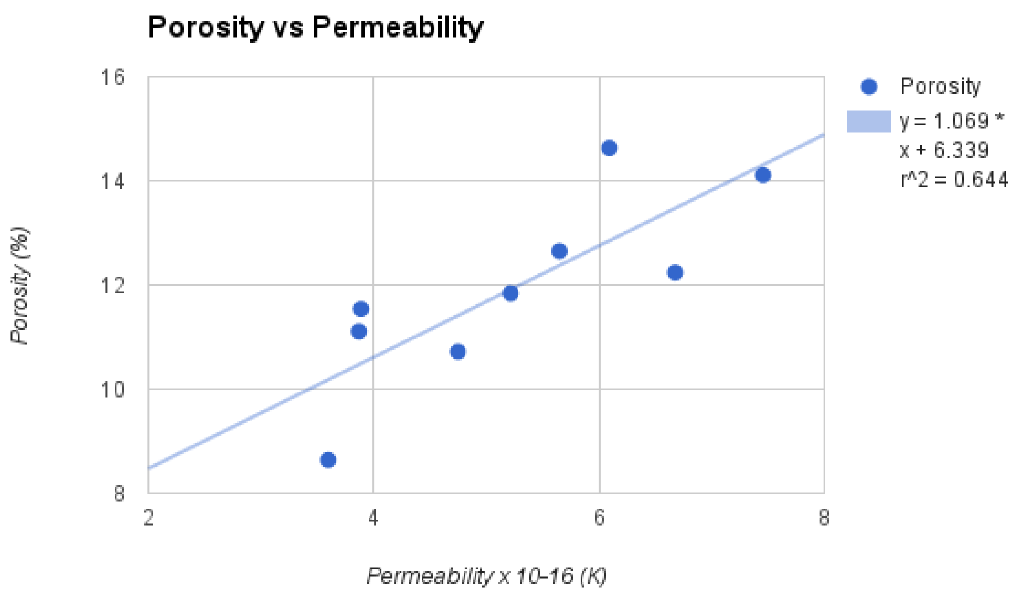


Figure 4.16 Correlations between Porosity and Permeability

Figure 4.16 illustrate the relationship between porosity and permeability for PMM. The graph shows that, increasing in percentage of porosity results in higher permeability. Lower porosity will gain higher water impermeability which increase the performance and durability of PMM. The correlation graph show positive relationship between porosity and permeability of PMM. It can be used to forecast the permeability of PMM by determining the porosity of PMM. The value of R^2 with 0.644 is the coefficient of determination for PMM.

4.6 Correlation between Compressive Strength and Porosity

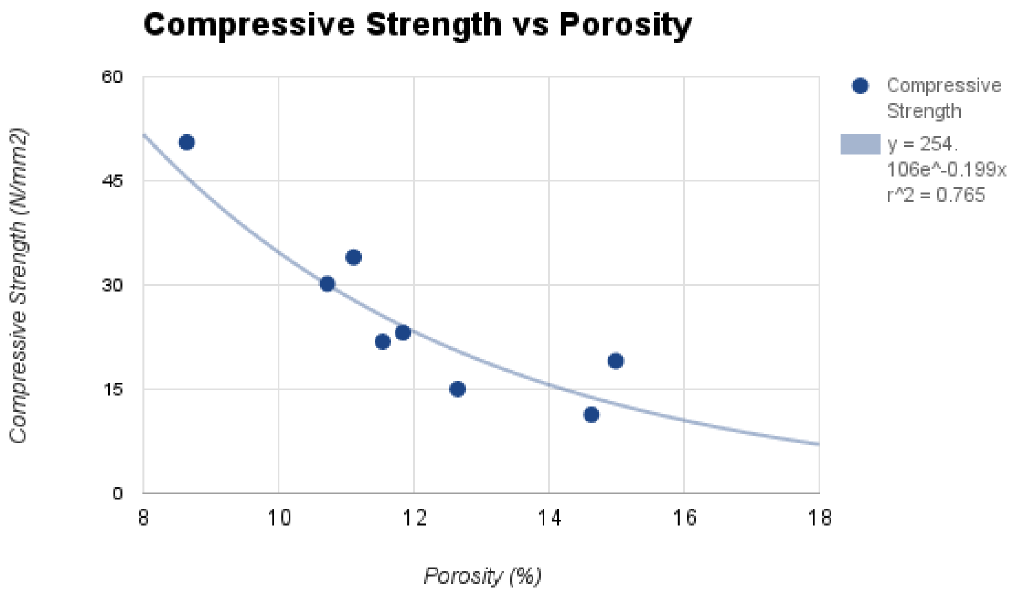


Figure 4.17 Correlations between Compressive Strength and Porosity

From the results obtained from the research, correlation between compressive strength and porosity are shown in figure 4.17. As percentage of porosity increase, the compressive strength decreased. When higher percentage of pores appears in the mortar, the hollowness of the internal structure increase and thus results in lower compressive strength. PMM generally has a lower compressive strength compared to the ordinary mortar (Ohama, 1995). The correlation can be used to forecast the compressive strength of PMM based on its porosity. The value of R^2 coefficient is the determination for the PMM.

4.7 Correlation between Acid Resistance and Permeability

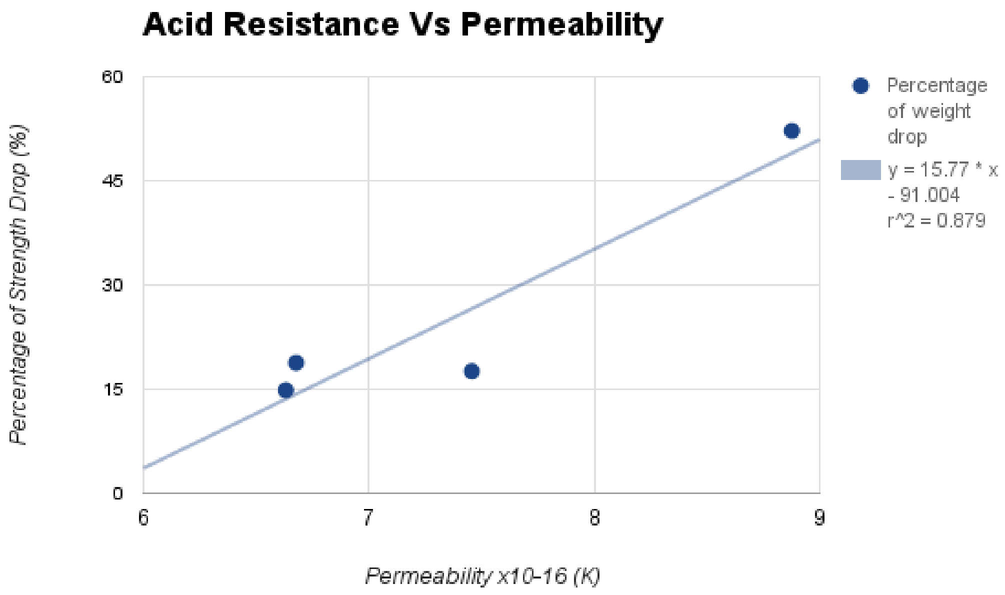


Figure 4.18 Correlations between Acid Resistance and Permeability

The research shown a positive relationship between the permeability and percentage of strength drop after submerge in 1 mol HCL solutions. Figure 4.18 illustrate the correlation by percentage of strength drop after submerge in acid versus permeability. Higher permeability results in higher percentage of strength drop as the acid solution easier to penetrate the surface layer of mortar. The internal layer of mortar cube specimens still able to give strength to the mortar but the eternal layer that being corrode by acid become brittle. Besides, the percentage of polymer content affects the chemical resistance as well (Kardon, 1997). Higher percentage of polymer has higher chemical resistance. The value of R^2 is the coefficient of determination for PMM.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study, investigation and evaluation throughout the laboratory experiments and literature review on the performance of PMM which include mechanical properties and durability properties was done to determine the engineering properties and durability properties of PMM with different SBR-Latex percentage and different types of market sample. Throughout the whole process, several conclusions can be made, including:

5.1.1 Mechanical Properties of PMM Mixed by SBR-Latex

The Optimum percentage of PMM obtained from SBR-Latex based on the compressive strength and intrinsic permeability is 11.5%. The workability of PMM is dependent on the percentage of polymer used. The higher the polymer cement ratio, the better the workability of mortar under same water cement ratio. PMM has a lower compressive strength compared with the ordinary mortar. A higher polymer cement ratio will results in lower compressive strength. The flexural strength of PMM depends on the types of polymer used. Acrylic based resin obtained the highest flexural strength compared to modified synthetic latex, SBR-Latex and fibre reinforced.

5.1.2 Durability Properties of PMM Mixed by SBR-Latex

Cement hydration process and polymer formation process are essential for mortar or concrete to develop its internal structure to have a better quality and higher density product. Porosity could determine the permeability of PMM. Higher porosity means higher permeability. Capillaries left after cement hydration process filled by the polymer through polymer formation process under ambient environment curing which reduced the porosity of PMM. Factor affecting the water absorption of PMM not merely on porosity of PMM, the type of polymer and the mixture in PMM affects the water absorption as well.

5.1.3 Comparison between PMM mixed by SBR-Latex and Market Sample

CMI has the highest water absorption due to high porosity where Sika has the second highest water absorption as the mixture inside it has a higher water absorption capacity. Based on the percentage of strength drop in acid resistance test, Sika has the lowest percentage of strength drop followed by CMI, Pentens and Optimum. CMI has the highest porosity compared to the other sample, Optimum sample has medium porosity. The porosity of PMM is highly dependent on mix proportion, polymer cement ratio and curing length. Air permeability of Pentens is the lowest as it has a better condition for cement hydration process due to its water cement ratio. Optimum has the similar air permeability as CMI which is the highest air permeability and results in less durable.

The compressive strength of Pentens is highest among all as it has lower water cement ratio and good workability caused by the polymer. Whereby, Optimum has the lowest compressive strength as it has high polymer cement ratio and high water cement ratio compared to other samples.

5.2 Recommendations

This research has some limitations and thus, the following recommendations are made for future studies to improve current research for PMM.

I. As the time constraint, long term strength development couldn't be discovered in this research. A longer period of ambient environment curing can be done to discover the strength development from polymer film formation.

II. The structure of different types of polymer can be discovered by polymer engineer to find out how the polymer structure affects the performance of PMM.

III. Further study on PMM mixed by geo-polymer which believe to be more environmental friendly and as a solution for pollution.

IV. Comparison between fully ambient environment curing and water curing can be done to determine the best curing method for PMM to develop its performance.

REFERENCE

Aggarwal, L. K., Thapliyal, P. C., & Karade, S. R. (2007). Properties of polymer-modified mortars using epoxy and acrylic emulsions. *Construction and Building Materials*, *21*(2), 379–383. http://doi.org/10.1016/j.conbuildmat.2005.08.007

Arooj, M. F., Haydar, S., & Ahmad, K. (2011). Development of Economical Polymer-modified Concrete for Repair of Concrete Structures in Pakistan. *Pakistan Journal of Engineering and Applied Sciences*, *8*, 21–25.

Cabrera, G & Lynsdale, CJ 1988, 'A new gas permeameter for measuring the permeability of mortar and concrete', Magazibe Concrete Research, vol 40, no. 144, pp. 177-182.

Cement in Malaysia. (2012). Retrieved March 15, 2016, from http://www.globalcement.com/magazine/articles/686-cement-in-malaysia

Cement/Polymer Composite Technology. (2015). Retrieved from https://www.lion-specialty-chem.co.jp/en/technology/t05/t05_02.htm

Chandra, S. (1994) Polymer Cement Composite - A Critical Review. *Engineering Foundation Conference*. July 24-29. New York: American Society of Civil Engineers, 15-36.

Chemgeek. (2006). Chemical Engineering Fundas. Retrieved from http://chemicalgeekz.blogspot.my/

Chong, E., & Mee, E. (2010). EFFECTS OF POLYMER ON COMPRESSIVE STRENGTH AND TOTAL POROSITY OF CONCRETE.

CIP 35 -Testing Compressive Strength of Concrete. (2003). *Concrete in Practice*.

CMI Marketing Sdn. Bhd. (2015). Retrieved from http://www.cmimalaysia.com.my/cmi-latex-admix-350/

Concrete Admixtures. (2011). Retrieved March 19, 2016, from http://www.concretenetwork.com/concrete/concrete_admixtures/

Concrete Materials and Admixtures. (2008). Retrieved March 19, 2016, from http://www.theconcreteproducer.com/concrete-materials-and-admixtures/admixture-or-additive-.aspx

Emerging Trends and Innovations in Concrete. (2015). Retrieved March 19, 2016, from http://www.cement.org/think-harder-concrete-/buildings-structures/design-aids/emerging-trends

Fried, Joel R. (1995). *Polymer Science and Technology*. Upper Saddle River, New Jersey: Prentice Hall.

Gjorv, O. E. (2012). *Trends and Chellanges in Concrete Technology*. Norway.

Hirde, S. K., & Dudhal, O. S. (2016). Review on Polymer Modified Concrete And Its Application To Concrete Structures. *International Journal of Engineering Research*, *ISSN*(3). http://doi.org/10.17950/ijer/v5i3/053

Islam, M. A., Rahman, M. M., & Ahme, M. (2011). Polymer-modified concrete: World experience and potential for Bangladesh. *Indian Concrete Journal*, *85*(1), 55–63.

Islam, M. A., Rahman, M. M., & Ahmed, M. (2010). Polymer-modified Concrete: World Experience and Potential for Bangladesh.

J. Klinkenberg, “The permeability of porous media to liquids and gases,” API Drilling and Production Practice, USA, 1941. pp. 200-213.

Kardon, B. J. B. (1997). Polymer-Modified Concrete : Review. *Journal of Materials in Civil Engineering*. *9*(MAY), 85–92.

Ma, H., & Li, Z. (2013). Microstructures and mechanical properties of polymer modified mortars under distinct mechanisms. *Construction and Building Materials*, *47*, 579–587. http://doi.org/10.1016/j.conbuildmat.2013.05.048

Materials of Construction : Polymer Concrete vs. Polymer Modified Concrete. (2008). Retrieved March 15, 2016, from http://www.corrosion-engineering.com/newsletterarticleshtml/PolymerConcretevsPolymerModifiedConcrete.html

Makhtar, A.M. (1997). *Properties and Performance of Polymer Modified Concrete*. The University of Leeds. PhD Thesis

Mindness, S. and Young, J.F. (1981). Concrete. Eaglewood CLiffs, N.J.: Prentice-Hall.

Neville, a. M. (2011). *Properties of Concrete*.

Nick Gromicko, K. S. (2014). The History of Concrete. Retrieved March 18, 2016, from https://www.nachi.org/history-of-concrete.htm?loadbetadesign=0

Ohama, Y. (1995). POLYMER-MODIFIED CONCRETE AND MORTARS Properties and Process Technology.

Paper, C. (2014). Performance Evaluation of Polymer Modified Concrete using Polyurethane and Poly (Vinyl Alcohol co-Ethylene), (OCTOBER). http://doi.org/10.13140/RG.2.1.1565.2963

Pentens LATEX-108. (2014). Retrieved August 31, 2016, from http://www.pentenswaterproof.com/#!latex-108/c1k36

Product Data Sheet Edition 1105 / 1 Sika ® MonoTop ® -R40. (2010).

Ramakrishnan, V. (1992). *Latex-Modified Concretes and Mortars*. Washington: National Cooperative Highway Research Program.

RILEM Recommendations. (1984). Absorption of water by concrete by immersion under vacuum. Materials and Structures.

SBR Latex - Euclid Chemical. (2016). Retrieved August 31, 2016, from http://www.euclidchemical.com/products/construction-products/bonding-agents-adhesives/latex-based/sbr-latex/

Suryakanta, 2013. Workability Of Concrete Using Flow Table Test Apparatus (IS:1199-1959) CivilBlog.Org. Available at: http://civilblog.org/2013/05/10/workability-of-concrete-using-flow-table-test-apparatus-is1199-1959/ [Accessed June 13, 2016].

Talah, A. & Kharchi, F., 2013. A Modified Test Procedure to Measure Gas Permeability of Hollow Cylinder Concrete Specimens. , 5(1), pp.91–94.

Timeline of Concrete & Cement History. (2010). Retrieved March 18, 2016, from http://www.concretenetwork.com/concrete-history/linear-timeline.html

Yoshihiko Ohama. (1994). *Polymers in Concrete*. *Polymers in Concrete*. Tokyo: CRC Press.

STANDARDS

British Standard Institution (2011). *Cement. Composition, specifications and conformity criteria for common cements*. London, BS EN 197-1:2011

British Standard Institution (2013). *Aggregates for concrete*. London, BS EN 12620-2013

ASTM International (2014). *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates,* West Conshohocken, PA, 2014, ASTM C136 / C136M-14. www.astm.org.

British Standard Institution (1999). *Methods of test for mortar for masonry. Determination of consistence of fresh mortar (by flow table)*. London, BS EN 1015-3:1999.

British Standard Institution (2012). *Testing hardened concrete. Shape, dimensions and other requirements for specimens and moulds*. London, BS EN 12390-1:2012.

British Standard Institution (2009). *Testing hardened concrete. Making and curing specimens for strength tests*. London, BS EN 12390-2:2009

British Standard Institution (2009). *Testing hardened concrete. Compressive strength of test specimens*. London, BS EN 12390-3:2009

British Standard Institution (2009). *Testing hardened concrete. Flexural strength of test specimens*. London, BS EN 12390-5:2009

British Standard Institution (2004). *Testing Concrete. Determination of ultrasonic pulse velocity*. London, BS EN 12504-4:2004.

British Standard Institution (2011). Testing concrete. Method for determination of water absorption. London, BS 1881-122:2011.