# EXPERIMENTAL STUDY ON EFFECT OF SILICA SAND AS PARTIAL FINE AGGREGATES REPLACEMENT IN EPOXY POLYMER CEMENT CONCRETE

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# ABSTRAK

Konkrit tradisional yang dihasilkan daripada campuran simen, agregat kasar, agregat halus dan air adalah kurang mesra alam sekitar kerana penambatan dan perlombongan pasir di sungai dan laut. Konkrit polimer dipromosikan di mana simen dan agregat halus diganti sebahagiannya dalam kandungan konkrit itu sendiri. Dalam kajian ini, sifat-sifat mekanik seperti kekuatan mampatan dan kekuatan pemisahan tegangan akan diukur melalui ujian mesin. Peratusan optimum pasir tradisional yang digantikan dengan pasir silika untuk mencapai kekuatan pemisahan tegangan tertinggi boleh didapati melalui ujian. Selepas pengawetan selama 28 hari, kekuatan pemisahan tegangan maksima konkrit simen polimer meningkat sehingga 2.83% dengan paras penggantian pasir tradisional dengan pasir silika sebanyak 20%.Bagi kekuatan mampatan pula, kekuatan tersebut menjadi semakin rendah apabila peratusan agregat halus yang diganti dengan pasir silika semakin bertambah. Selepas pengawetan selama 28 hari, kekuatan mampatan konkrit simen polimer maksima berkurangan sehingga 30% apabila paras penggantian pasir tradisional adalah sebanyak 60%. Pasir silika boleh digunakan untuk menggantikan pasir tradisional di sesetengah bahagian tertentu bangunan yang tidak mengambil beban tinggi kerana sifatnya yang lebih mesra alam. Projek-projek konkrit seperti laluan, jalan masuk dan lantai taman permainan yang tidak memerlukan tetulang boleh dibina dengan menggunakan konkrit simen polimer kerana penggunaan pasir silika juga dapat menjimatkan lebih banyak kos pembinaan.

## ABSTRACT

Conventional concrete which is produced by the mixture of cement, coarse aggregates, fine aggregates, and water is less environmental friendly due to calcination and mining of sand in river and sea. Polymer concrete is thus promoted where the cement and fine aggregates are replaced partially within itself. In this study, mechanical properties such as compressive strength and tensile splitting strength are measured. The optimum percentage of conventional sand replaced with silica sand to achieve the highest tensile splitting strength can be obtained which is 20%. After 28 days of curing, the maximum tensile splitting strength of polymer cement concrete with 20% replacement level of conventional sand with silica sand increases up to 2.83%. For compressive strength, the strength gets lower when the percentage of fine aggregates replaced with silica sand is higher. After 28 days of curing, the maximum compressive strength of polymer cement concrete decreases up to 30% when the replacement level of fine aggregates is 60%. Silica sand can be used instead of conventional sand in certain parts of the building that do not take high loading since it is more environmental friendly. Concrete projects such as pathways, driveways, and playhouse floor that do not require reinforcement can be constructed by using polymer cement concrete as the uses of silica sand can also save more construction cost.

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## LIST OF SYMBOLS

| | |
|---|---|
| $CO_2$ | Carbon Dioxide |
| w/c | Water to cement |
| w% | Water content |
| $kg/m^3$ | Kilogram per cubic meter |
| MPa | Mega Pascal |
| mm | Milimeter |
| $m^2/kg$ | Square meter per kilogram |
| μ | Micron |
| kN | Kilo Newton |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| C-S-H | Calcium-Silica-Hydrate |
| PC | Polymer Concrete |
| PIC | Polymer Impregnated Concrete |
| PPCC | Polymer Portland Cement Concrete |
| 3D | Three Dimensional |
| SF | Silica Fume |
| SSD | Specific Gravity |
| OPC | Ordinary Portland Cement |
| E/H | Epoxy/Hardener |
| PAIP | Pengurusan Air Pahang Berhad |
| FA | Fine Aggregates |
| ANOVA | Analysis Of Variance |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

The most popular and common artificial material on Earth is not steel or plastic but concrete because the materials used to produce concrete is readily available anywhere in the world and no complicated equipment is required. Concrete is created by binding find aggregates and coarse aggregates together with cement as binder through hydration process when water comes into contact with cement grains. High compressive strength and durability of concrete are the key reasons for its universal acceptance. However, it has few disadvantages and some critical limitations which include having low tensile strength, weak flexural strength, poor chemical resistance to acid etc. Therefore, a number of attempts have been made to replace cement with other building materials composition to overcome the weaknesses and those attempts lead to introduction of polymer concrete. Polymer concrete was introduced in the late 1950s and got its name well known in the 1970s because of its properties such as rapid curing, high compressive strength, high tensile strength and even great chemical resistance. Polymer concrete is a composite material which is produced from polymerization of aggregate and monomer mixture. The polymerized monomer as cement replacement acts as binder for coarse aggregates and fine aggregates and the resulting composite product is called polymer concrete. The properties of polymer concrete vary accordingly to the steps and process of its preparation. The properties of polymer concrete are affected by the binder content (polymer), size distribution of aggregates, condition and type of microfiller, and curing conditions(Bedi, Chandra, &Singh, 2013a). Generally, resins used for polymer concrete's production consist of methyl methacrylate, epoxy resins, unsaturated polyester resin, furan resins, urea formaldehyde resin, and polyurethane resins. Furan resin offers a variety of advantages over other synthetic resins because it is formed by using agricultural wastes that consist of furfuryl alcohol and furfuraldehyde(ManickamMuthukumar &Mohan, 2005). In order to increase the mechanical strength of polymer concrete, microfiller such as micro silica, steel fibres, and nylon fibres have been added to the polymer concrete mixture to fill the microvoids present in the system. Due to superb and preceding properties of polymer concrete like fast curing, high tensile and compressive strength, resistance to chemical attack and corrosion, and capability to constitute complex shape which allow a better molding process, polymer concrete materials have also been used in applications and fields other than for which they were developed originally(Bedi et al., 2013a).

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## 1.2 Problem Statement

While conventional concrete( cement concrete) acts as one of the most handy and adjustable construction materials in all around the world and steers the industrial growth in the last decades, it also contributes the most in terms of environmental impact especially in negative outcomes(Adam Knaack, 2012). Cement concrete is produced by mixing together coarse aggregates (crushed stones), fine aggregates (sand) with cement as binder after getting contact with water. Cement is a building material produced by grinding calcined limestone and traces of clay and gypsum and the main concern regarding cement production is the amount of greenhouse emissions that come along together. In order to produce cement, around 50% of carbon dioxide ($CO_2$) emissions are contributed by the electricity and heat demands meanwhile the other 50% comes from the process called calcination which acts as an important procedure where limestone (calcium carbonate) is heated up to transform into quicklime (calcium oxide), releasing out $CO_2$ in the process(Rackel San Nicolas, 2017). As the production of cement consumes a lot of energy and releases so much $CO_2$ it is considered non-environmental friendly to certain extent. Besides, fine aggregates (sand) used in the formation of concrete has also caused a lot of issues due to global deficiency for natural sand. Unpremeditated sand mining and continuous depletion of natural aggregates sources led to the fulfillment of new land use legislations which caused the purchasing of natural sand more difficult and costly. In 2014, illegal sand mining activities has been found continuing unabated in the Klang Valley, Malaysia. Report revealed mining was carried out in open daylight despite the operators not having permits. The activities created a lot of environmental problems, not excluding dusty and dirty lands caused by vehicles transporting the sand(ARYTON SOLIANO, 2014). Therefore, sand dredging is heavily taxed and prohibited in many places around the world. Furthermore, sand pits that are licensed are often located in far-off location which requires great cost in term of transportation. Cement conservation is much needed to ensure sustainability of construction material resources as well as preserving an environment with less $CO_2$ content therefore this can be done through partial replacement of cement and fine aggregates (sand) with synthetic polymer like epoxy resin and silica sand respectively. With such replacements, polymer cement concrete will be produced instead of conventional concrete which also brings along advantages such as rapid curing, excellent bond to cement concrete and steel reinforcement, high strength and durability(M.Muthukumar &Mohan, 2004). Furthermore, tensile strength and compressive strength of polymer cement concrete is expected to be higher than conventional cement concrete when cement and construction sand are replaced with epoxy resin and silica sand respectively. In order to improve mechanical strength of conventional concrete, a research needs to be done through the process of replacing certain portions of cement and construction sand with epoxy resin and silica sand to enhance its compressive strength and especially tensile strength which is originally considered very weak.

## 1.3 Objectives

The main purpose of this research is to study the enhancement on mechanical properties of polymer cement concrete. The objectives are listed as below in order to achieve the goal of this research.

1. To determine the effects of various proportions of silica sand as sand replacement on compressive strength of polymer cement concrete.

2. To determine the effects of various proportions of silica sand as sand replacement on tensile splitting strength of polymer cement concrete.

## 1.4 Scope of Research

The scope of research involves the study of mechanical properties of concrete mainly on compressive strength and tensile splitting strength with various proportions of silica sand as sand replacement. At the same time, a certain proportion of cement will be replaced with epoxy resin and this proportion of replacement will be fixed as a constant variable of 40% to allow manipulation of sand replacement's proportion in the concrete. So here in this project, silica sand will be used as replacement of fine aggregate by different percentage for making concrete of grade M-25, with w/c ratio of 0.65. The percentage replacement will be 0%, 20%, 40% and 60% with natural fine aggregates(Jignesh &Vaniya, 2015). A total of 90 cubes and cylinders will be casted and tested on compressive strength and tensile splitting strength. Optimum proportion of silica sand replacement can be used in structural concrete to improve the compressive strength and tensile splitting strength.

## 1.5 Significance of Research

Concrete mixture can be designed to meet a wide range of mechanical properties especially in its compressive strength. The compressive strength of concrete is the most significant characteristic as it excels in such aspect compared to other building materials. This research is done to improve the concrete's compressive strength with lower cost of materials like silica sand instead of natural fine aggregates. Silica sand with its micro filling effect can reduce the pores and voids in concrete thus enable a better structure linkage within the concrete compound. Besides, with epoxy resin fixed at certain proportion of cement replacement, the tensile splitting strength can be enhanced and this will reduce the amount of reinforcement needed. Time of construction and cost to purchase steel bars will be reduced. This will definitely ease the construction project in term of duration and cost for developer and contractor.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

Concrete acts as one of the most staple materials in field of civil engineering especially construction industries related to structural aspects. Conventional concrete is best renowned for its favorable advantages such as low cost of materials and simple application(Golestaneh, Amini, Najafpour, &Beygi, 2010). In terms of structural and geometrical benefits, conventional concrete possesses high durability, high temperature and water resistance, high compressive strength, low maintenance requirement and it can be casted to any shape desired. However, it has a few disadvantages and some critical limitations. Conventional concrete possesses low tensile strength, weak flexural strength, low sulphate and acid resistance(Suryakanta, 2015). All these weak spots of concrete have limited the extensive use of concrete.

Conventional concrete is a composite multiphase material for example a type of man-made solid stone produced by mixing cement, coarse aggregates, fine aggregates and water. The crushed stones and sands in cement paste and unhydrated cement grains make up the elastic skeleton of concrete body to support external loads. Under application of external loads, micro voids and the Calcium-Silica-Hydrate(C-S-H) gel at transition zone between cement mortar and aggregates allow concrete to have plastic deformation. Micro defects such as voids and cracks will initiate the process of concrete failure therefore the propagation of cracks and voids can severely affect the mechanical properties of concrete(Gu, Jin, &Zhou, 2016).

## 2.2 Relationship between Mineral Admixtures as Cement Replacement and Mechanical Properties of Concrete

Performance of concrete is identified by measuring and determining the mechanical properties which include shrinkage and creep, compressive strength, tensile strength, flexural strength, and modulus of elasticity. After all, compressive strength of concrete is the most crucial and concerned characteristic and it is commonly assumed that an enhancement in concrete compressive strength at the same time can improve its mechanical properties. Nevertheless, when cement and sand in concrete is partially replaced by synthetic resins and mineral admixtures, most of the mechanical properties are not directly related with compressive strength and the effects of the same quantity of unlike admixtures on the mechanical properties of hardened concrete will not be same(Ayub, Khan, &Memon, 2014). Many researches indicated that the deficiencies of concrete and significant efforts were made to improve the function of concrete, especially permeability and durability of concrete as these are the main concerns of the researchers. The use of mineral admixtures can reduce the porosity in concrete if certain proportion of cement is replaced by admixtures. Therefore, the demand of blended cement has risen rapidly to produce denser to impermeable concretes at the same time improving the strength of concrete such as compressive, tensile, and flexure ones. These admixtures blended with cement can produce concrete that enables itself to possess greater resistance against acid and chemical attack, freezing and thawing, sulphate attack and carbonation and on the other hand, they are important to sustain the environment as partial replacement of cement and sand are often considered less energy intensive. A lot of advantages can be obtained when mineral admixtures are used as cement replacement and some companies even used fly ash as partial replacement of fine aggregates.

The most commonly used mineral admixtures are fly ash, granulated blast furnace slag, silica fume, rice husk ash and metakaolin. Researches have been done to study the performances of concrete containing different mineral admixtures mentioned above. For example, metakaolin has been tried as an effective pozzolan giving greater durability and resistance against harmful solution due to enhanced pore structure. Besides, researchers-Mehta and Gjørv compared the properties of concrete made with

Portland cement containing silica fume and fly ash, Jianyong, Yan and Bágel compared silica fume and granulated blast furnace slag.

## 2.3 Introduction of Polymer Cement Concrete

In order to increase cement replacement in conventional concrete, several attempts have been made since 1924, when Victor Lefebure replaced cement with natural rubber latex to produce latex cement. Simultaneously, polymer concrete was developed in which the polymers such as epoxy resin, furan resin, polyester, methacrylate and styrene were used as full replacement for the cement as binder in conventional concrete. Due to the advantages and benefits given by using combination of polymer and hydraulic cement, a few researchers attempted to draw and shape the formation of the complex microstructure of polymer-cement mortar and concrete. Descriptions of the hardened product consisting of two interpenetrating matrices of polymer and hydrated cement with random distribution of coarse and fine aggregates have been provided then by them. This led to the organization of First International Congress on Polymer Concrete in London in 1975 which then allowed H.R Sasse to report on the interaction between polymer admixtures and cement hydrates. In his report, polymers were assumed to form extremely thin films or web-like structures on the cement hydrate surfaces that are penetrated by the latest hydration products that causes reduction in their effectiveness for low polymer-cement ratios(<2 w%). Initially, the model only gave pictures on the interaction of polymer, cement paste and aggregates in the hardened form. In 1987, Y. Ohama already proposed a starting 3 steps model that considered the hardening process of the polymer phase. Subsequently, specifications and modifications to this model have been proposed in great numbers(Ekolu, Dundu, &Gao, n.d.). New polymer concrete-like composites are highly used in construction, particularly where high chemical resistance of the concrete is vital. Their use is limited normally due to the cost of resin binders used. One solution to this problem is to develop lighter concrete(Dębska, Lichołai, &Krasoń, 2017). Resin concretes are different from conventional concrete as they consist of only synthetic resin rather than cement as binding agent. These materials are good alternatives for construction industry where factors such as high strength, fast curing, and durability are needed the most(Debska &Licholai, 2017)

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## 2.4 Physical Model of Microstructure Formation in P-C-C

In polymer-cement concrete, the binder consists of a co-matrix of polymer cement. During the process of hardening and curing of polymer concrete, the hardening of polymer and hydration of cement happen resulting in a co-matrix in which the cement hydrates are intermingled with polymer phase(R.Bareš, 1985). The first physical model of microstructure formation in polymer-cement concrete was shown by Prof. Yoshihiko Ohama in 1987, Figure 1. Afterwards, it acts as a basis for most of the later models(Ekolu et al., n.d.).

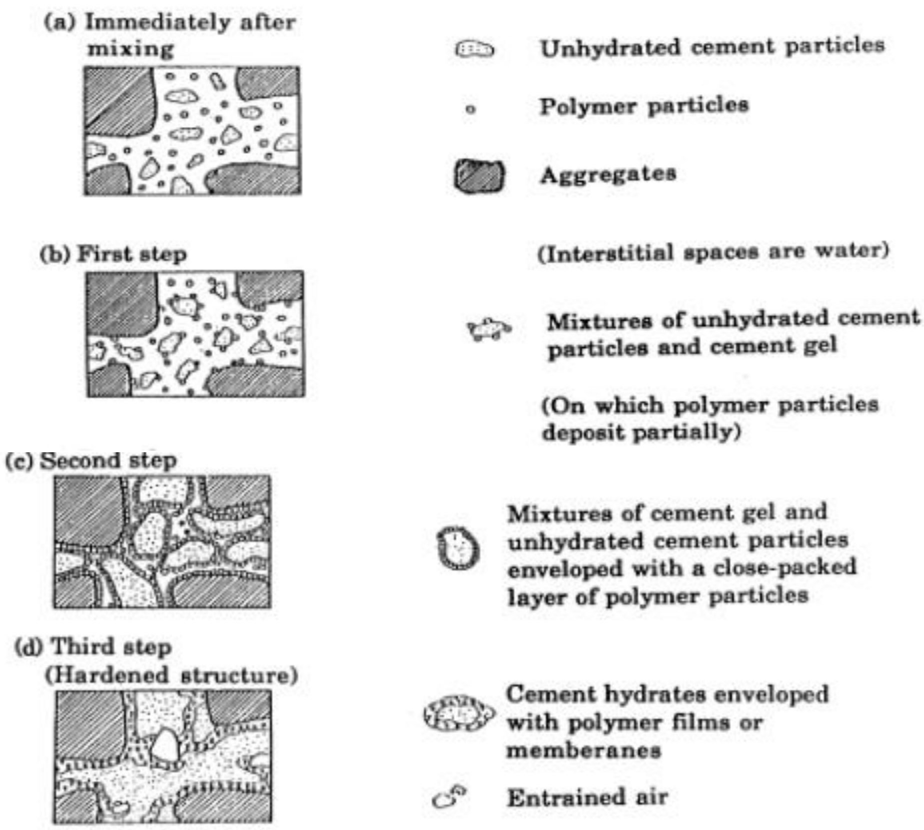


**Figure 2.1:** Simplified Model of Formation of Polymer-Cement Co-matrix in Polymer Modified Mortar and Concrete( Ohama, 1987)

Instantly the moment after mixing the polymer with fresh concrete, the particles of polymer are uniformly distributed and dispersed in the cement paste. During the first step, Calcium-Silica-Hydrate(C-S-H) gel is slowly formed by hydration of cement, and polymer particles deposit on the surfaces of the cement gel and of the unhydrated cement particles partially. In the next step, the particles of polymer are gently being confined in the network system. Process of cement hydration reduces the amount of water capillary thus the polymer particles flocculate to form a continuous layer on the surfaces of unhydrated cement and cement gel, as well as the interface between cement paste and aggregates. In the final step, water is continuously consumed due to hydration and the inter-molecular forces allow the polymer particles to merge into a large continuous film forming a monolithic network in which the cement hydrate is interpenetrated with polymer phase(Y.Ohama, 1987).

## 2.5 Synthetic Resins as Cement Replacement in Polymer Cement Concrete

Synthetic resins that are commonly used in producing polymer concrete are methacrylate, polyester resin, epoxy resin, vinylester resin, and furan resins. Unsaturated polyester resins are the most generally used resins to produce polymer cement concrete. This is due to their easy availability, excellent mechanical properties, and low cost. In European countries, furan resins are greatly used to large extent. The selection of specific type of resin depends mainly on factors like cost, wanted properties, and type of chemical resistance required. Epoxy resins are preferred rather than polyester resins because of their superior mechanical properties as well as better durability when subjected to rigorous environmental factors, but higher in cost is a barrier in their universal recognition. A study regarding the comparison on mechanical properties of polymer cement concrete formed by epoxy and polyester resins states that epoxy polymer cement concrete has better properties than polyester concrete. However, the properties of polyester concrete can be increased up to the same standard by addition of micro-fillers. The resin dosage used in producing polymer concrete reported by several authors mostly lies in the range of 10-20% by weight of polymer concrete. Early researches on polyester polymer concrete while setting resin content as a variable showed that compressive strength of polymer concrete varies with the resin content. As the polymer content increases, both the compressive strength and flexural strength also increase. These strengths either remain constant or decrease with further increase in the content of the resin after reaching the peak. The optimum polymer content for the system is obtained by determining the lowest polymer content at which the properties of compressive strength and flexural strength are at maximum. Observations obtained tell that 14-16% resin content by weight gives both flexural and compressive strength maximum values. All type of resins give highest strength at resin dosage of 12%. For two types of epoxy, increasing the resin content to 15% will decrease the strength, whereas, it almost stayed constant for polyester resin. However, the optimum polymer content for a specific polymer concrete is depending on the nature of aggregates used in the mixing process. Higher polymer dosage is preferred when using fine aggregate due to larger surface area of the fine aggregates(Bedi, Chandra, &Singh, 2013b). Significant and important research has been conducted to categorize all kinds of polymer concrete system. There are three existing principal types of polymer concrete materials which are Polymer Concrete (PC), Polymer Impregnated Concrete (PIC), and Polymer-Portland Cement Concrete (PPCC)(Gupta &Kumar, n.d.). New and creative construction materials have been created and improved in the construction industry to fulfill the demand for modern construction and maintenance works. Polymers are either impregnated in a cement-aggregate mix or used as single binding agent in concrete. The composites produced by using polymer along with cement and aggregates are called polymer-modified mortar or polymer-modified concrete. Concrete that consists only of polymer and aggregates is named polymer mortar or polymer concrete(Bărbuţă &Harja, n.d.).

## 2.6 Epoxy Resins as Partial Replacement for Cement in Polymer Cement Concrete

The factors and aspects that need to be considered when choosing the type of resins are dependent on the cost, availability, demanded properties and the application. For this study, Epoxy Resin has been chosen due to it availability and mechanical properties. Epoxy resin has great structural ability, minimum shrinkage during curing, superior chemical resistance, excellent fatigue resistance and low water absorption (Aravinthan, 2013). Epoxy resins are formed by the coupling reaction which consists two or more than two active hydrogen atoms with epichlorohydrin where dehydrohalogenation happens in the intermediate to produce epoxy resins(Kumar, 2016). The reaction is shown in Figure 2.2.

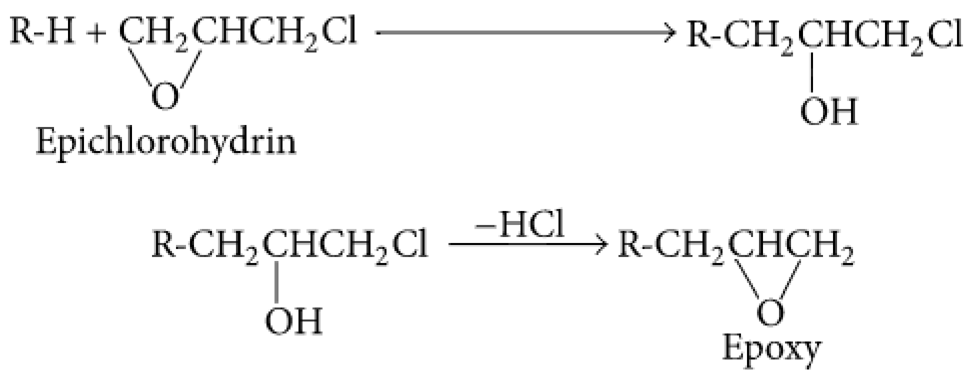


**Figure 2.2**: Reaction involved in formation of Epoxy Resins

All epoxy resins are normally transformed into infusible, solid and insoluble 3D thermoset networks for their uses by curing with cross-linkers. To cure epoxy resins, carboxylic functional compound and amine functional compound are normally used. The type of epoxy resins, curing agent, and process of curing will determine the final properties of cured epoxy resins. Exothermic reaction of small magnitude will occur during the process of curing reaction of epoxy resin. Therefore, epoxy resin can be poured far down in a mold during the preparation of epoxy polymer cement concrete without overheating. Epoxy resins can be used to produce both epoxy polymer concrete as well as epoxy polymer cement concrete. Epoxy resin, silica fume, and aggregates of different sizes are used to prepare epoxy polymer concrete in the research. The silica fume used in the reported literatures varied in the range of 2,100 and 2250kg/m$^3$. Hardener was also added in the prepared epoxy polymer concrete. The compressive strength and split tensile strength of the epoxy polymer concrete were found to be 60± 9 MPa and 12.1 MPa respectively with 0.4mm of aggregates used. In another report, epoxy polymer cement concrete specimens were prepared with varied polymer cement ratio from 0% to 30% by mass of cement. It was observed that the compressive strength of that concrete at 28 days increased with polymer cement ratio(Kumar, 2016).

## 2.7 Reinforcement of Polymer Cement Concrete

Beside replacement of cement with mineral admixtures or synthetic resin, addition of various types of fibers and micro fillers are also applied in the formation of polymer concrete to enhance its mechanical properties. In a various number of studies, glass fibers, steel fibers, polyester fibers, and carbon fibers have been added into polymer concrete in varying levels for improvement of its properties in terms of mechanical. Addition of glass fibers in the range from 0% to 6% by weight of polymer concrete have been reported in most of the studies conducted. Such addition shows that the postpeak behavior of polymer concrete has been enhanced as well as the strength and toughness of polymer concrete. If silane treatment is applied to glass fibers before adding them to the polymer concrete, report shows an enhancement in mechanical properties of polymer concrete up to the extent of 25%(Bedi et al., 2013b). Below is a table that provides details of different types of reinforcements and their effect on the polymer concrete’s properties as reported by several researchers.

**Table 2.1**: Fiber Reinforcement and their effect on polymer cement concrete

| Author | Resin | Agreggate | Fiber Addition | Brief findings |
|---|---|---|---|---|
| Broniewski et al. | Epoxy resin | Sand | Steel fibers of 0.24 mm diameter and 15 mm length, added in 0 to 3.5% by weight | Addition of 3.5% steel fibers increases the flexural strength by 40%. |
| Vipulanandan et al. | (i) Epoxy<br>(ii) Polyester | Ottawa sand, blasting sand | Glass fibres, 0–4% | i) Maximum compressive and flexural strength are |

| | | | | |
|---|---|---|---|---|
| | | | | reported at 14% resin content.<br>(ii) Addition of glass fibers increases the flexural strength, compressive strength.<br>(iii) Silane treatment increases the flexural strength by 25%. |
| Vipulanandan and Mebarkia | Polyester | Blasting sand | Glass fibres, 0–6% | (i) Flexural strength increases with increase in resin content.<br>(ii) Addition of glass fibers is reported to enhance the strength and toughness of polymer concrete.<br>(iii) Silane treatment of aggregate and fibers also |

| | | | | |
|---|---|---|---|---|
| | | | | enhanced the flexural strength. |
| Mebarkia and Vipulanandan | Polyester | Blasting sand | Glass fibers of 13 mm length, 0–6% | (i) For 18% resin and 4% glass fiber content, an increase of 33% in compressive strength was reported over unreinforced polymer concrete.<br>(ii) Failure strain and toughness increase with addition of fibers. |
| Xu and Yu | Polyester | Granite | Copper coated stainless steel fibers,<br>L/d ratio of 70 | (i) Addition of steel fibers improves the properties of polymer concrete.<br>(ii) Compressive strength of steel fiber reinforced polymer |

| | | | | |
|---|---|---|---|---|
| | | | | concrete is higher than that of plain polymer concrete. |

Other than fibers, micro filler is also commonly added to polymer concrete mix to fill up the void content in mixture of coarse and fine aggregates thereby enhancing the strength of polymer concrete. The micro filler is a type of powder with relatively particle size less than 80 microns. For example, fly ash, silica fume and calcium carbonates are various types of micro filler used in literature reported. Fly ash is a secondary product in the power plants due to coal burning and is chosen to be filler because it can be easily obtained yet the usage of fly ash in polymer concrete is reported to produce better mechanical properties at the same time allow a decrease in water absorption. Addition of fly ash according to several researchers will not only give improvement in the workability of polymer concrete but also has significant effect on the mechanical properties. Compressive strength can be increased to extent of 30% by addition of 15% fly ash in polymer concrete as reported by a number of researchers. Most of the researchers also suggested that the aggregates must be dried with assisted heat before mixing with polymer concrete because water content has been reported to have significant influence on the strength of polymer concrete and therefore the water content must be limited to 0.1%. Recommendation suggested that the moisture content of aggregates used shall be in the range of 0.1% to 0.5% for better mechanical properties(Bedi et al., 2013b). Application and capability of polymer concrete is dependent upon the particular polymer binder( resins) as well as the type of aggregates and its gradation. The aggregates shall be distributed in a manner such as to yield minimum void volume for dry packed aggregates which will eventually form a dense packing within the system. A denser packing of aggregates in polymer concrete allows a better performance of the polymer concrete in term of mechanical properties. One of the ways to achieve this is by minimizing the void content of the aggregate mix where the amount of binder needed will be less or use loosely packed aggregate with larger amount of binder content. The major components that form the total mass of polymer concrete are aggregates and micro fillers but there is no much emphasis on the mix proportion of these materials used in the system(Manickam Muthukumar &Mohan, 2005).

## 2.8 Silica Sand as Partial Replacement for Fine Aggregates Replacement in Polymer Cement Concrete

Due to high-speed industrialization and urbanization which involve infrastructure's construction, reduction of natural resources is a common phenomenon in developing countries like Malaysia and India. Occupation and degradation of precious land is the result due to disposal of waste materials in thousands of tons every year. Waste handling is currently a major problem which leads to conducting of many researches in order to utilize constructional and industrial waste for concrete mix. Silica sand is obtained from the raw material therefore the raw material needs to be washed before separating the silica sand by sieve size of 1.18 from the raw material. The purpose of washing the raw material is to take out the clay material which can be used for making of tiles. Different sizes of silica sand are separated from the raw material by different sieve size. Silica size of 30 mesh to 80 mesh (500 micron) can be used to produce glass whereas silica size of 1.18mm to 600 micron can be utilized as the partial replacement of fine aggregate in making concrete mix. Silica is made of composition of silicon and oxygen and these two components are the two most abundant elements on earth. One of the earth's three most common rocking forming materials is silica and it exists in three major crystalline forms. It has high durability and resistance to chemical attack and heat(Kerai &Vaniya, 2015).


**Figure 2.3**: Silica Sand

The strength evolution of concrete in which silica fume was used to partially replace fine aggregates has been studied in an extensive experimentation. Water to cement ratio was varied in the range from 0.50 to 0.60 and the replacement level for fine aggregate ranged from 0 to 15%. Compressive strength test was conducted at age of 7, 28 and 56 days and the results showed that concrete made with silica fume as fine aggregate replacement material had higher compressive strength compared to the control concrete. Commonly, silica fume (SF) is used as a replacement of cement as an admixture in producing concrete. Mix design that involves silica fume could enhance and increase the concrete basic properties in both fresh and hardened phases. Compressive strength, depletion of cement alkalis, resistance to chemical penetration, and durability of concrete can also be improved(Ashteyat, Ismeik, &Ramadan, 2012).

### 2.8.1 Materials and mix proportion in the experiment conducted

**Table 2.2**: Properties of ordinary Portland cement (Ashteyat et al., 2012)

| **Property** | **Value** |
|---|---|
| Fineness( 90-µm sieve) | 8.3 |
| Specific surface( $m^2$/kg) | 281 |
| Normal consistency( %) | 28 |
| Specific gravity | 3.15 |

**Table 2.3**: Properties of silica fume (Ashteyat et al., 2012)

| **Property** | **Value** |
|---|---|

| | |
|---|---|
| $SiO_2$ content (%) | 90 |
| Surface Area ($m^2$/kg) | 20,000 |
| Specific gravity | 2.2 |
| Unit weight (kg/$m^3$) | 245 |
| Fineness (45-µm sieve) | 5.1 |

**Table 2.4**: Physical properties of aggregate (Ashteyat et al., 2012)

| **Property** | **Fine Aggregate** | **Coarse Aggregate** |
|---|---|---|
| Specific gravity | 2.46 | 2.75 |
| Specific gravity (SSD) | 2.50 | 2.78 |
| Apparent relative density | 2.56 | 2.83 |
| Absorption (%) | 1.62 | 1.05 |
| Fineness modulus | 2.73 | 6.53 |
| Voids (%) | 36.7 | 38.1 |
| Unit weight (kg/$m^3$) | 1705 | 1617 |

**Table 2.5**: Concrete mix proportions and experimental results(Ashteyat et al., 2012)

| Series | Mix | W/C | R | P | W/CM | Weight (kg/m$^3$) | | | | | | Compressive strength (MPa) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | SF | C | CM | W | FA | CA | $f_{sf}^{7}$ | $f_{sf}^{28}$ | $f_{sf}^{56}$ |
| I | A | 0.50 | 0 | 0.000 | 0.50 | 0 | 400 | 400 | 200 | 340 | 1360 | 19.67 | 31.95 | 33.81 |
| | B | | 5 | 0.041 | 0.48 | 17 | 400 | 417 | 200 | 323 | 1359 | 27.04 | 35.11 | 39.62 |
| | C | | 10 | 0.078 | 0.46 | 34 | 400 | 433 | 200 | 306 | 1358 | 25.56 | 34.92 | 39.52 |
| | D | | 15 | 0.113 | 0.44 | 51 | 399 | 450 | 200 | 288 | 1357 | 25.38 | 34.46 | 37.49 |
| II | E | 0.55 | 0 | 0.000 | 0.55 | 0 | 392 | 392 | 216 | 333 | 1334 | 17.84 | 26.39 | 30.04 |
| | F | | 5 | 0.041 | 0.53 | 17 | 391 | 409 | 216 | 317 | 1333 | 21.97 | 32.88 | 37.21 |
| | G | | 10 | 0.078 | 0.51 | 33 | 391 | 425 | 215 | 300 | 1332 | 21.50 | 32.60 | 38.18 |
| | H | | 15 | 0.113 | 0.49 | 50 | 391 | 441 | 215 | 283 | 1331 | 21.23 | 30.46 | 33.71 |
| III | I | 0.60 | 0 | 0.000 | 0.60 | 0 | 385 | 385 | 231 | 327 | 1308 | 14.37 | 21.88 | 27.13 |
| | J | | 5 | 0.041 | 0.58 | 16 | 384 | 401 | 231 | 310 | 1307 | 17.02 | 27.31 | 30.37 |
| | K | | 10 | 0.078 | 0.55 | 31 | 384 | 417 | 231 | 294 | 1306 | 19.03 | 28.89 | 32.46 |
| | L | | 15 | 0.113 | 0.53 | 49 | 384 | 433 | 230 | 277 | 1305 | 18.57 | 27.14 | 31.49 |

*W/C = water to cement ratio, R = silica fume replacement level of fine aggregate, P = silica fume-to-cementitious materials ratio (SF/CM), W/CM = water-to-cementitious materials ratio, SF = silica fume, C = cement, CM = cementitious materials (SF+C), W = water, FA = fine aggregate, CA = coarse aggregate,* $f^{7}_{sf}$, $f^{28}_{sf}$, $f^{56}_{sf}$ *= compressive strength of concrete at 7, 28, and 56 days, respectively.*

## 2.9 Summary

This chapter presents a general concept of effect on mechanical properties of concrete and polymer concrete with various proportions of synthetic resins and fibers as partial replacement of cement and fine aggregates in the concrete system. Researches which involve different synthetic resins as partial or fully replacement of cement in polymer concrete without altering the coarse and fine aggregates used in the system has been revised in section 2.5 and 2.6. The optimum polymer content to be used in polymer cement concrete in order to give maximum performance in mechanical properties has also been revised in section 2.5. Furthermore, advantages of using silica sand and silica fume instead of fine aggregates in concrete production have also been revised in section 2.8. The compressive strengths of concrete samples with different mix designs with varying silica replacement level have also been revised in the study conducted by previous researchers in table 5.

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

In this chapter, the procedure in carrying out the experimental work and laboratory test to achieve objectives of this study will be discussed in detail. Details and preparation of material used for the mixing specimens will be presented. After that, step to produce epoxy polymer concrete with optimum silica content is also explained. The details and type of test that will be conducted in this experiment will also be discussed. Primary tests such as compressive strength test and split tensile strength test to determine and access the mechanical properties will be carried out on normal concrete and epoxy polymer cement concretes with varying silica content as fine aggregate replacement.

### 3.1.1 Flow Diagram for Methodology

This research is to determine the best mix designs of epoxy concrete polymer with varying silica content in the system to achieve the highest compressive strength and tensile splitting strength as compared to normal concrete. The flow diagram for this research is as shown in Figure 3.1.

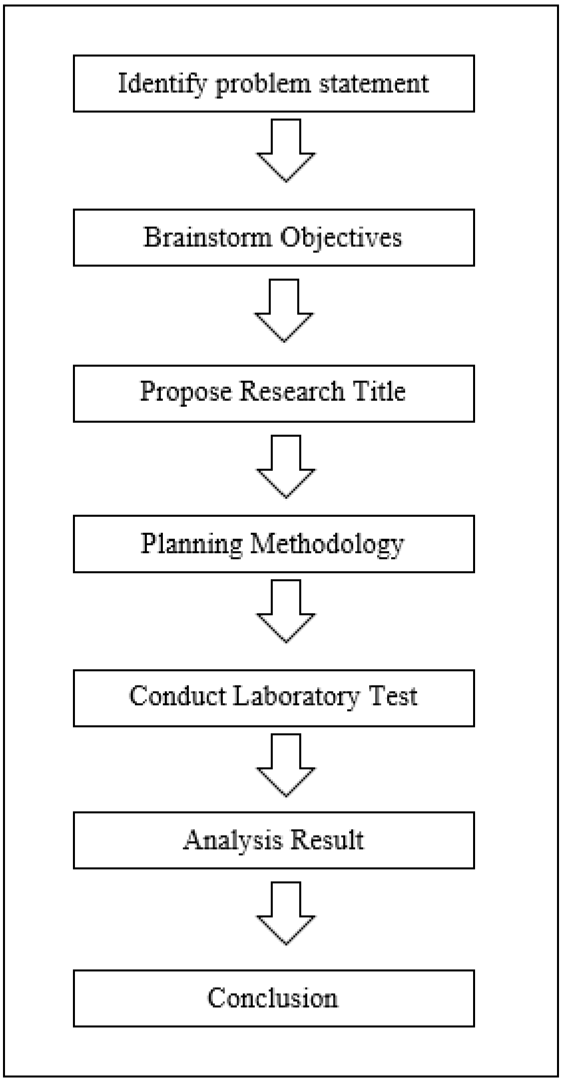


**Figure 3.1**: Flow diagram of research methodology

## 3.2 Mix Ingredients

The main ingredients and materials that will be used are Ordinary Portland Cement(OPC), epoxy resins, harderner, coarse aggregate(20mm and 10mm), fine aggregate, silica and water. These materials will be used to produce normal concrete and also epoxy polymer cement concrete.

### 3.2.1 Cement

A variety of Portland cement brands are available in the market. Figure below shows the type of cement used throughout the experiments which is of brand YTL. Conforming to MS 522:Part 1:2003 for Portland cement specification, this type of cement is suitable for structural concreting precast. Cement exists in dry powder form and sets when mixed with water by way of a complex series of chemical reactions still only partly understood. The main function of hydrated cement is to act as binder to bind the coarse aggregates and fine aggregates together in the system of concrete. The storage place of cement bags must be dry and away from damp environment. The chemical composition of Ordinary Portland Cement is shown in Table 3.1.


**Figure 3.2**: Ordinary Portland Cement

**Table 3.1**: Chemical composition of Ordinary Portland Cement

| Composition | Percentage by weight (%) |
|---|---|
| Silicon dioxide ($SiO_2$) | 21.25 |
| Aluminium oxide ($Al_2O_3$) | 4.33 |
| Iron(III) oxide ($Fe_2O_3$) | 1.85 |
| Titanium oxide (TiO) | 0.13 |
| Calcium oxide (CaO) | 64.30 |
| Magnesium oxide (MgO) | 1.81 |
| Sulphur trioxide ($SO_3$) | 3.70 |
| Potassium oxide ($K_2O$) | 0.71 |
| Sodium oxide ($Na_2O$) | 0.17 |
| Loss of ignition(L.o.i) | 1.50 |

### 3.2.2 Epoxy resin and hardener

Epoxy resins are polymers which commonly contain at least two epoxide groups. The raw materials to produce epoxy resin are mostly petroleum derived in industry.

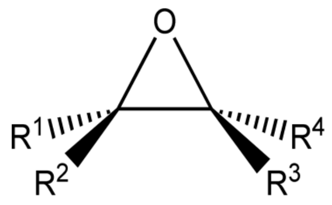


**Figure 3.3:** Structure of highly reactive epoxide group

The epoxy resins used in this research are supplied by Pan Asel Chemicals(M) Sdn. Bhd. The product code of epoxy resins used are E-110/H-110 that have a mixing ratio of 2:1 with hardeners. Hardeners are always necessary to make an epoxy resin useful for its demanded objective. Hardeners are used as curing component for epoxy resin to allow them achieving impressive mechanical and chemical properties. The correct type of hardeners must be selected according to the type of epoxy resins used. The hardeners utilized are also supplied by the same company that provides epoxy resins.

### 3.2.3 Coarse aggregates (20 mm and 10mm) and fine aggregates

Coarse aggregate is mined from rock quarries or dredged from river beds which make the size, texture, hardness and shape different based on different locations. Even aggregates coming from the same source can vary to a great extent. Meanwhile, fine aggregates are normally sands won from marine environment and generally consist of natural sand or crush stones that have size lesser than 10mm. The coarse aggregates and fine aggregates used in this research are crushed stones of 20mm and 10mm prepared by lab assistants They procured the aggregates from local supplier in Kuantan.

**Figure 3.4**: Coarse aggregates and fine aggregates

### 3.2.4 Silica sand

Silica sand is one of the refractory materials and it has a higher melting point than metal such as aluminium, iron, and copper. The refractoriness of the silica sand can help to resist high temperatures without breaking down thus sound casting can be done. Besides, it is the main structural component in a great variety of construction products. It is normally used in mortars, flooring components, specialty cements, and asphalt mixtures as it can provide packing density and flexural strength without affecting the chemical properties of binding agent severely. In epoxy based compounds, silica sand functions as extender to increase durability and corrosion resistance.

### 3.2.5 Water

In this research, tap water is used for the production of concrete samples (both cube and cylinder). To initiate hydration, water is needed to allow the reaction to occur in cement mixtures. The chemical reaction between water and cement is very significant to generate cohesive properties of hydrated cement. The tap water must be made sure to be not polluted or contain any other substance that may affect the reaction between cement and water. Throughout the study, the tap water will be supplied by Pengurusan Air Pahang Berhad (PAIP).

### 3.3 MATERIAL AND SAMPLE PREPARATION

Epoxy resins and silica sands are purchased from suppliers in Malaysia whereas the other materials such as cement, coarse aggregates, and fine aggregates are prepared by lab assistants. The dimensions of samples to be prepared are listed in table below. Calculation to obtain the mix design involving different proportion of cement and fine aggregate replacements is done.

**Table 3.2**: Details of specimen

| TESTING | DETAIL OF SPECIMEN | | |
|---|---|---|---|
| MECHANICAL PROPERTIES | TYPE | DIMENSION | NO. OF SAMPLE |
| Compressive Strength | Cube | 0.1m X 0.1m X 0.1m | 45 |
| Tensile Splitting Strength | Cylinder | 0.1m of diameter, 0.2m of height | 45 |

In this research, 40% of cement proportion will be replaced by epoxy resin whereas silica sand will be used to replace 0%, 20%, 40%, and 60% of fine aggregate in a single specimen. Therefore there will be four different types of samples in this study and every type of specimen will be made up to quantity of three similar samples (for both cube and cylinder each). For unmodified normal concrete of Grade M25, the number of samples that will be made is also three.

For **compressive strength test**, the weights of components in the mix design for different proportions of fine aggregate replacement are shown in the table below.

**Table 3.3**: Weight proportion of components for different mix design

| **Component** | Cement | Epoxy Resin | Water | Fine Aggregate (FA) | **Proportion of FA replacement** | Silica Sand | Coarse Aggregate | Quantity of sample |
|---|---|---|---|---|---|---|---|---|
| **Weight (kg)** | 0.320 | - | 0.205 | 0.890 | - | - | 1.010 | 9 |
| **Weight (kg) when 40% of cement is replaced by epoxy resin** | 0.192 | 0.128 | 0.205 | 0.890 | 0% | 0.000 | 1.010 | 9 |
| | 0.192 | 0.128 | 0.205 | 0.712 | 20% | 0.178 | 1.010 | 9 |
| | 0.192 | 0.128 | 0.205 | 0.534 | 40% | 0.356 | 1.010 | 9 |
| | 0.192 | 0.128 | 0.205 | 0.356 | 60% | 0.534 | 1.010 | 9 |

For **tensile splitting test**, the weights of components in the mix design for different proportions of fine aggregate replacement are shown in the table below.

**Table 3.4**: Weight proportion of components for different mix design

| **Component** | Cement | Epoxy Resin | Water | Fine Aggregate (FA) | **Proportion of FA replacement** | Silica Sand | Coarse Aggregate | Quantity of sample |
|---|---|---|---|---|---|---|---|---|
| **Weight (kg)** | 0.502 | - | 0.322 | 1.397 | - | - | 1.586 | 9 |
| **Weight (kg) when 40% of cement is replaced by epoxy resin** | 0.301 | 0.201 | 0.322 | 1.397 | 0% | 0.000 | 1.586 | 9 |
| | 0.301 | 0.201 | 0.322 | 1.118 | 20% | 0.279 | 1.586 | 9 |
| | 0.301 | 0.201 | 0.322 | 0.838 | 40% | 0.559 | 1.586 | 9 |
| | 0.301 | 0.201 | 0.322 | 0.559 | 60% | 0.838 | 1.586 | 9 |

All of the sample mixtures are poured into molds and the molds are vibrated by using the vibration table. Then, the molds are rested for one day and demolded after 24 hours. The samples are then put into the curing tanks for 3 days, 7days, and 28days before conducting the necessary testings.

### 3.4 Setting Up of Test on Mechanical Properties

#### 3.4.1 Compressive strength test

Compressive strength test is the major testing of concrete which is to determine the concrete cube strength. The compressive strength of the specimens is tested according to ASTM C39 standard which acts as standard test method for compressive strength. Compressive axial load of 50kN will be applied to the samples (cubes) with a rate of 0.25±0.05 MPa/s until failure of the samples happen (BS EN12390-3, 2009). The dimension of cube samples must be measured to make sure that the deviation is not more than 2% with other samples. The dimension of cube sample desired is 0.1m (width) X 0.1m (length) X0.1m (height). The test on specimen is conducted immediately after the removal of specimen from curing tank. Before the test is conducted, the surface of machine is wiped cleanly to reduce possible errors. The test is considered complete when the reading on load indicator is decreasing smoothly and a well-defined fracture pattern is shown on cubes. The maximum load readings that can be carried by the samples are recorded. The readings of maximum loads carried by the samples are compared to determine the highest compressive strength among the samples. Then, an analysis regarding the compressive strength of the samples can be done.

#### 3.4.2 Tensile splitting test

Tensile splitting test on concrete cylinder is a method to determine the tensile strength of concrete. This is because concrete has high compressive strength but weak tensile strength due to its brittle nature and it is not expected to resist direct tension. The splitting tensile strength of concrete mixtures are determined according to ASTM C496. The specimen of concrete cylinder has a diameter of 0.1m and a height of 0.2m. The concrete cylinder specimen is placed horizontally between loading surface of compression testing machine. Rather than compressive failure, tensile failure occurs instead due to the area of load application are in a state of triaxial compression. The load is applied continuously and without shock at constant rate of range 0.7-1.4 MPa/min until failure occurs (ASTM C496, 2011). The maximum load applied at failure shown on the indicator is recorded for each sample's testing. During the testing, plywood bearing strips are used to make sure that the load applied along the cylinder is uniform. The readings recorded are divided by suitable geometrical factor for every sample to determine the tensile splitting strength.

### 3.4.3 Statistical analysis of data

The data collected from compressive strength test and tensile splitting test needs to be analyzed to compare the results. Graphical representation and ANOVA are the methods utilized in this research to do analysis on the data collect. In ANOVA, single factor or one- way ANOVA is used to find out whether the difference between two results is significant or the other way round.

Single factor ANOVA is used to statistically determine if the data collected is significant for samples with various proportion of fine aggregate replacement with silica sand. The ANOVA test is done by using Microsoft Excel. After entering the data in excel sheet, the data will be selected to run with ANOVA one-way test to obtain P-value and F-critical value. When P-value is less than 5%, the data selected is considered statistically significant. Also when the F-critical value is less than F-value obtained from the ANOVA table, the data is considered significant statistically.

Other than ANOVA test, the experimental data is also arranged in accordance to its categories. The average value of the data for the similar samples is calculated to improve the accuracy of the result. For each proportion of fine aggregate replaced with silica sand, there is a total of three samples where one of the sample acts as spare sample. Therefore, two readings will be obtained for every type of specimen tested so the readings will be added up and divided by two to obtain the average value. Next, the specimens tested after 3 days of curing will generate 4 sets of data (fine aggregate replacement of 0%, 20%, 40%, and 60%). The data sets will be represented graphically by arranging them into line graph. Same method is done for specimens tested after 7 days and 28 days respectively. By using this method, significant difference between every specimen can be well observed and defined. In a nut shell, the optimum percentage for fine aggregate replacement with silica sand can be determined.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Introduction

The current research deals with studies on compressive strength and tensile splitting strength of epoxy polymer cement concrete. The samples of epoxy polymer cement concrete were produced by using a series of silica sand as partial replacement of fine aggregates where 40% of cement replacement with epoxy resins within the concrete proportion was fixed. Towards this, four different types of epoxy polymer cement concrete were synthesized using different ratios of silica sand as fine aggregate's replacement (0%, 20%, 40% and 60%). With 40% replacement of cement with epoxy resins, they both act as binder for the present investigation. All of the samples of epoxy polymer cement concrete have the same proportion of percentage in terms of cement and epoxy resins which are 60% and 40% respectively. The epoxy polymer cement concretes of different compositions were made and had their compressive strength and tensile splitting strength checked at regular intervals of time.

## 4.2 Effect of Silica Sand on Compressive Strength of Epoxy Polymer Cement Concrete

To investigate the effect of fine aggregates' replacement with silica sand at different proportions on the compressive strength of epoxy polymer cement concrete, the amount of epoxy resins used to replace cement was kept at 40%. The curing time for the samples can be categorized into 3 days, 7 days, and 28 days. The effect of fine aggregates replaced with silica sand on the compressive strength of the concrete after 3 days, 7 days, and 28 days of curing is shown in table 4.1, table 4.2, and table 4.3 respectively. The trends that show the effects of each composition on the compressive strength can be observed through figure 4.1, figure 4.2, and figure 4.3 accordingly.

**Table 4.1**: Effects on compressive strength after 3 days of curing

| Percentage of fine aggregates replaced with silica sand (%) | Compressive strength (MPa) | | | | |
|---|---|---|---|---|---|
| | Sample 1 | Sample 2 | Sample 3 | **Average** | **Standard deviation** |
| 0 | 14.993 | 14.077 | 14.246 | **14.017** | **0.487** |
| 20 | 13.333 | 12.640 | 12.980 | **12.984** | **0.347** |
| 40 | 12.170 | 12.493 | 12.321 | **12.328** | **0.162** |
| 60 | 12.098 | 12.119 | 12.107 | **12.108** | **0.011** |

**Table 4.2**: Effects on compressive strength after 7 days of curing

| Percentage of fine aggregates replaced with silica sand (%) | Compressive strength (MPa) | | | | |
|---|---|---|---|---|---|
| | Sample 1 | Sample 2 | Sample 3 | **Average** | **Standard deviation** |
| 0 | 17.682 | 17.888 | 17.718 | **17.763** | **0.110** |
| 20 | 16.018 | 16.603 | 16.305 | **16.309** | **0.293** |
| 40 | 15.748 | 15.632 | 15.667 | **15.682** | **0.060** |
| 60 | 14.362 | 14.492 | 14.413 | **14.422** | **0.066** |

**Table 4.3**: Effects on compressive strength after 28 days of curing

| Percentage of fine aggregates replaced with silica sand (%) | Compressive strength (MPa) | | | | |
|---|---|---|---|---|---|
| | Sample 1 | Sample 2 | Sample 3 | **Average** | **Standard deviation** |
| 0 | 20.085 | 20.176 | 20.103 | **20.121** | **0.048** |
| 20 | 18.568 | 18.471 | 18.505 | **18.515** | **0.049** |
| 40 | 16.945 | 17.057 | 17.014 | **17.005** | **0.057** |
| 60 | 15.350 | 15.580 | 15.460 | **15.463** | **0.115** |

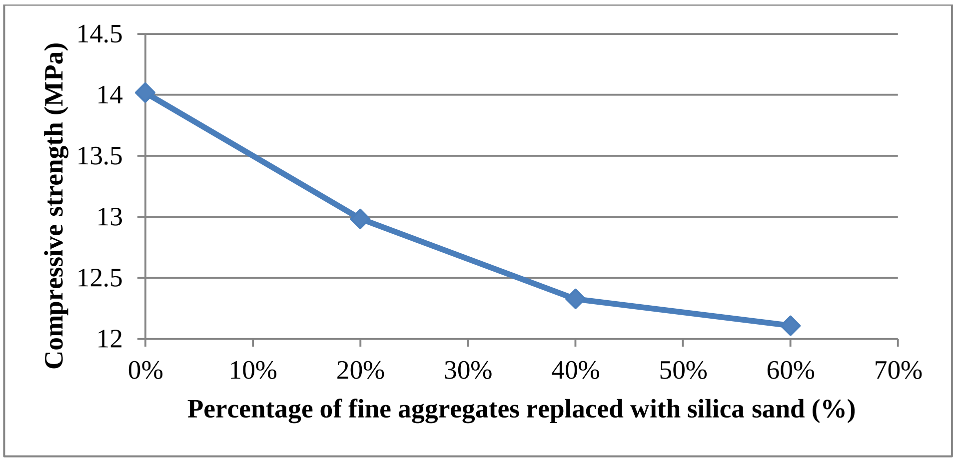


**Figure 4.1**: Effects on compressive strength after 3 days of curing

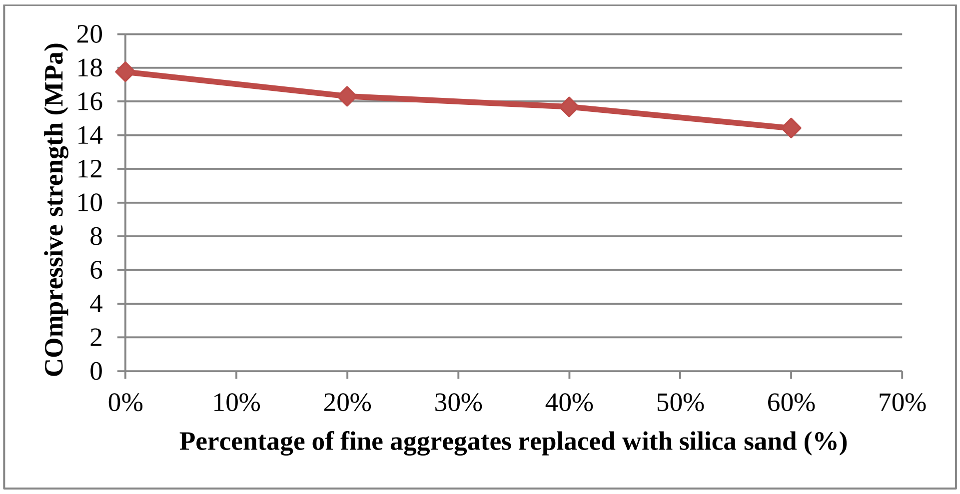


**Figure 4.2**: Effects on compressive strength after 7 days of curing

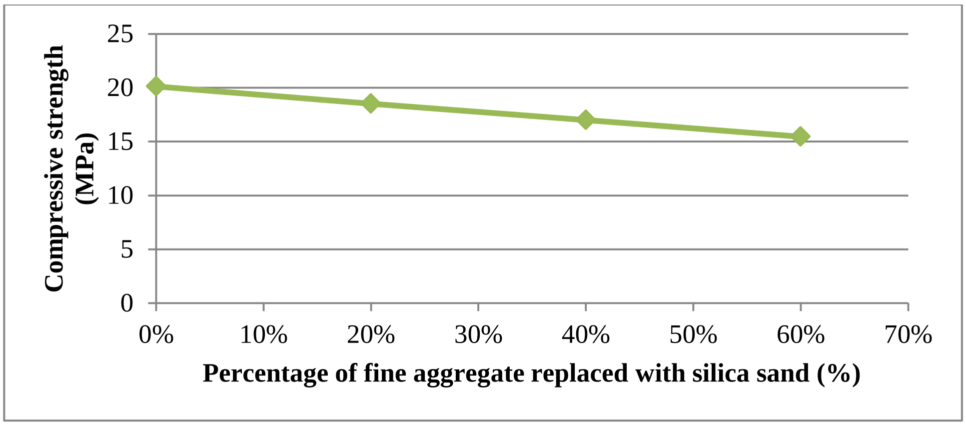


**Figure 4.3**: Effects on compressive strength after 28 days of curing

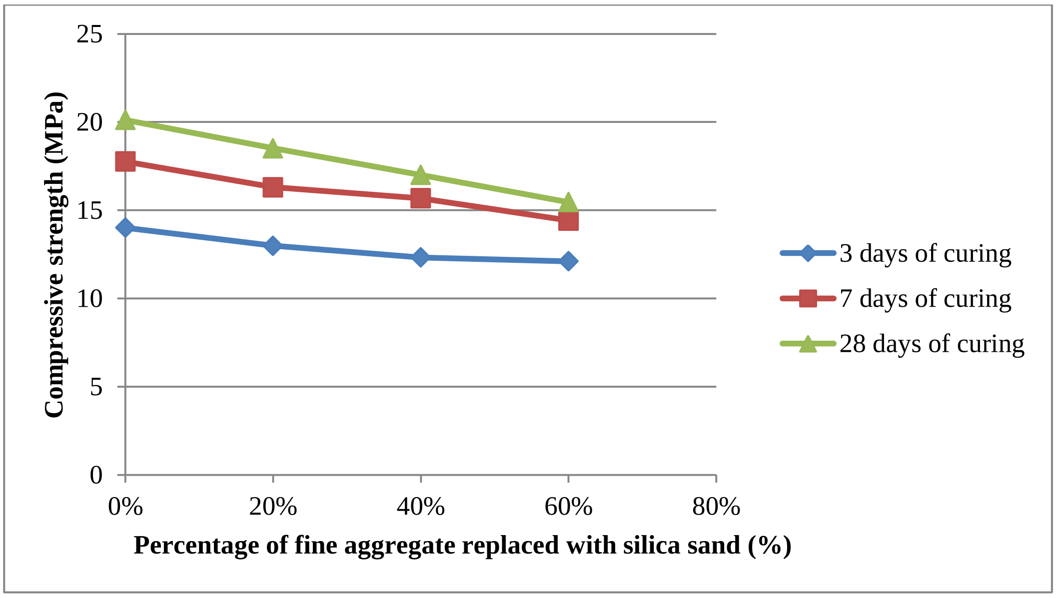


**Figure 4.4**: Effects on compressive strength after 3 days, 7 days, and 28 days of curing

Figure 4.4 shows the relationship between effects of percentage of fine aggregates replaced with silica sand within the concrete mixture and the compressive strength of the concrete itself. The concrete samples where percentage of fine aggregates replaced with silica sand is 0% act as the control variable for the subsequent 20%, 40%, and 60% of fine aggregates' replacement. The highest compressive strength marks a value of 14.017MPa where the fine aggregates were not replaced by any amount of silica sand and the lowest compressive strength is 12.108MPa where the fine aggregates were replaced by 60% of silica sand after three days of curing for epoxy polymer cement concrete. For concrete samples after seven days of curing, the highest compressive strength stands at 17.763MPa where no fine aggregates were replaced and the lowest compressive strength is 14.422MPa where 60% of fine aggregates were replaced with silica sand. The compressive strength of the concrete sample after 28 days of curing is the highest which is 20.121MPa where no fine aggregates were replaced and the lowest compressive strength is 15.463MPa where 60% of fine aggregates were replaced by silica sand. The curves in figure 4.4 indicate that as the percentage of fine aggregates replaced with silica sand increases, the compressive strength of the concrete sample will reduce accordingly. Besides, the compressive strength of the concrete sample gets higher when the curing time of the sample is longer for every percentage of fine aggregates replaced by silica sand. The compressive strength development with time for concrete sample where 0% of fine aggregates were replaced by silica sand is the highest while the concrete sample where 60% of fine aggregates were replaced by silica sand is the lowest after 28 days.

### 4.2.1 Analysis of variance (ANOVA) on compressive strength after 3, 7, and 28 days of curing

**Table 4.4**: Summary for compressive strength after 3 days of curing

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| 0 | 3 | 43.316 | 14.43867 | 0.237604 |
| 0.2 | 3 | 38.953 | 12.98433 | 0.120076 |
| 0.4 | 3 | 36.984 | 12.328 | 0.026119 |
| 0.6 | 3 | 36.324 | 12.108 | 0.000111 |

**Table 4.5**: ANOVA for compressive strength after 3 days of curing

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 9.936855 | 3 | 3.312285 | 34.511 | 6.32E-05 | 4.066181 |
| Within Groups | 0.767821 | 8 | 0.095978 | | | |
| | | | | | | |
| Total | 10.70468 | 11 | | | | |

**Table 4.6**: Summary for compressive strength after 7 days of curing

| ***Groups*** | ***Count*** | ***Sum*** | ***Average*** | ***Variance*** |
|---|---|---|---|---|
| 0 | 3 | 53.288 | 17.76267 | 0.012105 |
| 0.2 | 3 | 48.926 | 16.30867 | 0.085566 |
| 0.4 | 3 | 47.047 | 15.68233 | 0.00354 |
| 0.6 | 3 | 43.267 | 14.42233 | 0.00429 |

**Table 4.7**: ANOVA for compressive strength after 7 days of curing

| ***Source of Variation*** | ***SS*** | ***df*** | ***MS*** | ***F*** | ***P-value*** | ***F crit*** |
|---|---|---|---|---|---|---|
| Between Groups | 17.35341 | 3 | 5.784469 | 219.3115 | 5.1E-08 | 4.066181 |
| Within Groups | 0.211005 | 8 | 0.026376 | | | |
| | | | | | | |
| Total | 17.56441 | 11 | | | | |

**Table 4.8**: Summary for compressive strength after 28 days of curing

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| 0 | 3 | 60.364 | 20.12133 | 0.002322 |
| 0.2 | 3 | 55.544 | 18.51467 | 0.002422 |
| 0.4 | 3 | 51.016 | 17.00533 | 0.003192 |
| 0.6 | 3 | 46.39 | 15.46333 | 0.013233 |

**Table 4.9**: ANOVA for compressive strength after 28 days of curing

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 35.96571 | 3 | 11.98857 | 2265.164 | 4.7E-12 | 4.066181 |
| Within Groups | 0.042341 | 8 | 0.005293 | | | |
| | | | | | | |
| Total | 36.00805 | 11 | | | | |

ANOVA tests were carried out to determine if the results on compressive strength of the cubes are significant. One-way ANOVA was used to statistically compare the means from four independent groups (0, 0.2, 0.4, 0.6) using the F-distribution. A significance level, α of 0.05 was used.

**$H_o$: *All the percentage groups have equal average compressive strength.***

**$H_1$: *All the percentage groups have different average compressive strength*.**

From the analysis of variance carried out as above, all the P-values after 3, 7, and 28 days of curing are less than $\alpha = 0.05$ which mean that the results are significant. Besides, All the F values are also larger than the $F_{crit}$ values for all the percentage groups. In these cases, null hypothesis is rejected. All the percentage groups are concluded to have different average compressive strengths. Furthermore, the variance values of all the percentage groups are very small that they are less than 0.25 averagely. This indicates that all the data values tend to very close to the mean and to each other. The reliability of the results can thus be enhanced.

## 4.3 Effects of silica sand on tensile splitting strength of epoxy polymer cement concrete

To investigate the effect of fine aggregates' replacement with silica sand at different proportions on the tensile splitting strength of epoxy polymer cement concrete, the amount of epoxy resins used to replace cement was kept at 40%. The curing time for the samples can be categorized into 3 days, 7 days, and 28 days. The effect of fine aggregates replaced with silica sand on the tensile splitting strength of the concrete after 3 days, 7 days, and 28 days of curing is shown in table 4.4, table 4.5, and table 4.6 respectively. The trends that show the effects of each composition on the tensile splitting strength can be observed through figure 4.4, figure 4.5, and figure 4.6 accordingly.

**Table 4.10**: Effects on tensile splitting strength after 3 days of curing

| Percentage of fine aggregates replaced with silica sand (%) | Tensile splitting strength (MPa) | | | | |
|---|---|---|---|---|---|
| | Sample 1 | Sample 2 | Sample 3 | **Average** | **Standard deviation** |
| 0 | 0.752 | 0.825 | 0.806 | **0.794** | **0.038** |
| 20 | 0.980 | 0.930 | 0.950 | **0.953** | **0.025** |
| 40 | 0.660 | 0.606 | 0.635 | **0.634** | **0.027** |
| 60 | 0.497 | 0.509 | 0.503 | **0.503** | **0.006** |

**Table 4.11**: Effects on tensile splitting strength after 7 days of curing

| Percentage of fine aggregates replaced with silica sand (%) | Tensile splitting strength (MPa) | | | | |
|---|---|---|---|---|---|
| | Sample 1 | Sample 2 | Sample 3 | **Average** | **Standard deviation** |
| 0 | 0.978 | 1.063 | 0.998 | **1.013** | **0.044** |
| 20 | 1.080 | 1.069 | 1.071 | **1.073** | **0.006** |
| 40 | 0.841 | 0.896 | 0.865 | **0.867** | **0.028** |
| 60 | 0.535 | 0.529 | 0.531 | **0.532** | **0.003** |

**Table 4.12**: Effects on tensile splitting strength after 28 days of curing

| Percentage of fine aggregates replaced with silica sand (%) | Tensile splitting strength (MPa) | | | | |
|---|---|---|---|---|---|
| | Sample 1 | Sample 2 | Sample 3 | **Average** | **Standard deviation** |
| 0 | 1.100 | 1.095 | 1.105 | **1.100** | **0.005** |
| 20 | 1.130 | 1.140 | 1.125 | **1.132** | **0.008** |
| 40 | 1.106 | 1.121 | 1.113 | **1.113** | **0.008** |
| 60 | 0.694 | 0.682 | 0.686 | **0.687** | **0.006** |

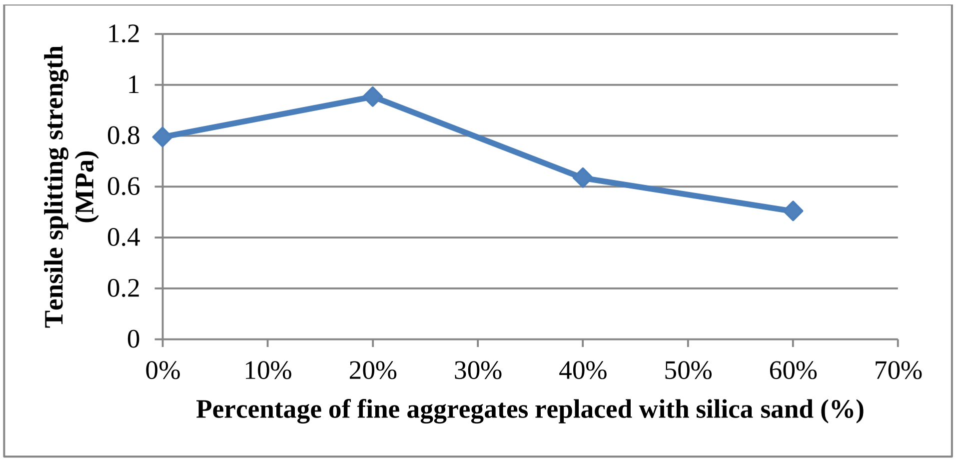


**Figure 4.5**: Effects on tensile splitting strength after 3 days of curing

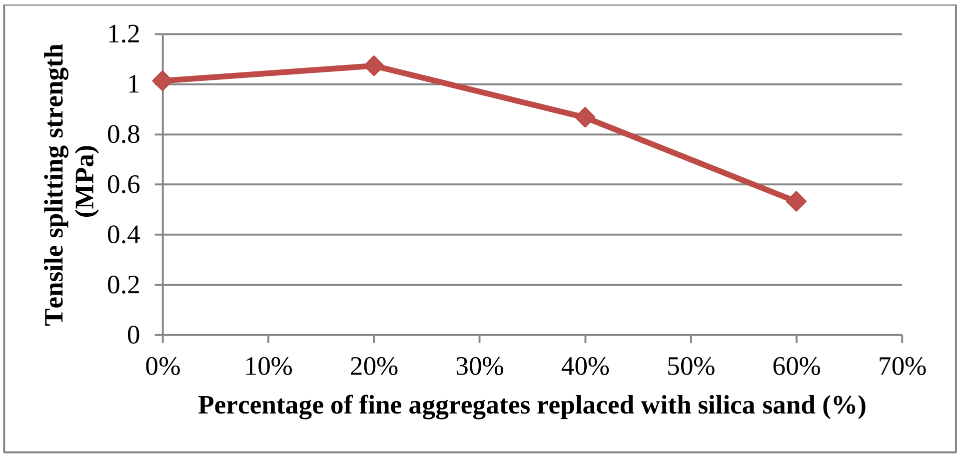


**Figure 4.6**: Effects on tensile splitting strength after 7 days of curing

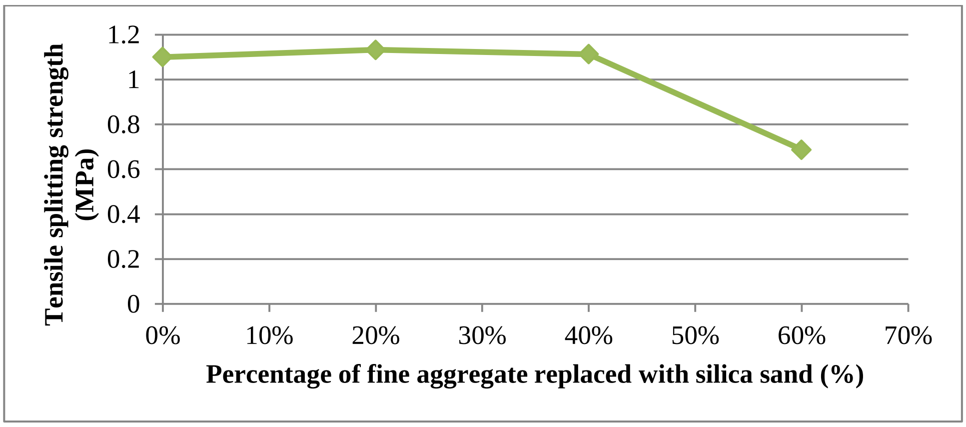


**Figure 4.7**: Effects on tensile splitting strength after 28 days of curing

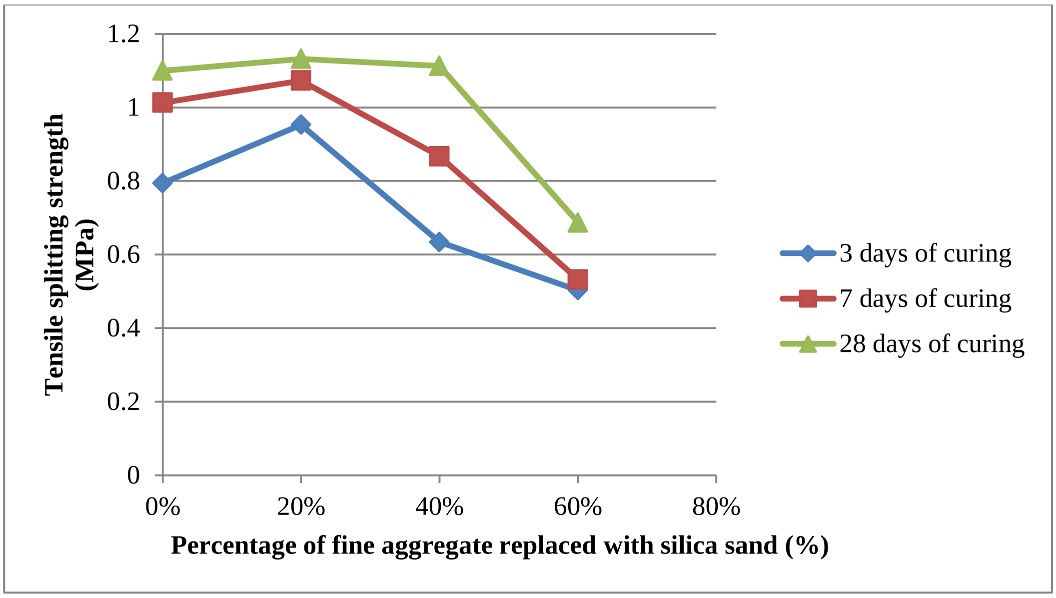


**Figure 4.8**: Effects on tensile splitting strength after 3 days, 7 days, and 28 days of curing

Figure 4.8 shows the relationship between effects of percentage of fine aggregates replaced with silica sand within the concrete mixture and the tensile splitting strength of the concrete itself. The concrete samples where percentage of fine aggregates replaced with silica sand is 0% act as the control variable for the subsequent 20%, 40%, and 60% of fine aggregates' replacement. The highest tensile splitting strength marks a value of 0.953MPa where the fine aggregates were replaced by 20% of silica sand and the lowest tensile splitting strength is 0.503MPa where the fine aggregates were replaced by 60% of silica sand after three days of curing for epoxy polymer cement concrete. For concrete samples after seven days of curing, the highest compressive strength stands at 1.073MPa where 20% of fine aggregates were replaced and the lowest tensile splitting strength is 0.532MPa where 60% of fine aggregates were replaced with silica sand. The tensile splitting strength of the concrete sample after 28 days of curing is the highest which is 1.132MPa where 20% of fine aggregates were replaced and the lowest tensile splitting strength is 0.687MPa where 60% of fine aggregates were replaced by silica sand. The curves in figure 4.4 indicate that as the percentage of fine aggregates replaced with silica sand increases from 0% to 20%, the tensile splitting strength of the concrete sample will also increase gradually. When the percentage of fine aggregates replaced by silica sand increases from 20% to 60%, the tensile splitting strength is noticed to be dropping rapidly after 3, 7, and 28 days of curing. Therefore, the optimum percentage of replacing fine aggregates with silica sand stands at 20% to achieve the highest tensile splitting strength. Besides, the tensile splitting strength of the concrete sample gets higher when the curing time of the sample is longer for every percentage of fine aggregates replaced by silica sand. The tensile splitting strength development with time for concrete sample where 20% of fine aggregates were replaced by silica sand is the highest while the concrete sample where 60% of fine aggregates were replaced by silica sand is the lowest after 28 days.

### 4.3.1 Analysis of variance (ANOVA) on tensile splitting strength after 3, 7, and 28 days of curing

**Table 4.13**: Summary for tensile splitting strength after 3 days of curing

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| 0 | 3 | 2.383 | 0.794333 | 0.001434 |
| 0.2 | 3 | 2.86 | 0.953333 | 0.000633 |
| 0.4 | 3 | 1.901 | 0.633667 | 0.00073 |
| 0.6 | 3 | 1.509 | 0.503 | 3.6E-05 |

**Table 4.14**: ANOVA for tensile splitting strength after 3 days of curing

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.343523 | 3 | 0.114508 | 161.6198 | 1.7E-07 | 4.066181 |
| Within Groups | 0.005668 | 8 | 0.000709 | | | |
| | | | | | | |
| Total | 0.349191 | 11 | | | | |

**Table 4.15**: Summary for tensile splitting strength after 7 days of curing

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| 0 | 3 | 3.039 | 1.013 | 0.001975 |
| 0.2 | 3 | 3.22 | 1.073333 | 3.43E-05 |
| 0.4 | 3 | 2.602 | 0.867333 | 0.00076 |
| 0.6 | 3 | 1.595 | 0.531667 | 9.33E-06 |

**Table 4.16**: ANOVA for tensile splitting strength after 7 days of curing

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.528789 | 3 | 0.176263 | 253.7069 | 2.87E-08 | 4.066181 |
| Within Groups | 0.005558 | 8 | 0.000695 | | | |
| | | | | | | |
| Total | 0.534347 | 11 | | | | |

**Table 4.17**: Summary for tensile splitting strength after 28 days of curing

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| 0 | 3 | 3.3 | 1.1 | 0.000025 |
| 0.2 | 3 | 3.395 | 1.131667 | 5.83E-05 |
| 0.4 | 3 | 3.34 | 1.113333 | 5.63E-05 |
| 0.6 | 3 | 2.062 | 0.687333 | 3.73E-05 |

**Table 4.18**: ANOVA for tensile splitting strength after 28 days of curing

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.413039 | 3 | 0.13768 | 3111.404 | 1.32E-12 | 4.066181 |
| Within Groups | 0.000354 | 8 | 4.42E-05 | | | |
| | | | | | | |
| Total | 0.413393 | 11 | | | | |

ANOVA tests were carried out to determine if the results on tensile splitting strength of the cubes are significant. One-way ANOVA was used to statistically compare the means from four independent groups (0, 0.2, 0.4, 0.6) using the F-distribution. A significance level, α of 0.05 was used.

**$H_o$: *All the percentage groups have equal average tensile splitting strength.***

**$H_1$: *All the percentage groups have different average tensile splitting strength*.**

From the analysis of variance carried out as above, all the P-values after 3, 7, and 28 days of curing are less than $\alpha = 0.05$ which mean that the results are significant. Besides, All the F values are also larger than the $F_{crit}$ values for all the percentage groups. In these cases, null hypothesis is rejected. All the percentage groups are concluded to have different average tensile splitting strengths. Furthermore, the variance values of all the percentage groups are very small that they are less than 0.25 averagely. This indicates that all the data values tend to very close to the mean and to each other. The reliability of the results can thus be increased.

# CHAPTER 5

# CONCLUSION

## 5.1 Summary

This final year project which is conducted and practiced through two semesters needs a large amount of time mainly on its material preparation and experimental works in concrete lab. Material such as epoxy resins are obtained from industrial supplier where this process takes a lot of time while other materials are prepared by lab assistants.

The main purpose of this research is to study the enhancement of epoxy polymer cement concrete on its mechanical properties which are compressive strength and tensile splitting strength. By replacing and maintaining 40% of cement with epoxy resins and using various proportion of silica sand as fine aggregates' replacement for every sample, the mixture that also consist coarse aggregates, fine aggregates, silica sand, and water do not seem to be bonded as strongly as in conventional concrete. When the result of testing comes out, it is proven that the strength of the polymer concrete in terms of compressive and tensile splitting is lower than conventional concrete. This might due to the selection of epoxy resins to be used throughout the research as the hardener within is oil-based agent. Cement needs water to undergo hydration process but the epoxy resin needs oil-based hardener to undergo hardening process. In this case, both the binding agents which are cement and epoxy resin will definitely have difficulties in combining together to bind the aggregates and eventually resulting in bad gradation of the polymer concrete. This type of gradation can be categorized as gap-graded. The coarse aggregate particles are almost similar in size but greatly different in size from the fine aggregates in the polymer concrete. Fields of fine aggregate are interspersed with slightly isolated and large aggregate pieces that are embedded in the fine aggregates causing low compressive strength and tensile splitting strength. By replacing fine aggregates with silica sand at various proportions while maintaining replacement of cement by 40% of epoxy resins, the compressive strength of the polymer concrete samples reduce as the percentage replacement of fine aggregates with silica sand increases. After 28 days of curing, the maximum compressive strength of polymer concrete decreases up to 30% which is 14.017MPa compared to control mix sample with value of 20.121MPa when the replacement level of fine aggregates is 60%. Besides, tensile splitting strength increases with replacement level of fine aggregates up to 20%. This happened due to micro filler effect of silica sand as the size of silica sand is smaller than fine aggregates. Above 20% replacement of fine aggregates with silica sand the tensile splitting strength of polymer concrete gets reduced than that of the control mix. The optimum percentage of fine aggregates replaced with silica sand is thus can be concluded at 20%. After 28 days of curing, the maximum tensile splitting strength of polymer concrete with 20% replacement level of fine aggregates increases up to 2.83% which is 1.132MPa compared to control mix sample with value of 1.100MPa. When the replacement level of fine aggregates by silica sand is increased up to 60%, the tensile splitting strength decreases up to 39.3% compared to sample with 20% replacement level.

## 5.2 Recommendation

Both the compressive strength and tensile splitting strength of the polymer concrete are said to be much lower than normal concrete. Therefore, this polymer concrete is not suitable to be used in the structures of building that require high strength to support large loading. However, construction of concrete apron around the house can be done by using polymer concrete where the conventional sand is replaced partially by silica sand. On the other hand, silica sand can also be utilized to replace conventional sand while doing plastering of wall and cement rendering. Not all concrete work requires reinforcement of steel bars for example concrete projects such as pathways, driveways and playhouse floor. Some slabs on ground such as building floors and highway pavement do not need tensile strength and therefore this kind of polymer concrete can come into uses.

For any further researches in future, I suggest that experimental study on polymer concrete should be conducted by using water-based hardener instead of oil-based hardener for epoxy resins. Furthermore, other brand or type of epoxy resins should also be utilized instead of epoxy resins of E110I and hardener of H-9 supplied by Pan Asel Chemicals (M) Sdn. Bhd. Besides, silica sand is a by-product of cement industries and is mostly discarded as waste products. Thus, silica sand should be continually to be utilized to replace conventional sand in producing concrete in experimental study where no cement is being replaced. This is due to cheaper cost of silica sand compared to conventional sand and it will be more environmental friendly.

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# APPENDIX A
# GANTT CHART

| TASK | Sep-17 | Oct-17 | Nov-17 | Dec-17 | Jan-18 | Feb-18 | Mar-18 | Apr-18 | May-18 |
|---|---|---|---|---|---|---|---|---|---|
| IDENTIFICATION OF PROBLEM STATEMENT | ■ | | | | | | | | |
| BRAINSTORM OF OBJECTIVE | ■ | | | | | | | | |
| PROPOSE OF RESEARCH TITLE | | ■ | | | | | | | |
| PLANNING OF METHODOLOGY | | ■ | | | | | | | |
| SUBMISSION OF RESEARCH PROPOSAL | | | ■ | | | | | | |
| PRESENTATION OF PROPOSAL | | | | ■ | | | | | |
| CONDUCT OF EXPERIMENTAL WORK | | | | ■ | ■ | ■ | | | |
| ANALYSIS OF RESULT | | | | | ■ | ■ | ■ | | |
| PREPARATION OF THESIS 1ST DRAFT | | | | | | | ■ | ■ | |
| SUBMISSION OF THESIS 1ST DRAFT | | | | | | | | ■ | |
| PRESENTATION OF THESIS | | | | | | | | | ■ |
| SUBMISSION OF FINAL THESIS | | | | | | | | | ■ |

# APPENDIX B
# TECHNICAL DATA SHEET OF EPOXY RESINS & HARDENER

Pan Asel 寰亞
Epoxy Resin & Hardener

## E-110I / H-9

**E-110I/H-9** is a two component, non-volatile liquid high gloss epoxy resin that forms hard enamel like finish. It is specially formulated for maximum durability and aesthetic appeal. It exhibits several outstanding features as follow:

### Advantages:

1. Non-toxic, non-volatile and colorless.
2. Low viscosity and long pot life provide easy application.
3. Tenacious adhesion to variety of substrates including wood, plate metals, plastic etc...
4. The coated transparent surface is very smooth and glossy as well as more attractive and eye-catching.
5. Excellent resistance to brushing and scratching.
6. Can be cured either at room temperature or elevated temperature.

### Typical Properties

| | E-110I | H-9 |
|---|---|---|
| Appearance | **Clear liquid** (Color paste can be provided) | **Clear liquid** (Color paste can be provided) |
| Viscosity (CPS) | 3,500 – 4,500 cps | 100 – 150 cps |
| Mixing Ratio (by weight) | 2 : 1 | |
| Pot Life | 60 minutes | |
| Shelf Life | 6 months | |
| Cure Condition | R. T. : *14 – 16 hrs : 70℃ : *70 – 80 mins | |
| Compression Strength | 728 $kg/cm^2$ | |
| Flexural Strength | 297 $kg/cm^2$ | |
| Tensile Strength | 136 $kg/cm^2$ | |
| Flash Point | > 300℃ | > 150℃ |

**Technical Data Sheet**
**E-110I / H-9**

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## Applications Data

1. Use proper container and mixing rod.
2. To minimize wastage, accurate the ratio 2 : 1 of resin & hardener on each application by weight.
3. Mix thoroughly, scraped the edge of the container and mixed uniformly.
4. Complete preparation and apply it within the pot life period.

## Cautions

1. For storage, once the pack has been opened the cap must be properly sealed and store in cool conditions, preferably away from sunlight or excessive heat.
2. Precaution must be taken to prevent E-110I and H-9 contaminating each other during operation to ensure longer storage life.

## Safety Precaution

1. Provide adequate ventilation when mixing the Resin and Hardener.
2. It may cause skin irritation in sensitive individuals. Keep material and solvent off skin with protective gloves.
3. In case of eye contact, flush with clean, running water for at least 15 minutes then seek medical attention.