COMPARISONS BETWEEN MIX DESIGNS TOWARDS SF-OPSC MECHANICAL PROPERTIES

AZMIRA BINTI AB AZIZ

Bachelor of Engineering (Hons) in Civil Engineering

UNIVERSITI MALAYSIA PAHANG

COMPARISONS BETWEEN MIX DESIGNS TOWARDS SF-OPSC MECHANICAL PROPERTIES

AZMIRA BINTI AB AZIZ

Report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering (Hons.) in Civil Engineering

Faculty of Civil Engineering & Earth Resources

UNIVERSITI MALAYSIA PAHANG

JUNE 2015

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS / UNDERGRADUATE PROJECT PAPER AND COPYRIGHT

Author's full name	:	**AZMIRA BINTI AB AZIZ**
Date of birth	:	**21 MAY 1992**
Title	:	**COMPARISONS BETWEEN MIX DESIGNS TOWARDS SFOPSC MECHANICAL PROPERTIES**
Academic Session	:	**2014/2015**

I declare that this thesis is classified as:

☐	**CONFIDENTIAL**	(Contains confidential information under the Official Secret Act 1972)*
☐	**RESTRICTED**	(Contains restricted information as specified by the organization where research was done)*
✓	**OPEN ACCESS**	I agree that my thesis to be published as online open access (full text)

I acknowledged that University Malaysia Pahang reserves the right as follows:

1. The thesis is the property of University Malaysia Pahang.
2. The Library of University Malaysia Pahang has the right to make copies for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by:

_________________________	_________________________
SIGNATURE	SIGNATURE OF SUPERVISOR
920521-03-5244	DR. NOOR NABILAH BINTI SARBINI
(NEW IC NO./PASSPORT NO.)	NAME OF SUPERVISOR
Date:	Date:

NOTES: *If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or Restriction

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Concrete is widely used as a construction material. Therefore, there is no escaping from the influenced of concrete in everyday life. It is estimated that the present consumption of concrete in the world is of the order of ten billion tonnes every year. Concrete is a composite material composed mainly of water, aggregate and cement. Usually there are admixtures and reinforcements included to achieve the desired properties of the finished products. When these compositions are mixed together, they form a fluid mass that is easily molded into shape. Over time, the cement forms a hard matrix which binds the rest of the ingredients together into a durable stone.

Cement is a finely pulverized, dry, material that by itself is not a binder but develops the binding property as a result of hydration. Water is responsible for the hydration reactions with the cement. Aggregate is the granular material, such as sand, gravel, or crushed stone that is used with a cementing medium to produce either concrete or mortar. Meanwhile, admixtures are defined as materials other than aggregates, cement, and water, which are added to the concrete batch immediately before or during mixing. The use of admixtures in concrete is now widespread due to many benefits which are possible by their application.

However, these primary materials can be replaced with others to obtain or to develop a more sustainable concrete. It has been reported that oil palm shell (OPS) can be used as replaced aggregate in concrete. Since OPS is an organic material, its properties differ from that of conventional granite aggregates. OPS is lightweight in nature and has bulk density of about 590 kg/m^3 (Teo *et al.*, 2009). Consequently, the resulting concrete is lightweight. OPS aggregate can be used as an alternative to the conventional granite aggregates for the production of lightweight concrete. The utilization of OPS as aggregate replacement in concrete is a good way of practicing sustainable development (Teo *et al.*, 2009).

Steel fibers (SF) with different yield strengths are available in various shapes and sizes which improves the mechanical properties of the concrete in a wide range. Addition of SF changes the workability of the concrete and also balling of these fibers in concrete may occur depending on the amount and shape of the fiber used (Tadepalli *et al.*, 2009). SF are available in various shapes namely straight, crimped, hooked single, hooked collated and twisted. Among the fibers, hooked fibers performs better than straight and crimped SF in terms of flexural strengths and energy absorption capacities (Bayasi *et al*., 1992).

1.2 PROBLEM STATEMENT

The environmental impact of oil palm cultivation is a highly controversial topic. OPS are agricultural solid end products of oil palm manufacturing processes. Palm trees grow in regions where the temperature is hot with copious rainfall such as Malaysia, Indonesia, and Nigeria. The utilization of OPS as lightweight aggregate (LWA) in the production of lightweight aggregate concrete (LWAC) has been a topic of research since the early 1984 in Malaysia. OPS are one of the wastes produced during palm oil processing. Figure 1.1 shows the oil palm efficiency compared to the other major oil crops.

Recently, a large amount of OPS waste materials are stockpiled and dumped, which causes storage problems within the vicinity of factories as large quantities of these wastes are produced every day. In Malaysia, it is estimated that over 4.6 million tonnes of OPS is produced annually as waste. A cost analysis in Nigeria revealed that a cost reduction of 42% is possible for concrete made from OPS. Several studies showed that although the engineering properties of oil palm shell concrete (OPSC) are generally satisfactory, there is still reluctance in implementing OPSC compared with other types of LWAC. The reason for this was given by Okafor., 1988 who concluded that OPS are incapable of producing concrete with a compressive strength above 30 MPa (Ming *et al.*, 2014).

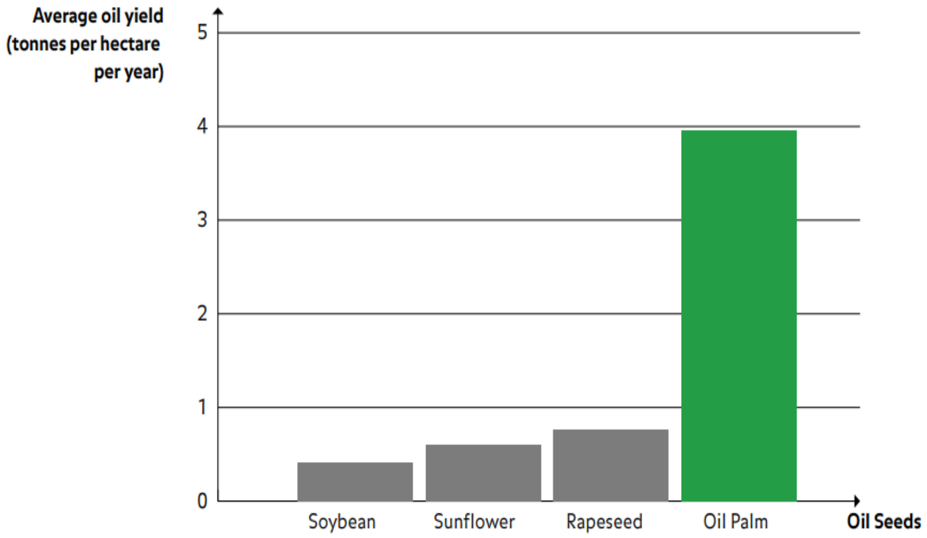


Figure 1.1: Oil palm efficiency compared to the other major oil crops

Due to the higher amount of oil palm shell wastes, we can create something that useful to the public by using this kind of wastes for example the OPSC reinforced with SF. This solution will provide a good strength of reinforced concrete.

1.3 RESEARCH OBJECTIVES

The objectives of this research are :

i. To determine the effect of different mix designs to the behaviour of steel fiber oil palm shell concrete (SF-OPSC).
ii. To study the mechanical properties of SF-OPSC.

1.4 SCOPE OF STUDY

The scopes of this study are :

i. Testing specimen of cube, cylinder and prism specimens
ii. The size of cube is 100 mm x 100 mm x 100 mm, cylinder with 150 mm in diameter and 300 mm in height and prism with the cross-section of 100 mm x 100 mm and 500 mm in length

iii. The concrete grade that is used is 25 MPa

iv. The tests that are conducted are slump test, compressive strength test, flexural strength test, tensile strength test and modulus of elasticity test

v. The type of fiber that is used is hooked end steel fiber

vi. The volume fraction of SF is same which is 1%

vii. The mix designs that will be used are different in W/C which are 0.58 and 0.62

viii. The amount of OPS aggregate that are used in the specimen are 50% and 100%

1.5 RESEARCH SIGNIFICANCE

The expected outcomes from this research is on the improvement of OPS and SF when inside the structural element. Besides that, we can investigate the mechanical properties when the steel fiber and oil palm shell were in lightweight concrete and get the knowledge about it. It is economical to use OPS in the lightweight concrete because of the higher amount of OPS wastes.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

OPS is considered as a waste material produced from the extraction of palm oil in South East Asian countries, such as Indonesia, Malaysia, and Thailand (U. Johnson *et al.,* 2014). In Malaysia, OPS is an agricultural solid waste originating from the palm oil industry. The Palm Oil Industry is a significant industry in the Malaysian economy. This country currently accounts for 51% of world palm oil production and 62% of world exports. Almost 80% of the volume from the processing of the fresh fruit bunch is removed as waste (P. Shafigh *et al.*, 2012). OPS is one of the wastes produced during the palm oil processing. Recently, plenty of OPS waste, as a lignocellulosic material, was obtained due to the increasing number of plantations of oil palm trees. It was estimated that over 4.56 million tonnes of waste OPS is produced annually (P. Shafigh *et al*., 2012).

The applications of agricultural wastes as aggregate or cement replacement material in concrete have engineering potential and economic advantage. Each of the agricultural waste consists of physical and chemical properties. Solid agricultural waste as coarse aggregate together with cement matrix can meet design specifications in low-cost lightweight structures (M. A. Mannan *et al*., 2004).

In palm oil mills, the hard shells are directly attained by breaking the palm karnel shells by using the machinery. Usually, OPS aggregates are composed of different shapes as shown in the Figure 2.1. Before using the OPS aggregate in concrete, pre-treatment is necessary because it contains dust and oil coating. The processes are :

(i) partial oxidation of organic aggregate, (ii) waterproofing, (iii) neutralisation with alkali or precipitation of tannates, or sulphate treatment, (iv) mixing with lime or calcium chloride for better performance of concrete as an accelerator, (v) micro organism treatment of aggregate by boiled water with ferrous sulphate, and (vi) removing oil coating with detergent and water (M. A. Mannan *et al*., 2004).

Steel fiber-reinforced concrete (SFRC) is concrete made of hydraulic cements containing fine and coarse aggregate and discontinuous discrete steel fibers. Addition of randomly distributed steel fibers improves concrete properties, such as static flexural strength, ductility and flexural toughness. Many researchers have shown that the impact resistance can be increased substantially with the addition of randomly distributed steel fibers to concretes (Zhang *et al*., 2014). Since the invention of SFRC in 1874, it has become a useful structural material since 1970's, mainly because the addition of steel fibers significantly improves the mechanical properties of concrete, including impact strength, toughness, flexural strength, tensile strength, ductility and the ability to resist cracking and spalling (Chen *et al*., 2014).

Figure 2.1: Sample of OPS aggregate

2.2 FIBER

2.2.1 Background of Fiber

Plain concrete is a brittle material with low tensile strength and low tensile strain and hence requires reinforcing material to be used as a structural member. Currently, continuous steel fiber distributed appropriately has been used as the reinforcing material to improve tensile strength (Lee *et al.,* 2014).

Due to the weakness of concrete in tensile, fiber is introduced. Fibers are not only discontinuous, but they also end up distributed irregularly in the concrete. Therefore, fiber reinforcements do not effectively resist tensile stress. However, fibers are effective at controlling cracking included in a concrete element because the distance between the fibers is less than the distance between the steel rebar sections. Therefore, if both fiber and steel rebar are used as reinforcing materials, this helps to enhance the load-bearing capacity of the concrete, and the fiber will effectively control cracking (Lee et al., 2014).

The fiber can be divided into many types for example natural fiber, synthetic fiber and steel fiber. These are elaborated more in next sections.

2.2.2 Types of Fiber

2.2.2.1 Natural Fiber

The natural fibers, abundantly available in nature and also generated from agricultural waste. They can be used in improving certain physical properties of concrete, eventhough the durability of resultant mix is relatively poor. As compared to the fibers widely used in construction activities viz. Steel, glass carbon synthetic and others, these are advantageous in the sense that they are renewable, non abrasive, cheaper, comparatively more flexible and others. Also, the health and safety concerns during their handling, processing and mixing are less. Several natural fibers have been used in research works. Their objectives are on investigating and improving the mechanical properties of concrete matrices which are brittle in nature (Srivastava *et al*., 2013).

The natural fibers potentially to be used as reinforcement in concrete to overcome some inherent deficiencies of these materials. These fibers are advantageous as compared to widely used artificial fibres because they are cheaper, renewable, non abrasive, abundant and do not create health and safety problems during handling, processing and mixing operations. The fibers includes coconut, sugarcane bagesse, banana, san, date-palm, coir, eucalyptus, flax, bamboo, agava, elephant grass, roselle, palm oil and others (Srivastava *et al*., 2013). The types of natural fibers are shown in the Figure 2.2.

The cotton fiber grows on the seed of a various of plants of the genus *Gossypium*. Of the four cotton species cultivated for fiber, the most important are *G. hirsutum*, which originated in Mexico and produces 90% of the world's cotton, and *G. barbadense*, of Peruvian origin, which accounts for 5%. World average cotton yields are around 800 kg per hectare. Cotton is almost pure cellulose, with softness and breathability that have made it the world's most popular natural fiber. It absorbs moisture readily, which makes cotton clothes comfortable in hot weather, while high tensile strength in soap solutions means they are easy to wash. An estimated 60% of cotton fiber is used as yarn and threads in a wide range of clothing, most notably in shirts, T-shirts and jeans, but also in coats, jackets and foundation garments. Cotton is also used to make home furnishings, such as draperies, bedspreads and window blinds, and is the most commonly used fiber in sheets, pillowcases, towels and washcloths. The cotton fiber is shown in the Figure 2.2 (a).

Jute is extracted from the bark of the white jute plant, *Corchorus capsularis* and to a lesser extent from tossa jute (*C. olitorius*). It flourishes in tropical lowland areas with humidity of 60% to 90%. A hectare of jute plants consumes about 15 tonnes of carbon dioxide and releases 11 tonnes of oxygen. Yields are about 2 tonnes of dry jute fibre per hectare. Jute has high insulating and anti-static properties, moderate moisture regain and low thermal conductivity. During the Industrial Revolution, jute yarn largely replaced flax and hemp fibres in sackcloth. Today, sacking still makes up the bulk of manufactured jute products. Jute yarn and twines are also woven into curtains, chair coverings, carpets, rugs and backing for linoleum. Blended with other fibres, it is used in cushion covers, toys, wall hangings, lamp shades and shoes. Very fine threads can be separated out and made into imitation silk. Jute is being used increasingly in rigid packaging and reinforced plastic and is replacing wood in pulp and paper. Geotextiles made from jute are biodegradable, flexible, absorb moisture and drain well. They are used to prevent soil erosion and landslides . The jute fiber is shown in the Figure 2.2 (b).

Sheep are shorn of their wool usually once a year. After scouring to remove grease and dirt, wool is carded and combed, then spun into yarn for fabrics or knitted garments. Merino sheep produce up to 18 kg of greasy wool a year. Wool has natural crimpiness and scale patterns that make it easy t spin. Fabrics made from wool have greater bulk than other textiles, provide better insulation and are resilient, elastic and durable. Fiber diameter ranges from 16 microns in superfine merino wool to more than 40 microns in coarse hairy wools. Wool is a multifunctional fibre with a range of diameters that make it suitable for clothing, household fabrics and technical textiles. Its ability to absorb and release moisture makes woollen garments comfortable as well as warm. Two thirds of wool is used in the manufacture of garments, including sweaters, dresses, coats, suits and active sportswear. Blended with other natural or synthetic fibres, wool adds drape and crease resistance. Slightly less than a third of wool goes into the manufacture of blankets anti-static and noise-absorbing carpets, and durable upholstery. Wool's inherent resistance to flame and heat makes it one of the safest of all household textiles). Industrial uses of wool include sheets of bonded coarse wool used for thermal and acoustic insulation in home construction, as well pads for soaking up oil spills. The wool fiber is shown in the Figure 2.2 (c).

Coir is extracted from the tissues surrounding the seed of the coconut palm (*Cocos nucifera*). There are two types of coir which are brown fiber, which is obtained from mature coconuts, and finer white fiber, which is extracted from immature green coconuts after soaking for up to 10 months. Coir fibers measure up to 35 cm in length with a diameter of 12-25 microns. Among vegetable fibers, coir has one of the highest concentrations of lignin, making it stronger but less flexible than cotton and unsuitable for dyeing. The tensile strength of coir is low compared to abaca, but it has good resistance to microbial action and salt water damage. White coir spun into yarn is used in the manufacture of rope and it is strong resistance to salt water, in fishing nets. Brown coir is used in sacking, brushes, doormats, rugs, mattresses, insulation panels and packaging. The coir fiber is shown in the Figure 2.2 (d).

Abaca is extracted from the leaf sheath around the trunk of the abaca plant (*Musa textilis*), a close relative of the banana, native to the Philippines and widely distributed in the humid tropics. Harvesting abaca is labourious. Each stalk must be cut into strips which are scraped to remove the pulp. The fibres are then washed and dried.

Abaca is a leaf fiber, composed of long slim cells that form part of the leaf's supporting structure. Lignin content is 15% high. Abaca has great mechanical strength, buoyancy, resistance to salt water damage, and long fiber length up to 3 metres. The best grades of abaca are fine, lustrous, light beige in colour and very strong. During the 19th century abaca was widely used for ships' rigging, and pulped to make sturdy manila envelopes. Today, it is still used to make ropes, twines, fishing lines and nets, as well as coarse cloth for sacking. There is also a flourishing niche market for abaca clothing, curtains, screens and furnishings. The abaca fiber is shown in the Figure 2.2 (e).

Silk is produced by the silkworm, *Bombyx mori*. Fed on mulberry leaves, it produces liquid silk that hardens into filaments to form its cocoon. The larva is then killed, and heat is used to soften the hardened filaments so they can be unwound. Single filaments are combined with a slight twist into one strand, a process known as filature or silkreeling. A silk filament is a continuous thread of great tensile strength measuring from 500 to 1500 metres in length, with a diameter of 10 to 13 microns. In woven silk, the fiber's triangular structure acts as a prism that refracts light. It has good absorbency, low conductivity and dyes easily. Silk's natural beauty and other properties such as comfort in warm weather and warmth during colder months have made it sought after for use in high-fashion clothes. It is used in sewing thread for high quality articles, particularly silk apparel, and in a range of household textiles, including upholstery, wall coverings and rugs and carpets. The silk fiber is shown in the Figure 2.2 (f).

(a) cotton

(b) jute

(c) wool

(d) coir

(e) abaca

(f) silk

Figure 2.2: Types of natural fibers

2.2.2.2 Synthetic Fiber

Synthetic fibers are the result of extensive research by scientists to improve natural fibers. Before synthetic fibers were developed, artificially manufactured fibers were made from polymers obtained from petro chemicals. These fibers are called synthetic fibers and also called as artificial fibers.

Most important applications of fibers are generally to prevent or control the tensile cracking occurring in concrete. Synthetic fibers are the fibers exhibiting structurally-effective properties such as increase of toughness and load-carrying capacity after cracking. These synthetic fibers have advantages compared to steel or other fibers in that they are corrosion-resistant and exhibit high energy-absorption capacity (Oh *et al*., 2007).

Synthetic fiber has recently been studied as a substitute reinforcing material for steel fiber. Synthetic fiber is known to exhibit similar features to steel fiber, such as good tensile strength, flexural strength, flexural toughness, and impact resistance. It has good chemical resistance and no possibility of corrosion, and it is easily movable due to its low specific gravity. Additionally, it is not dangerous to workers and is economically advantageous compared with steel fiber. Nonetheless, structural synthetic fibers are often used because the fiber ends are fixed in the concrete and elongate simultaneously during pull-out to induce ductile behaviour, unlike steel fibers, which resist cracking with high stiffness when pulled (Lee et al., 2014). The types of synthetic fibers are shown in the Figure 2.3.

Acrylic fibers are synthetic fibers that are made from any long chain synthetic polymer composed of at least 85 % by weight of acrylonitrile units. Acrylic fiber is characterized with inherent polarity which is the ability to attract and convey moisture. Due to this quality acrylic fiber gives lifetime wicking capability to fabrics that are made from it. These days the active wear or sports wear are growingly made from these acrylic fabrics as the wearer feels more comfortable because of moisture management done by them. Acrylic fabrics are used for making various clothings, home furnishings and other items. They also find application in industries due to their high performance values. Acrylic Fabrics are mostly used to make such garments that need to make the wearer more and more comfortable through moisture management such as outerwear pile fabrics, , socks & tights, sweaters and sleepwear. They are also used in making home furnishings like carpets, rugs, upholstery, cushions,blankets, pile sheets, and others. The acrylic fiber is shown in the Figure 2.3 (a).

Rayon is a man-made redeveloped cellulose fiber. Rayon is a semi-synthetic or artificial fiber. Rayon is recognized by the name viscose rayon and art silk in the textile industry. Rayon fibre is a synthetic textile material which is fully the collection of cellulose acquired from cotton linters or from the soft tissue of trees such as spruce. Rayon fibres are used in apparel industry such as Aloha shirts, blouses, dresses, jackets, lingerie, scarves, suits, ties, hats and socks. Some rayon fibres are for filling in zippo lighters, furnishings including bedspreads, bedsheets, blankets, window covers, upholstery and slipcovers and also for industrial purposes such as medical surgery products, non-woven items, tire cord and some other uses like diapers, and towels. The rayon fiber is shown in the Figure 2.3 (b).

Polyester fibres are the first choice for apparel and are used in trousers, skirts, dresses, suits, jackets, blouses and outdoor clothing. Polyester fibres are produced by the melt spinning process. Raw materials are heated to a spinning mass, which is then pressed through spinnerets. They can have round, oval or angular profiles, making them firm to the touch. They can be dull, bright or glittery. Polyester fibres are particularly resistant to light and weather and can withstand climatic effects. They can be used where lightness and fineness are primary requirements. Polyester fibres are very well suited to blends with natural fibres. Fabrics in 100% polyester, or blends with an appropriately high proportion, are very crease-resistant and retain shape even when affected by moisture. Polyester fibres have good moisture transport and dry quickly and they are easy care. The polyester fiber is shown in the Figure 2.3 (c).

Nylon fibers are used for a variety of uses from clothing to home furnishings and industrial uses. Comparing other synthetic fibers, great advantages of nylon fibers are resistant to abrasion and flexing. Accordingly, thin, light and flexible woven or knitted fabric can be manufactured. Nylon fibers can be produced in a variety of cross-section and fineness. Composite fibers, having unique appearance and tactile feeling, can also be produced by combining with other types of fibers. Heat storage or warmth retention fibers consisting of extremely fine filament yarns in which carbonaceous material converting the light to heat is inserted. Transparent nylon fibers exhibiting more transparent and beautiful colors. Thus a wide variety of nylon fibers are available giving much more performances and fabric hand. The nylon fiber is shown in the Figure 2.3 (d).

(a) acrylic

(c) polyester

(b) rayon

(d) nylon

Figure 2.3: Types of synthetic fibers

2.2.2.3 Steel Fiber

Steel fiber-reinforced concrete (SFRC) is concrete made of hydraulic cements containing fine and coarse aggregate and discontinuous discrete steel fibers. Addition of randomly distributed steel fibers improves concrete properties, such as static flexural strength, ductility and flexural toughness. Many researchers have shown that the impact resistance can be increased substantially with the addition of randomly distributed steel fibers to concretes (Zhang *et al*., 2014).

Since the invention of SFRC in 1874, it has become a useful structural material since 1970's, mainly because the addition of steel fibers significantly improves the mechanical properties of concrete, including impact strength, toughness, flexural strength, tensile strength, ductility and the ability to resist cracking and spalling (Chen *et al*., 2014). Figure 2.4 presents the various types of steel fibers.

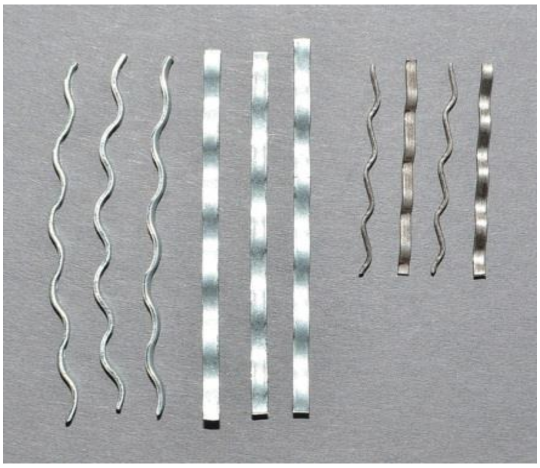
Hooked end fibre has been in the market for over 25 years. This shape is probably the most popular and successful in the history of steel fibre reinforced concrete. This is due to the fact that over the last decade almost all fibre manufacturers have added the hooked end shape to their product range. Hooked end can be used in almost any known application for steel fibre reinforced concrete. Hooked end can be used with any concrete mix and high concrete density is less mandatory then for undulated or for flat-end fibres. Load transfer in the crack is very good with this fibre shape. Thus after the appearance of the first crack the loss of load-bearing capacity occurs quickly but then stabilizes and in some cases even begins to increase again after large cracks have developed. The hooked-end steel fiber is shown in the Figure 2.4 (a).

Stainless steel fibers are manufactured fibers composed of stainless steel. Composition may include carbon (C), silicon (Si), manganese (Mn), phosphorus (P), sulphur (S), and other elements. The most common uses for stainlesss steel fibers is in the field of the electrical and textiles industry such as anti-radiation cloth, thermal resistant fabric, and anti-static brushes. Many people also use stainless steel fibers in weaving. Increasingly common today are stainless steel fibers in clothing, including radiation protection for pregnant women. Stainless steel yarns are woven, braided, and knit into many industrial fabrics.

For additional variety, stainless steel yarns are twisted with other fibers such as wool, nylon, cotton, and synthetic blends to produce yarns which add novelty effects to the end cloth. Stainless steel and other metal fibers are used in communication lines such as telephone lines and cable television lines. Stainless steel fibers are also used in carpets. They are dispersed throughout the carpet with other fibers so they are not detected. The presence of the fibers helps to conduct electricity so that the static shock is reduced. These types of carpets are often used in computer-use areas where risks of electrostatic discharge are much greater. Other uses include tire cord, missile nose cones, work clothing such as protective suits, space suits, and cut resistant gloves forbutchers and other people working near bladed or dangerous machinery. The stainless steel fiber is shown in the Figure 2.4 (c).

(a) hooked-end steel fiber

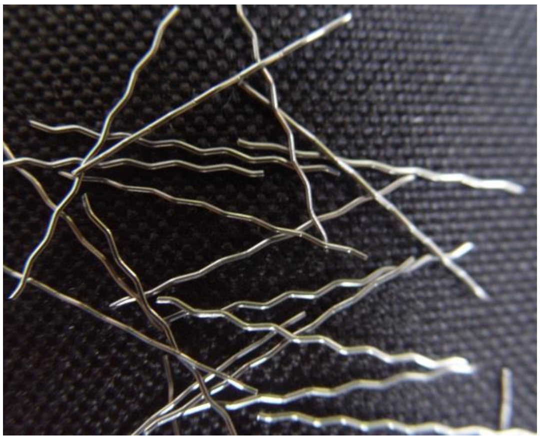
(d) flat-end steel fiber



(b) wavy steel fiber

(e) crimped steel fibers

Figure 2.4: Types of steel fibers



(c) stainless steel fibers

Figure 2.4: Continued

2.3 BEHAVIOUR OF OIL PALM SHELL AND STEEL FIBER REINFORCED LIGHTWEIGHT CONCRETE

2.3.1 Workability

The workability of a concrete mix is defined as the case with which it can be mixed, trasported, placed and compacted in position. Slump test is carried out to measures the consistency of plastic concrete. It is suitable for detecting changes in workability. This test is being used extensively on site.

The mixing ratio used by (P. Shafigh *et al*., 2011) are shown in Table 2.1. Typically, the amount of steel fibers used in concrete is in the range of 0.25% - 2%. This is because the effect of the cost and increase the density of concrete that caused by the addition of steel fibers and low volume fraction (≤1%) fibers are used. The volume fraction of steel fibers used in OPS concrete is 0%, 0.25%, 0.5%, 0.75% and 1%. All the mixtures have 0.7% of superplasticizer (SP) by weight of cement.

Table 2.1: Mix proportions (kg/m^3)

Mix Code	Cement	Water	Sand	OPS	Fiber Volume (%)
L0	500	190	868	360	0
L0.25	500	190	868	360	0.25
L0.5	500	190	868	360	0.5
L0.75	500	190	868	360	0.75
L1	500	190	868	360	1

Source: P. Shafigh *et al*. 2011

The workability of OPS concrete decreases as the volume fraction of steel fibers increased. The quantity of SP and water were kept constant in all the mixtures. Therefore, the surfac area becomes larger due to the higher volume of fiber content. Thus, the slump of fresh concrete reduces. The addition of fibers to the mixtures from 0% to 0.25%, 0.5%, 0.75% and 1% make the workability decrease about 19.5%, 41%, 60% and 82.5%, respectively. Figure 2.5 shows that there is a linear relationship between the fiber volume and slump of OPS concrete.

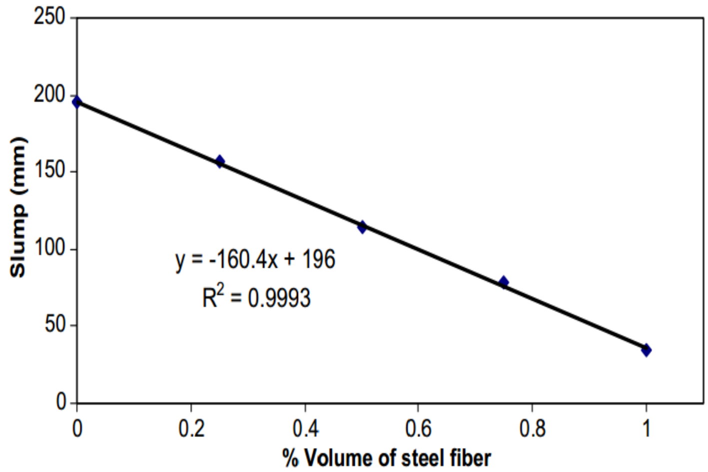


Figure 2.5: Relationship between slump and steel fiber volume

Source: P. Shafigh *et al*. 2011

2.3.2 Compressive Strength Test

As can be seen from Table 2.2, the compressive strength of concrete increased in all age groups with increased quantities of steel fiber fraction. Increasing the ratio of steel fibers from 0% to 0.25%, 0.5%, 0.75% and 1% increase in compressive strength of approximately 1.7%, 2.5%, 7.8% and 3% at age 3 days, 6.1%, 4%, 9.1% and 10% at 7 days of age, 6.2%, 6.9%, 14% and 14.3% at 28 days and 5.3%, 8.9%, 16% and 18.8% at 56 days of age, respectively. A comparison of strength in the early and later ages indicate that the rate of strength development is greater as age increased, especially for concrete with higher steel fiber content.

From the results of Table 2.2, it can be seen that at 3 and 7 days, the percentage of strength decreases and at 56 days it increased as the ratio of the steel fibers increased. This is because of the higher rate of strength gain in later times. This rate is important for steel fiber ratio of 1%. It seems that, for all volume fractions the performance of steel fiber in OPS concrete increases at later ages. This may be due to the better bond between the fiber and the matrix at later ages.

Table 2.2: Development compressive strength of OPS concrete in moist curing.

Mix Code	**Compressive Strength (Mpa)**			
	3 days	**7 days**	**28 days**	**56 days**
L0	34.80 (88%)	37.19 (95%)	39.34	40.30 (102%)
L0.25	35.40 (85%)	39.45 (94%)	41.77	42.42 (102%)
L0.5	35.68 (85%)	38.68 (92%)	42.04	43.70 (104%)
L0.75	37.52 (84%)	40.56 (90%)	44.84	46.74 (104%)
L1	35.83 (80%)	40.90 (91%)	44.95	47.88 (107%)

Note: All data in parentheses are percentages of 28 day compressive strength.

Source: P. Shafigh *et al.* (2011)

2.3.3 Tensile Strength Test

The splitting tensile test is an indirect method and it is easier method to determine the tensile strength of concrete. The determination of tensile strength of concrete is required to provide the information about the maximum tensile load of concrete members that can sustain before it cracks. In this research, it was found that the addition of steel fibers improved the splitting tensile strength of the concrete. As found from this experimental investigation, an increase of 0.5%, 0.75% and 1.0% of total steel fibers volume increase the splitting tensile strength of up to 93%, 133% and 178% respectively compared with the control concrete. When a large amount of tensile stress was introduced in concrete, micro-cracks and macro-cracks thus formed. The increase in the load induces critical crack growth at the tip of macro-cracks which eventually led to failure of concrete. The steel fibers act as a means of stress transfer any tensile stress has moved across the fiber, which in turn slows the spread of macro-cracks and increase the splitting tensile strength of concrete (K. H. Mo *et al.*, 2014). The relationship between the compressive strength and the splitting tensile strength for SFOPSC at the age of 28 days was associated in Figure 2.6.

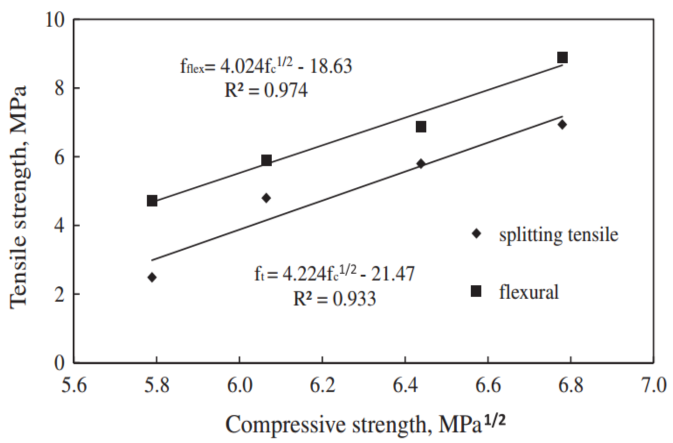


Figure 2.6: Relationship between tensile strength (splitting tensile and flexural strength) and compressive strength

Source: K. H. Mo *et al.* 2014

2.3.4 Flexural Strength Test

Steel fibers are generally found to have aggregate much greater effect on the flexural strength of steel fiber reinforced concrete (SFRC) than on either the compressive or tensile strength, with increases of more than 100% having been reported (Chanh). The increases in flexural strength is particularly sensitive, not only to the fiber volume, but also to the aspect ratio of the fibers, with higher aspect ratio leading to larger strength increases.

Fibers are added to concrete to improve the strength, but primarily to improve the toughness, or energy absorption capacity. Commonly, the flexural toughness is defined as the area under the complete load-deflection curve in flexure; this is sometimes referred to as the total energy to fracture. Alternatively, the toughness may be defined as the area under the load-deflection curve out to some particular deflection, or out to the point at which the load has fallen back to some fixed percentage of the peak load.

By increasing the fiber content of 0% to 1%, the 28 days flexural strength increased from 5.42 to 7.09 MPa, between 13.8 to 15.8% of the 28-day compressive strength. Compared with a mixture of L0, the rate of increase in flexural strength for L0.25, L0.5, L0.75 and L1 mixes is 17%, 15%, 18% and 31% respectively. This rate shows that the increase in the number of steel fiber up to 0.75%, almost the same effect on the increase in the flexural strength that shown in Figure 2.7. However, using the higher amounts of fiber (1%) led to a significant increase in flexural strength. Shi *et al*. reported that the addition of a small amount of fiber does not affect the flexural strength of lightweight concrete, but raise the ductility significantly. The lightweight concrete are reported in this study has a compressive strengths of 8-50 MPa with dry densities of 800-1400 kg / m^3 (P. Shafigh *et al*., 2011).

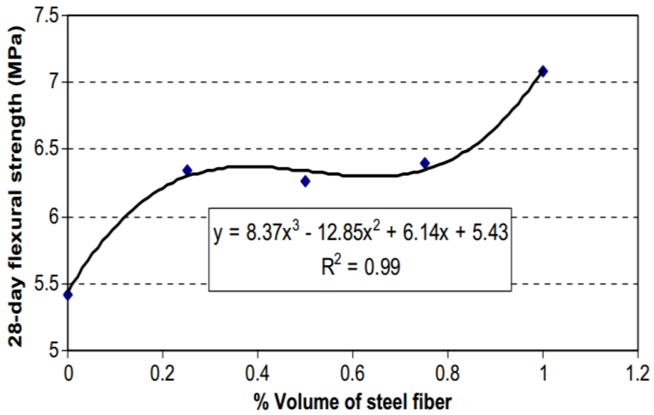


Figure 2.7: Relationship between flexural strength and steel fiber volume

Source: P. Shafigh *et al*. (2011)

2.3.5 Modulus of Elasticity (MOE)

The Modulus of Elasticity (MOE) is one of the most important material properties used in the design of concrete structures because it provides useful information on the ability of concrete to deform elastically. The 28 days MOE of OPSC was found to increase with the addition of steel fibers. The enhancement of MOE with the addition of steel fibers can be attributed to the effect of fiber shrinkage cracks original capture in concrete and the fiber enhanced the stress redistribution and reduced the local strain, thereby providing a steeper slope in the stress-strain curve. The increase of the MOE for mixes with 0.5%, 0.75% and 1.0% of steel fibers were found in about 10%, 52% and 58% respectively.

As can be seen from these results, the increase of the steel fiber from 0.75% to 1.0% had a negligible effect in improving the MOE of SFOPSC. It can be concluded that the use of 0.75% of the total consumption of steel fiber potential is maximized in the elastic stress transfer during the initial stages of SFOPSC. 0.75% of the total effectiveness of steel fibers in improving the MOE also reported by Kurugol *et al.*, albeit even though using a pumice stone as lightweight aggregate. As the MOE is a function of the compressive strength of concrete, as seen from Figure 2.8, a good correlation was established between the two parameters.

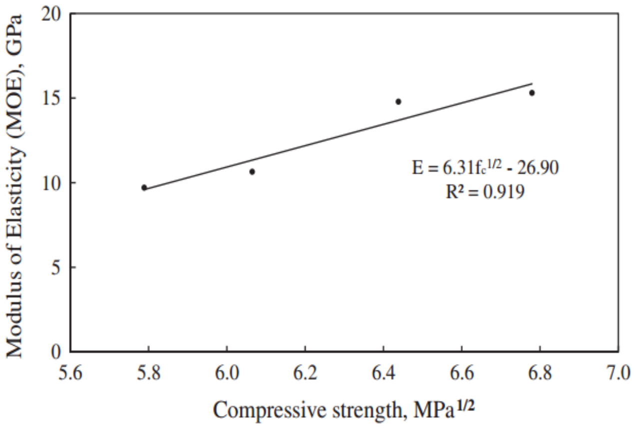


Figure 2.8: The relationship of 28-day MOE and compressive strength

Source: K. H. Mo *et al*., (2014)

2.4 APPLICATION TO STRUCTURE

Simple addition of short efficient natural low modulus fibers to cement matrix overcomes their brittle behaviour permitting a ductile behaviour in both compression and tensile tests, while retaining the very high strength of the cement paste. The composites of fiber-reinforcement improve the avoidance of bulk shattering required in the presence of the external load, and also improve its superiority in certain applications.

The uses of SFRC over the past thirty years have been so varied and so widespread, that it is difficult to categorize them. There has also been some recent experimental work on roller-compacted concrete (RCC) renforced with steel fibers. The list is endless, apparently limited only by the ingenuity of the engineers involved. The fibers themselves are, unfortunately, relatively expensive; a 1% steel fiber addition will approximately double the material costs of the concrete, and this has tended to limit use of SFRC to special applications.

The test on reinforced concrete slab using OPS concrete has been conducted. OPS concrete can replace concrete in all its normal usage especially when the OPSs are available in plenty as solid waste material, it can be used as concrete drains and for flooring of building. In this, a test on concrete slab of 125 mm thickness with reinforced 10 mm diameter high-yield steel (Type Y) at 300 mm cm^3 is tested and results are discussed. According to British Standards, the live load of 150 kg/m^2 has been considered for the design of this slab as a residential building. The slab is with 3100 mm span, 1000 mm width and 125 mm thick in size. The dial gauges have been set up to record the deflections for different amount of live loads (M. A. Mannan *et al*., 2004).

2.5 SUMMARY

Agricultural waste namely OPS is generated in large quantities in countries like Malaysia and this has been found as a useful replacement as coarse aggregate in concrete. OPS develops into a lightweight concrete and this can be used as a very cost effective construction material in many situations especially as precast concrete products in the areas where oil palm shells are in abundant supply. It can occupy about 40% of total volume of concrete saving the conventional construction material and has a great saving, economically, as the material is free of cost at production place. OPS concrete offers as a potential construction material and simultaneously solving the environmental problem of reduction in solid waste (M. A. Mannan et al., 2004).

The workability decreases by increasing the steel fiber ratio. The maximum reduction of about 82% was observed for OPS concrete with 1% steel fiber content. The compressive strength of OPS concrete increased at all ages with an increase in steel fiber. The effect of steel fiber on strength is more obvious at later ages, because of the better bond between the fiber and the matrix. The addition of steel fiber increases the splitting tensile strength significantly. The addition of steel fiber to OPS concrete does not have a significant effect on the modulus of elasticity. There is not many researchers make a research about the volume fraction of steel fiber and oil palm shells aggregate. From that, we can improve our knowledge if we can make a research about that volume fraction.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

Over the past years, the results of several research projects showed that by adding the discrete and randomly distributed steel fibers can improve the mechanical properties of concrete, such as compressive strength, tensile strength, flexural strength and modulus of elasticity (Ou *et al*., 2012). Therefore, the test that are conducted in this research are compressive strength test, tensile strength test, flexural strength test and modulus of elasticity test.

3.2 MATERIALS

3.2.1 Cement

Ordinary Portland Cement (OPC) is the most common type of cement. It is a fine powder produced by heating materials in a kiln to form what is called clinker, grinding the clinker, and adding small amounts of other materials. Several types of Portland cement are available with the most common being called ordinary Portland cement (OPC) which is grey in color, but a white Portland cement is also available. Figure 3.1 shows the Ordinary Portland Cement (OPC).

Figure 3.1: Ordinary Portland Cement (OPC)

3.2.2 Superplasticizer (SP)

Superplasticizers also known as high range water reducers, are chemical admixtures used where well-dispersed particle suspension is required. These polymers are used as dispersants to avoid particle segregation (coarse and fine sands), and to improve the flow characteristics of suspensions such as in concrete applications. Their addition to concrete or mortar allows the reduction of the water to cement ratio, not affecting the workability of the mixture, and enables the production of self-consolidating concrete and high performance concrete.This effect drastically improves the performance of the hardening fresh paste. The strength of concrete increases when the water to cement ratio decreases. However, their working mechanisms lack a full understanding, revealing in certain cases cement-superplasticizer incompatibilities. Figure 3.2 shows the superplasticizers.

Figure 3.2: Superplasticizer

3.2.3 Aggregates

Aggregates are inert granular materials such as sand, gravel or crushed stone that are an end product in their own right. They are also the raw materials that are an essential ingredient in concrete. For a good concrete mix, aggregates need to be clean, hard, strong particles free of absorbed chemicals or coatings of clay and other fine materials that could cause the deterioration of concrete. In this research, the size of coarse aggregates that will be used is 10 mm. Figure 3.3 and Figure 3.4 show the coarse aggregate and fine aggregate respectively.

Figure 3.3: Coarse aggregates

Figure 3.4: Fine aggregates

3.2.4 Oil Palm Shell (OPS)

OPS are collected from Kilang Sawit Panching, Kuantan, Pahang. It is obtained after the oil extraction in the factory from the fresh fruit bunch. The shells are air dry for one week . Then the OPS are need to be sieved to get the size of 5 mm to 14 mm. Figure 3.5 shows the OPS.

Figure 3.5: OPS

3.2.5 Steel Fiber (SF)

In this research, the types of steel fiber that is used is hooked-end steel fiber. This is because among the fibers, hooked-end steel fibers performs better than straight and crimped steel fibers in terms of flexural strengths and energy absorption capacities. The length of this steel fiber is 35 mm. Figure 3.6 shows the hooked-end steel fiber.

Figure 3.6: Hooked-end steel fiber

3.3 MIX PROPORTIONS

The two different mix designs with different W/C are used throughout this research. The mix design 1 (MD1) has W/C = 5.8 and mix design 2 (MD2) has W/C = 6.2. The mix designs are shown in Table 3.1.

Table 3.1: Two mix designs with different W/C

	WATER (kg/m^3)	**CEMENT (kg/m^3)**	**FINE AGGREGATE (kg/m^3)**	**COARSE AGGREGATE (kg/m^3)**
MD1	230	400	762	1011
MD2	215	345	875	985

The number of concrete batches are shown in Table 3.2. Each batch have 9 cubes, 3 cylinders and 3 prisms. The cube specimen is 100 mm x 100 mm x 100 mm. The prism specimen is 100 mm x 100 mm x 500 mm. The cylinder specimen is 150 mm in diameter and 300 mm in length. The hardened SF-OPSC are tested for compressive strength test, flexural strength test, splitting tensile test and modulus of elasticity.

Table 3.2: Number of concrete batches

No. of batch	Description
Batch 1-MD1	Plain Concrete; W/C = 0.58
Batch 2-MD1	SF (1%) + OPS (50%); W/C = 0.58
Batch 3-MD1	SF (1%) + OPS (100%); W/C = 0.58
Batch 1-MD2	Plain Concrete; W/C = 0.62
Batch 2-MD2	SF (1%) + OPS (50%); W/C = 0.62
Batch 3-MD2	SF (1%) + OPS (100%); W/C = 0.62

3.4 SPECIMEN PREPARATIONS

Concrete specimens of different batches from different mix designs must be sampled and analysed for the purpose of quality control. Tests are performed on concrete cube specimens, cylinder specimens and prism specimens to evaluate the compressive strength, flexural strength, splitting tensile strength and modulus of elasticity of the concrete. The cube moulds, cylinder moulds and prism moulds must be cleaned before used to ensure the quality of the concrete. The size of cube moulds are 100 mm x 100 mm x 100 mm and the size of cylinder moulds are 150 mm in diameter and 300 mm in length. The prism moulds are 100 mm x 100 mm x 500 mm in size. The moulds support the fresh concrete until it becomes hardened concrete.

The fresh concrete must be compacted so that it will flow into the inner part of the moulds and to prevent from the seggregation. Poker vibrator was used to compact the fresh concrete. Figure 3.7 shows the poker vibrator. Besides that, the other materials also need to be checked before casting for example the quantities of cement, water, fine aggregates, coarse aggregates, OPS, steel fiber and superplastisizer.

Figure 3.7: Poker vibrator

3.5 CURING

Curing can be described as keeping the concrete moist and warm enough so that the hydration of cement can continue. More elaborately, it can be described as the process of maintaining a satisfactory moisture content and a favorable temperature in concrete during the period immediately following placement, so that hydration of cement may continue until the desired properties are developed to a sufficient degree to meet the requirement of service. If curing is neglected in the early period of hydration, the quality of concrete will experience a sort of irreparable loss.

In this research, the curing with wet gunny bags is used. This is a widely used method of curing, particularly for structural concrete. Thus exposed surface of concrete is prevented from drying out by covering it with wet gunny bags. The covering over vertical and slopping surfaces should be secured properly. These are periodically wetted. The interval of wetting will depend upon the rate of evaporation of water. It should be ensured that the surface of concrete is not allowed to dry even for a short time during the curing period. Figure 3.8 shows the curing process using the wet gunny bags.

Figure 3.8: Curing process using wet gunny bags

3.6 MECHANICAL PROPERTIES TEST

3.6.1 Compressive Strength Test

Compressive strength test, mechanical test measuring the maximum amount of compressive load a material can bear before fracturing. The test piece, usually in the form of a cube, prism, or cylinder, is compressed between the platens of a compression-testing machine by a gradually applied load.

This test used the hardened SF-OPSC. The concrete is with the grade of 25 MPa. The size of cube is 100 mm x 100 mm x 100 mm. The Figure 3.9 shows the cube mould. Other than that, this test also used compression-testing machine. The compression-testing machine is shown in Figure 3.10.

Figure 3.9: Cube mould

Figure 3.10: Compression-testing machine

3.6.1.1 Procedure

Compressive strength test will be measured at 7 and 28 days in accordance with BS EN 12390-3:2009 : Compressive strength test for concrete specimens. The wet gunny cured specimens are tested at saturated state. Three specimens for each of the curing ages are tested to failure by crushing, and the average failure load is recorded. The average failure load of the specimens then divided by the area of the specimens to obtain the compressive strength.

3.6.2 Splitting Tensile Strength Test

The splitting tensile test is an indirect method and it is easier method to determine the tensile strength of concrete. The determination of tensile strength of concrete is required to provide the information about the maximum tensile load of concrete members that can sustain before it cracks.

This test used the hardened SF-OPSC. The concrete is with the grade of 25 MPa. The size of cylinder is 150 mm in diameter and 300 mm in height. Figure 3.11 shows the cylinder mould. Other than that, this test also used compression-testing machine. The compression-testing machine is shown in Figure 3.12.

Figure 3.11: Cylinder mould

Figure 3.12: Compression-testing machine

3.6.2.1 Procedure

The splitting tensile strength test is carried out on the concrete in accordance to BS EN 12390-5:2009 : Tensile strength test for concrete specimens. The specimens are cylinder with 150 mm in diameter and 300 mm in height. They were wet gunny cured for 7 and 28 days until the day of testing. The cylinders will be compressed on their sides with 600 kN that is determined by the Avery Denison Universal Testing machine.

3.6.3 Flexural Strength Test

Flexural strength, also known as modulus of rupture, bend strength, or fracture strength, a mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load. The transverse bending test is most frequently employed, in which a specimen having either a circular or rectangular cross-section is bent until fracture or yielding using a three point flexural test technique.

This test used the hardened SF-OPSC. The concrete is with the grade of 25 MPa. The size of prism is 100 mm x 100 mm in cross-section area and 500 mm in length. The prism specimen is shown in Figure 3.13.

Figure 3.13: Prism mould

3.6.3.1 Procedure

The flexural strength test is carried out on the concrete in accordance to BS EN 12390-6:2009 and C1 609/1609M-10 : Method for determination of flexural strength. Measure the weight and dimension of prism specimen. Indicate the location of supports and loading points on beam surface. Turn the test specimen on its side with respect to its position as moulded and center it on the support blocks. Grind, cap or use leather shims on the specimen contact surface to eliminate any gap in excess of 0.10 mm between the specimen and the load applying or support blocks. Load the specimen continuously and without shock until rupture occurs. Record the maximum load carried by the specimen during testing and measure the specimen cross section at one of the fractured faces. For each dimension of cross section, take one measurement at each edge and one at the center of the cross section. Use the three measurements for each direction to determine the average width and depth to the nearest 1 mm include the cap thickness if the fracture occurs at a capped section. The flexural test is conducted by using the flexural testing machine as shown in Figure 3.14.

Figure 3.14: Flexural Testing Machine

3.6.4 Modulus of Elasticity Test

The Modulus of Elasticity (MOE) is one of the most important material properties used in the design of concrete structures because it provides useful information on the ability of concrete to deform elastically.

This test used the hardened SF-OPSC. The concrete is with the grade of 25 MPa. The size of cylinder is 150 mm in diameter and 300 mm in height. Figure 3.15 shows the cylinder mould.

Figure 3.15: Cylinder mould

The apparatus that will be using in this test are the compression testing machine and strain measuring apparatus. The compression testing machine shall be comply with BS 1881-115. It must be capable of applying the loads at a specified rate and can maintain it at the required level. The strain measuring apparatus must have accurate level of ± 5 micro strain.

3.6.4.1 Procedure

The moulded test specimens shall be made, cured and stored in accordance with BS 1881-121:1983 : Method for determination of static modulus of elasticity in compression. For cylindrical specimens, finish the surface of the concrete level with the top of the mould while the concrete is still fresh and then press the top plate, coated with a thin film of mould oil, down on to the concrete with a rotary motion until it makes complete contact with the rim of that mould. Then, attach the top plate to the top of the mould and lay the mould, with top and base plates. Allow the concrete in cylinder mould to harden in a horizontal position until it will be removed from that mould. After that, specimens will be drilled as cores from a structure, stored and their ends prepared by grinding or capping in accordance with Part 120 of this standard.

To determine the static modulus of elasticity, the test specimens shall be placed with the measuring instruments or fixing points attached axially, centrally in the machine. Apply the basic stress of 0.5 N/mm^2 and then record the readings of strain gauge at each of measurement line. Increase the stress steadily at a constant rate within the range 0.6 ± 0.4 $N/(mm^2s)$ until the stress equal to one-third of the compressive strength of the concrete.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 COMPRESSIVE STRENGTH TEST

4.1.1 Compressive Strength Value

Table 4.1 shows that the compressive strength for each specimens of each type of mix designs. For mix design with W/C = 5.8, the compressive strength for each specimens were 27.92, 28.64, 25.83, 19.08, 17.51, 16.55, 18.42, 17.24 and 18.13 MPa for specimens B1 a, B1 b, B1 c, B2 a, B2 b, B2 c, B3 a, B3 b and B3 c respectively. For mix design with W/C = 6.2, the compressive strength for each specimens were 28.76, 29.96, 30.81, 19.46, 24.72, 18.67, 19.44, 19.41 and 19.56 MPa for specimens B1 a, B1 b, B1 c, B2 a, B2 b, B2 c, B3 a, B3 b and B3 c respectively. B1 presented the Batch 1 that consisted of 0% OPS, while B2 and B3 presented the Batch 2 and Batch 3 that consisted of 50% OPS and 100% OPS respectively.

Table 4.1: The compressive strength for each specimens

SPECIMENS	PERCENTAGE OF OPS (%)	COMPRESSIVE STRENGTH (MPa)	
		W/C = 5.8	**W/C = 6.2**
B1 a	0	27.92	28.76
B1 b	0	28.64	29.96
B1 c	0	25.83	30.81
B2 a	50	19.08	19.46
B2 b	50	17.51	24.72
B2 c	50	16.55	18.67
B3 a	100	18.42	19.44
B3 b	100	17.24	19.41
B3 c	100	18.13	19.56

Table 4.2 shows the average of compressive strength for each batches. For Batch 1, the average compressive strength for mix design of W/C = 5.8 was 27.46 MPa while for mix design of W/C = 6.2 was 29.80 MPa. For Batch 2, the average compressive strength for mix design of W/C = 5.8 was 17.71 MPa while for mix design of W/C = 6.2 was 20.95 MPa. For Batch 3, the average compressive strength for mix design of W/C = 5.8 was 17.93 MPa while for mix design of W/C = 6.2 was 19.45 MPa. These results were illustrated in the Figure 4.1. Figure 4.1 shows the average compressive strength versus the percentage of OPS.

Table 4.2: The average compressive strength for each batches

PERCENTAGE OF OPS (%)	AVERAGE COMPRESSIVE STRENGTH (MPa)	
	W/C = 5.8	**W/C = 6.2**
0	27.46	29.80
50	17.71	20.95
100	17.93	19.45

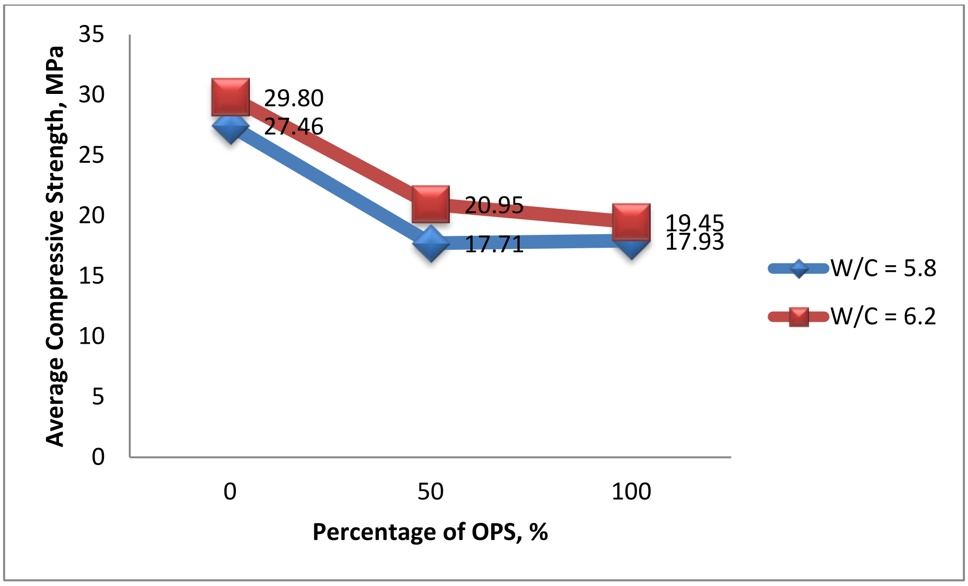


Figure 4.1: Average compressive strength versus the percentage of OPS

From that average compressive strength results for each batches in the Table 4.2, the difference in compressive strength between the two mix designs were calculated. The difference in compressive strength between the two mix designs have shown in the Table 4.3. These results were plotted in the bar chart in the Figure 4.2.

Table 4.3: The difference in compressive strength

PERCENTAGE OF OPS (%)	DIFFERENCE IN COMPRESSIVE STRENGTH (%)
0	7.84
50	15.45
100	7.81

Figure 4.2 shows the difference in compressive strength versus the percentage of OPS. For 0% OPS, the difference in compressive strength was 7.84%. For 50% OPS, the difference in compressive strength was 15.45% and for 100% OPS, the difference was 7.81 %. These results showed that the compressive strength of specimens from mix design of W/C = 6.2 had more higher value of compressive strength compared to the mix design of W/C = 5.8. So, the difference in compressive strength of SF-OPSC increased when the W/C increased.

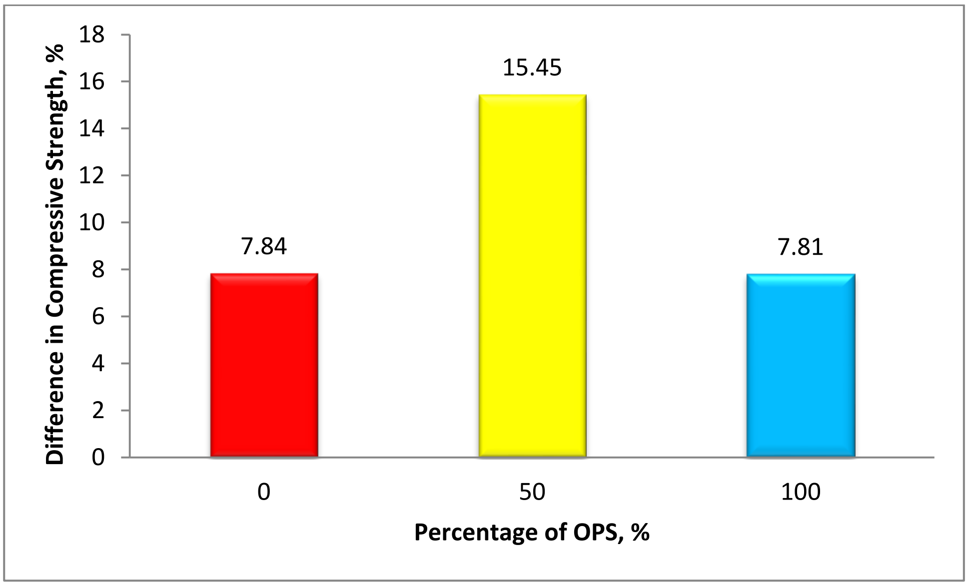


Figure 4.2: Difference in compressive strength versus the percentage of OPS

4.1.2 Mode of Failure

The compression failure pattern in SF-OPSC indicated that OPS aggregates and steel fibers governed the failure as observed by broken cube specimens. The failure was due to the breakdown in the bond between the OPS aggregate, cement and steel fibers. As can be seen in the result in the Table 4.2, the compressive strength of Batch 1 which is the plain concrete is the highest compared to the concrete with 50% OPS and 100%

OPS. It is the same with the concrete with W/C of 6.2 have the highest compressive strength than the concrete with 5.8 of W/C. This indicated that bond between the cement, OPS aggregates and the steel fibers was not strong. Figure 4.3, 4.4 and 4.5 show the cube specimens before testing and after the testing for Batch 1, 2 and 3.

Before testing　　　　After testing

Figure 4.3: Cube specimen for Batch 1

Before testing　　　　After testing

Figure 4.4: Cube specimen for Batch 2

Before testing　　　　Before testing

Figure 4.5: Cube specimen for Batch 3

4.2 FLEXURAL STRENGTH TEST

4.2.1 Flexural Strength Value

Table 4.4 shows that the flexural strength for each specimens of each type of mix designs. For mix design with W/C = 5.8, the flexural strength for each specimens were 6.37, 7.12, 6.62, 6.77, 7.29, 8.63, 7.55, 9.01 and 8.72 MPa for specimens B1 a, B1 b, B1 c, B2 a, B2 b, B2 c, B3 a, B3 b and B3 c respectively. For mix design with W/C = 6.2, the flexural strength for each specimens were 7.44, 8.02, 7.08, 0.00, 7.72, 9.65, 7.23, 8.93 and 6.81 MPa for specimens B1 a, B1 b, B1 c, B2 a, B2 b, B2 c, B3 a, B3 b and B3 c respectively. B1 presented the Batch 1 that consisted of 0% OPS, while B2 and B3 presented the Batch 2 and Batch 3 that consisted of 50% OPS and 100% OPS respectively.

Table 4.4: The flexural strength for each specimens

SPECIMENS	PERCENTAGE OF OPS (%)	FLEXURAL STRENGTH (MPa)	
		W/C = 5.8	W/C = 6.2
B1 a	0	6.37	7.44
B1 b	0	7.12	8.02
B1 c	0	6.62	7.08
B2 a	50	6.77	0.00
B2 b	50	7.29	7.72
B2 c	50	8.63	9.65
B3 a	100	7.55	7.23
B3 b	100	9.01	8.93
B3 c	100	8.72	6.81

Table 4.5 shows the average of flexural strength for each batches. For Batch 1, the average flexural strength for mix design of W/C = 5.8 was 6.70 MPa while for mix design of W/C = 6.2 was 7.51 MPa. For Batch 2, the average flexural strength for mix design of W/C = 5.8 was 7.56 MPa while for mix design of W/C = 6.2 was 8.69 MPa. For Batch 3, the average flexural strength for mix design of W/C = 5.8 was 8.43 MPa while for mix design of W/C = 6.2 was 7.66 MPa. These results were illustrated in the Figure 4.6. Figure 4.6 shows the average flexural strength versus the percentage of OPS.

Table 4.5: Average of flexural strength for each batches

PERCENTAGE OF OPS (%)	AVERAGE FLEXURAL STRENGTH (MPa)	
	W/C = 5.8	**W/C = 6.2**
0	6.70	7.51
50	7.56	8.69
100	8.43	7.66

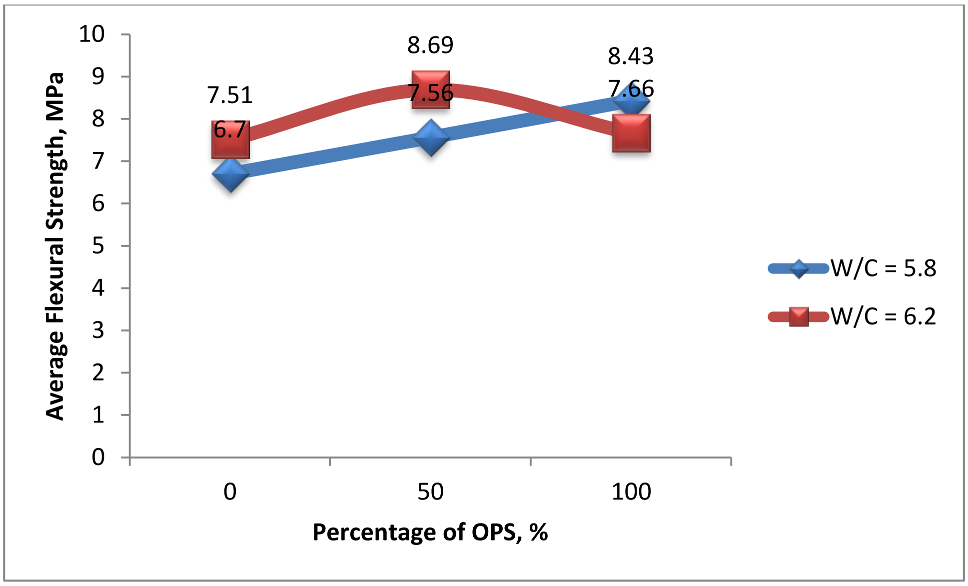


Figure 4.6: Average flexural strength versus the percentage of OPS

From that average flexural strength results for each batches in the Table 4.5, the difference in flexural strength between the two mix designs were calculated. The difference in flexural strength between the two mix designs have shown in the Table 4.6. These results were plotted in the bar chart in the Figure 4.7.

Table 4.6: Difference in flexural strength for each batches

PERCENTAGE OF OPS (%)	DIFFERENCE IN FLEXURAL STRENGTH (%)
0	10.79
50	13.00
100	-10.05

Figure 4.7 shows the difference in flexural strength versus the percentage of OPS. For 0% OPS, the difference in flexural strength was 10.79%. For 50% OPS, the difference in flexural strength was 13.00% and for 100% OPS, the difference was -

10.05%. These results showed that the flexural strength of specimens from mix design of W/C = 6.2 had more higher value of flexural strength compared to the mix design of W/C = 5.8 for 0% and 50% OPS but vise versa for 100% OPS. So, the difference in flexural strength of SF-OPSC increased when the W/C increased for plain concrete and 50% OPS while the difference in flexural strength of SF-OPSC decreased when the W/C increased for 100% OPS.

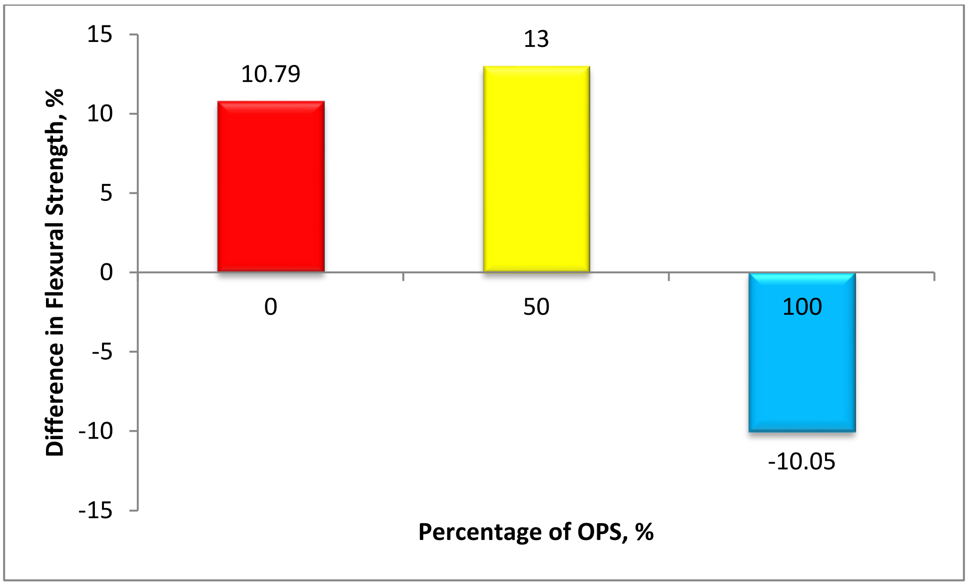


Figure 4.7: Difference in flexural strength versus percentage of OPS

4.2.2 Mode of Failure

The flexural failure pattern in SF-OPSC indicated that OPS aggregates and steel fibers governed the failure as observed by broken prism specimens. The failure was due to the breakdown in the bond between the OPS aggregate, cement and steel fibers. As can be seen in the result in the Table 4.5, the flexural strength of Batch 1 which is the plain concrete is the lowest compared to the concrete with 50% OPS and 100% OPS. It is the same with the concrete with W/C of 6.2 have the highest flexural strength than the concrete with 5.8 of W/C. This indicated that bond between the cement, OPS aggregates and the steel fibers was strong. Figure 4.8, 4.9 and 4.10 show the prism specimens before testing and after the testing for Batch 1,2 and 3.

Before testing   After testing

Figure 4.8: Prism specimen for Batch 1

Before testing   After testing

Figure 4.9: Prism specimen for Batch 2

Before testing   After testing

Figure 4.10: Prism specimen for Batch 3

4.3 SPLITTING TENSILE TEST

4.3.1 Splitting Tensile Strength Value

Table 4.7 shows that the splitting tensile strength for each specimens of each type of mix designs. For mix design with W/C = 5.8, the splitting tensile strength for each specimens were 1.87, 2.50, 1.71, 2.99, 2.22, 2.65, 1.93, 1.94 and 2.13 MPa for specimens B1 a, B1 b, B1 c, B2 a, B2 b, B2 c, B3 a, B3 b and B3 c respectively. For mix design with W/C = 6.2, the splitting tensile strength for each specimens were 2.02, 1.74, 2.34, 2.29, 2.60, 2.37, 1.85, 1.87 and 1.84 MPa for specimens B1 a, B1 b, B1 c, B2 a, B2 b, B2 c, B3 a, B3 b and B3 c respectively. B1 presented the Batch 1 that consisted of 0% OPS, while B2 and B3 presented the Batch 2 and Batch 3 that consisted of 50% OPS and 100% OPS respectively.

Table 4.7: Splitting tensile strength for each specimens

SPECIMENS	PERCENTAGE OF OPS (%)	SPLITTING TENSILE STRENGTH (MPa)	
		W/C = 5.8	**W/C = 6.2**
B1 a	0	1.87	2.02
B1 b	0	2.50	1.74
B1 c	0	1.71	2.34
B2 a	50	2.99	2.29
B2 b	50	2.22	2.60
B2 c	50	2.65	2.37
B3 a	100	1.93	1.85
B3 b	100	1.94	1.87
B3 c	100	2.13	1.84

Table 4.8 shows the average of splitting tensile strength for each batches. For Batch 1, the average splitting tensile strength for mix design of W/C = 5.8 was 2.03 MPa while for mix design of W/C = 6.2 was 2.03 MPa. For Batch 2, the average splitting tensile strength for mix design of W/C = 5.8 was 2.62 MPa while for mix design of W/C = 6.2 was 2.42 MPa. For Batch 3, the average splitting tensile strength for mix design of W/C = 5.8 was 2.00 MPa while for mix design of W/C = 6.2 was 1.86 MPa. These results were illustrated in the Figure 4.11. Figure 4.11 shows the average splitting tensile strength versus the percentage of OPS.

Table 4.8: Average of splitting tensile strength

PERCENTAGE OF OPS (%)	AVERAGE SPLITTING TENSILE STRENGTH (MPa)	
	W/C = 5.8	**W/C = 6.2**
0	2.03	2.03
50	2.62	2.42
100	2.00	1.86

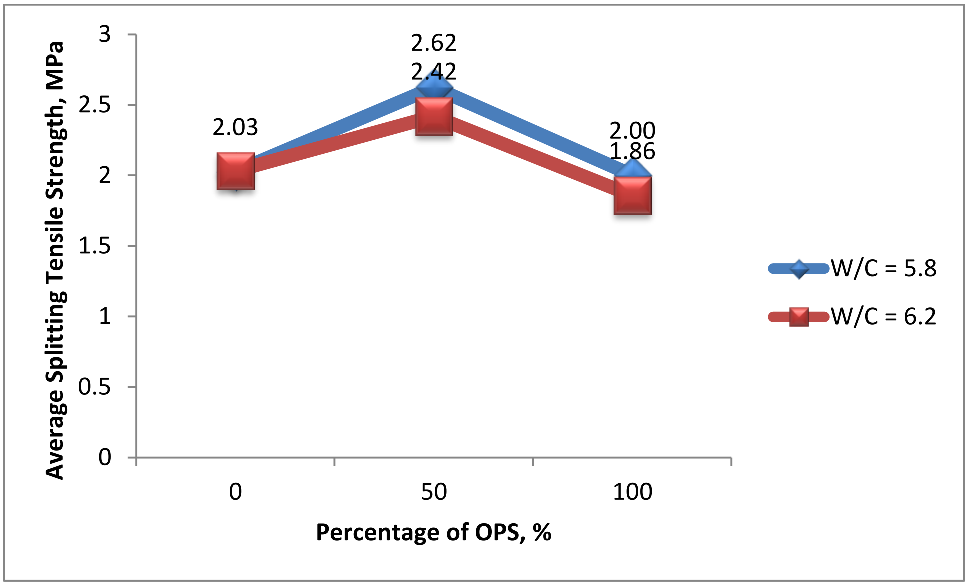


Figure 4.11: Average in splitting tensile strength versus percentage of OPS

From that average of splitting tensile strength results for each batches in the Table, the difference in splitting tensile strength between the two mix designs were calculated. The difference in splitting tensile strength between the two mix designs have shown in the Table 4.9. These results were plotted in the bar chart in the Figure 4.12.

Table 4.9: Difference in splitting tensile strength

PERCENTAGE OF OPS (%)	DIFFERENCE IN SPLITTING TENSILE STRENGTH (%)
0	0.00
50	-8.43
100	-7.81

Figure 4.24 shows the difference in splitting tensile strength versus the percentage of OPS. For 0% OPS, the difference in splitting tensile strength was 0.00%. For 50% OPS, the difference in splitting tensile strength was -8.43% and for 100%

OPS, the difference was -7.81%. These results showed that the splitting tensile strength of specimens from mix design of W/C = 6.2 had more higher value of splitting tensile strength compared to the mix design of W/C = 5.8 for 0% OPS but vise versa for 50% and 100% OPS. So, the difference in splitting tensile strength of SF-OPSC increased when the W/C increased for plain concrete while the difference in splitting tensile strength of SF-OPSC decreased when the W/C increased for 50% and 100% OPS.

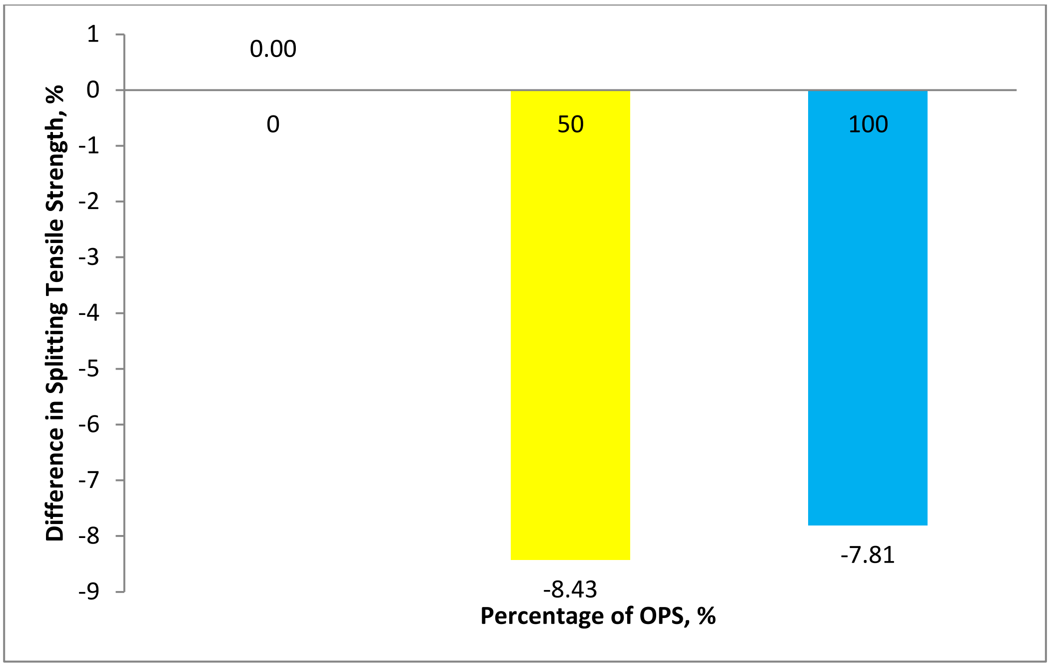
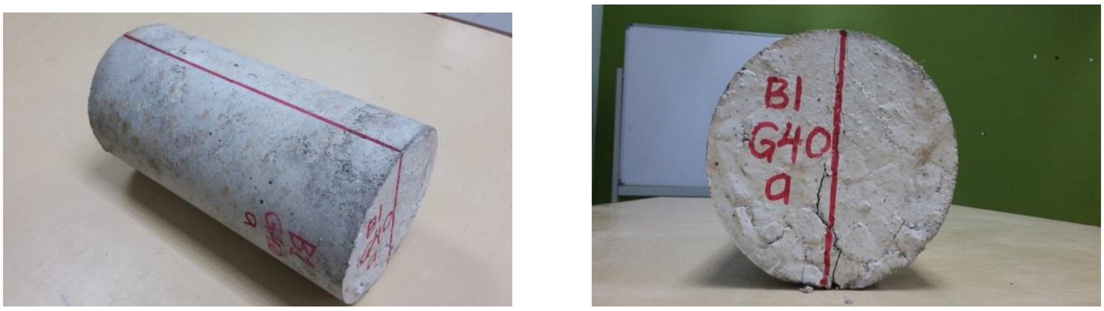


Figure 4.12: Difference in splitting tensile strength versus percentage of OPS

4.3.2 Mode of Failure

The splitting tensile failure pattern in SF-OPSC indicated that OPS aggregates and steel fibers governed the failure as observed by broken cylinder specimens. The failure was due to the breakdown in the bond between the OPS aggregate, cement and steel fibers. As can be seen in the result in the Table 4.8, the splitting tensile strength of Batch 2 which is the 50% coarse aggregate replacement with OPS aggregates is the highest compared to the plain concrete and 100% OPS. It is the same with the concrete with W/C of 5.8 have the highest splitting tensile strength than the concrete with 6.2 of W/C. This indicated that bond between the cement, OPS aggregates and the steel fibers was strong. Figure 4.13, 4.14 and 4.15 show the cylinder specimens before testing and after the testing for Batch 1, 2 and 3..



Before testing After testing

Figure 4.13: Cylinder specimen for Batch 1

Before testing After testing

Figure 4.14: Cylinder specimen for Batch 2

Before testing After testing

Figure 4.15: Cylinder specimen for Batch 3

4.4 MODULUS OF ELASTICITY TEST

4.4.1 Modulus of Elasticity Value

The data from this research are collected and the stress for this test was calculated. The equation for the stress is expressed as in Eq. (4.1)

$$\sigma = \frac{F}{A} \tag{4.1}$$

A indicates the area of the cylinder which is 17671.459 mm^2. For Batch 1 of W/C = 5.8, the data of stress is shown in Table 4.10.

Table 4.10: Data of load, stress and strain (Batch 1; W/C = 5.8)

TIME (sec)	LOAD (kN)	STRAIN	STRESS (N/mm2)
0	-2.512	0	-0.142
1	-0.047	0	-0.003
2	3.954	-7	0.224
3	6.792	-15	0.384
4	12.794	-18	0.724
5	13.305	-26	0.753
6	18.842	-35	1.066
7	26.657	-46	1.508
8	33.403	-58	1.890
9	42.475	-73	2.404
10	52.105	-87	2.949
11	59.921	-99	3.391
12	65.922	-110	3.730
13	66.62	-140	3.770
14	82.717	-167	4.681
15	94.301	-194	5.336
16	103.838	-232	5.876
17	116.399	-274	6.587
18	130.123	-320	7.363
19	138.916	-400	7.861
20	156.502	-511	8.856
21	178.832	-662	10.120
22	203.746	-873	11.530
23	231.515	-1156	13.101
24	259.892	-1481	14.707
25	286.256	-1816	16.199
26	310.185	-2135	17.553
27	329.572	-2335	18.650

28	345.633	-2304	19.559
29	362.959	-2172	20.539
30	379.396	-2041	21.469
31	394.334	-1817	22.315
32	407.148	-1402	23.040
33	416.865	-1093	23.590
34	422.144	-946	23.888
35	424.901	-879	24.044
36	422.471	-3602	23.907
37	414.015	-13156	23.428
38	401.775	-13156	22.736
39	384.219	-13156	21.742
40	365.535	-13156	20.685
41	336.642	-13156	19.050
42	295.247	-13156	16.708

From the stress and strain data in Table 4.10, the graph of stress versus strain can be plotted as shown in Figure 4.16.

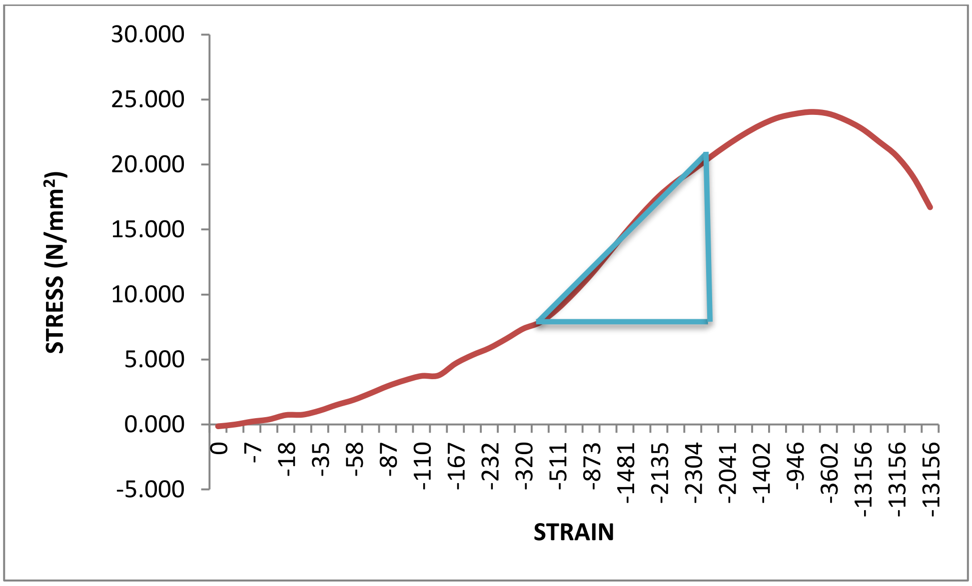


Figure 4.16: Stress versus strain (Batch 1; W/C = 5.8)

Based on the Figure 4.16, the value of Modulus of Elasticity can be calculated from the value in the graph. The value from the graph is shown in Table 4.11.

Table 4.11: Points from graph stress versus strain (Batch 1; W/C = 5.8)

POINT	**VALUE**
y_2	20.54 N/mm^2
y_1	7.86 N/mm^2
x_2	-2172
x_1	-400

The value of Modulus of Elasticity can be calculated by using the Eq. (4.2)

$$E = \frac{\sigma}{\varepsilon} \quad (4.2)$$

So, from the Eq. (4.2), the value of Modulus of Elasticity is -0.01 N/mm^2.

The data from this research are collected and the stress for this test was calculated. The stress are calculated by using the Eq. (4.1) and the value for Batch 1 of W/C = 6.2 is shown in Table 4.12.

Table 4.12: Data of load, stress and strain (Batch 1; W/C = 6.2)

TIME (sec)	**LOAD (kN)**	**STRAIN**	**STRESS (N/mm^2)**
0	-2.233	0	-0.126
1	3.815	0	0.216
2	12.421	-3	0.703
3	22.563	-2	1.277
4	35.078	7	1.985
5	49.267	23	2.788
6	36.52	27	2.067
7	49.546	33	2.804
8	69.784	41	3.949
9	89.928	47	5.089
10	112.305	47	6.355
11	136.125	43	7.703
12	159.665	36	9.035
13	182.694	26	10.338
14	205.011	9	11.601
15	226.879	-12	12.839
16	246.453	-39	13.946

17	264.95	-67	14.993
18	282.65	-94	15.995
19	297.542	-119	16.837
20	307.563	-138	17.405
21	315.945	-175	17.879
22	328.775	-228	18.605
23	339.312	-273	19.201
24	346.242	-310	19.593
25	351.206	-344	19.874
26	352.236	-366	19.932
27	346.429	-372	19.604
28	339.546	-390	19.214
29	330.649	-419	18.711
30	318.52	-452	18.025
31	305.362	-459	17.280
32	292.156	-446	16.533
33	274.924	-392	15.558
34	252.306	-242	14.278
35	228.377	-56	12.923

From the stress and strain data in Table 4.12, the graph of stress versus strain can be plotted as shown in Figure 4.17.

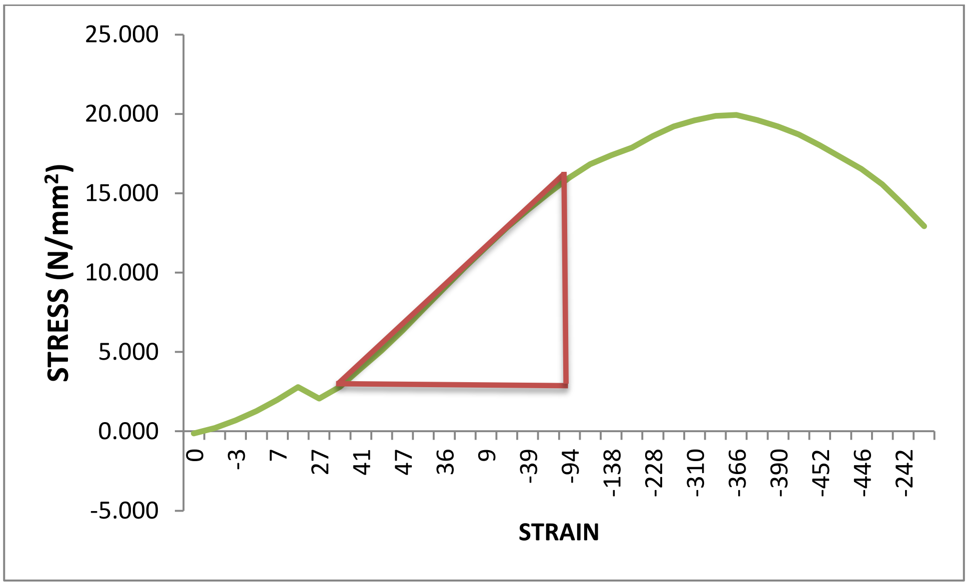


Figure 4.17: Stress versus strain (Batch 1; W/C = 6.2)

Based on the Figure 4.17, the value of Modulus of Elasticity can be calculated from the value in the graph. The value from the graph is shown in Table 4.13.

Table 4.13: Points from graph stress versus strain (Batch 1; W/C = 6.2)

POINT	VALUE
y_2	16.00 N/mm^2
y_1	2.80 N/mm^2
x_2	-94
x_1	33

The value of Modulus of Elasticity can be calculated by using the Eq. (4.2). So, from the Eq. (4.2), the value of Modulus of Elasticity is -0.10 N/mm^2.

The data from this research are collected and the stress for this test was calculated. The stress are calculated by using the Eq. (4.1) and the value for Batch 2 of W/C = 5.8 is shown in Table 4.14.

Table 4.14: Data of load, stress and strain (Batch 2; W/C = 5.8)

TIME (sec)	LOAD (kN)	STRAIN	STRESS (N/mm2)
0	-2.559	0	-0.145
1	-1.721	0	-0.097
2	-0.837	-2	-0.047
3	0.093	-8	0.005
4	1.117	-9	0.063
5	2.14	-15	0.121
6	3.303	-25	0.187
7	4.606	-35	0.261
8	6.141	-46	0.348
9	8.374	-58	0.474
10	10.84	-69	0.613
11	13.352	-81	0.756
12	15.957	-93	0.903
13	18.562	-106	1.050
14	21.726	-122	1.229
15	24.703	-140	1.398
16	28.053	-159	1.587
17	31.868	-181	1.803
18	36.241	-206	2.051

19	41.265	-235	2.335
20	46.802	-270	2.648
21	52.803	-307	2.988
22	59.502	-345	3.367
23	67.271	-387	3.807
24	75.599	-429	4.278
25	84.066	-472	4.757
26	93.557	-517	5.294
27	102.582	-561	5.805
28	111.654	-609	6.318
29	120.4	-661	6.813
30	129.518	-720	7.329
31	138.404	-790	7.832
32	147.895	-866	8.369
33	157.246	-946	8.898
34	167.341	-1026	9.470
35	177.39	-1107	10.038
36	187.672	-1188	10.620
37	197.767	-1264	11.191
38	208.007	-1341	11.771
39	217.56	-1436	12.311
40	226.458	-1516	12.815
41	234.84	-1600	13.289
42	242.426	-1701	13.719
43	249.824	-1808	14.137
44	256.755	-1929	14.529
45	263.638	-2034	14.919
46	269.679	-2102	15.261
47	275.439	-2160	15.587
48	280.543	-2232	15.875
49	284.477	-2283	16.098
50	287.848	-2076	16.289
51	290.049	-2033	16.413
52	291.173	-1997	16.477
53	291.267	-1976	16.482
54	290.19	-1954	16.421
55	288.41	-1936	16.321
56	285.366	-1919	16.148
57	281.527	-1894	15.931
58	276.937	-1864	15.671
59	272.348	-1833	15.412
60	267.197	-1808	15.120
61	261.906	-6694	14.821
62	256.755	-16520	14.529
63	251.276	-16520	14.219

64	245.891	-16520	13.915
65	239.71	-16520	13.565
66	233.528	-16520	13.215
67	227.066	-16520	12.849
68	220.651	-16520	12.486
69	214.189	-16520	12.121
70	207.586	-16520	11.747
71	200.796	-16520	11.363
72	194.324	-16520	10.996
73	187.672	-16520	10.620
74	179.995	-16520	10.186

From the stress and strain data in Table 4.14, the graph of stress versus strain can be plotted as shown in Figure 4.18.

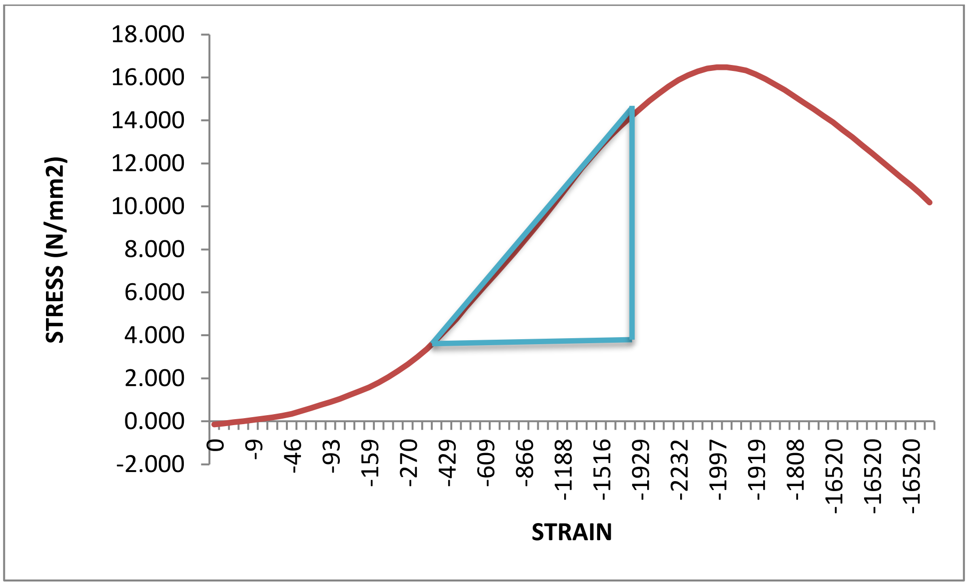


Figure 4.18: Stress versus strain (Batch 2; W/C = 5.8)

Based on the Figure 4.18, the value of Modulus of Elasticity can be calculated from the value in the graph. The value from the graph is shown in Table 4.15.

Table 4.15: Points from graph stress versus strain (Batch 2; W/C = 5.8)

POINT	VALUE
y_2	14.14 N/mm^2
y_1	3.37 N/mm^2
x_2	-1808
x_1	-345

The value of Modulus of Elasticity can be calculated by using the Eq. (4.2). So, from the Eq. (4.2), the value of Modulus of Elasticity is -0.01 N/mm^2.

The data from this research are collected and the stress for this test was calculated. The stress are calculated by using the Eq. (4.1) and the value for Batch 2 of W/C = 6.2 is shown in Table 4.16.

Table 4.16: Data of load, stress and strain (Batch 2; W/C = 6.2)

TIME (sec)	LOAD (kN)	STRAIN	STRESS (N/mm^2)
0	-2.28	0	-0.129
1	4.513	0	0.255
2	6.978	-11	0.395
3	11.072	-25	0.627
4	15.445	-42	0.874
5	20.423	-61	1.156
6	25.913	-83	1.466
7	31.728	-108	1.795
8	38.241	-134	2.164
9	45.685	-169	2.585
10	53.733	-206	3.041
11	62.107	-245	3.515
12	70.761	-291	4.004
13	80.112	-341	4.533
14	89.323	-396	5.055
15	98.953	-451	5.600
16	109.281	-508	6.184
17	120.307	-569	6.808
18	131.333	-633	7.432
19	143.289	-703	8.108
20	154.641	-780	8.751
21	165.853	-866	9.385

22	176.599	-961	9.993
23	186.834	-1065	10.573
24	196.139	-1175	11.099
25	204.917	-1272	11.596
26	213.205	-1361	12.065
27	220.745	-1446	12.492
28	227.956	-1530	12.900
29	234.418	-1543	13.265
30	240.553	-1503	13.613
31	246.031	-1483	13.923
32	251.089	-1371	14.209
33	255.537	-1325	14.460
34	259.424	-1307	14.680
35	263.077	-1265	14.887
36	266.074	-1194	15.057
37	268.93	-1122	15.218
38	271.084	-1074	15.340
39	273.332	-1025	15.467
40	275.018	-979	15.563
41	276.516	-926	15.648
42	277.874	-913	15.724
43	278.67	-888	15.769
44	279.607	-813	15.823
45	280.028	-653	15.846
46	280.543	-587	15.875
47	280.637	-410	15.881
48	280.824	-346	15.891
49	280.824	-297	15.891
50	280.496	-259	15.873
51	280.309	-217	15.862
52	279.7	-171	15.828
53	279.279	-138	15.804
54	278.53	-137	15.762
55	277.687	-121	15.714
56	276.844	-91	15.666
57	275.72	-62	15.603
58	274.596	-22	15.539
59	273.238	30	15.462
60	272.114	111	15.399
61	270.475	189	15.306
62	268.977	216	15.221
63	267.525	312	15.139
64	265.886	376	15.046
65	264.294	490	14.956
66	262.234	654	14.839

67	260.501	777	14.741
68	258.394	-180	14.622
69	256.474	-15808	14.513
70	254.413	-15808	14.397
71	252.259	-15808	14.275
72	250.293	-15808	14.164
73	247.998	-15808	14.034
74	246.078	-15808	13.925
75	243.737	-15808	13.793
76	241.489	-15808	13.665
77	238.633	-15808	13.504
78	236.385	-15808	13.377
79	233.856	-15808	13.234
80	231.421	-15808	13.096
81	229.033	-15808	12.961
82	226.504	-15808	12.818
83	224.21	-15808	12.688
84	221.494	-15808	12.534
85	219.059	-15808	12.396
86	216.53	-15808	12.253
87	214.095	-15808	12.115
88	211.379	-15808	11.962
89	208.85	-15808	11.818
90	206.228	-15808	11.670
91	203.559	-15808	11.519
92	200.843	-15808	11.365
93	198.186	-15808	11.215
94	195.813	-15808	11.081
95	193.115	-15808	10.928
96	190.742	-15808	10.794
97	188.044	-15808	10.641
98	185.485	-15808	10.496
99	183.019	-15808	10.357
100	180.786	-15808	10.230
101	178.321	-15808	10.091
102	175.901	-15808	9.954
103	173.668	-15808	9.828
104	171.435	-15808	9.701
105	169.063	-15808	9.567

From the stress and strain data in Table 4.16, the graph of stress versus strain can be plotted as shown in Figure 4.19.

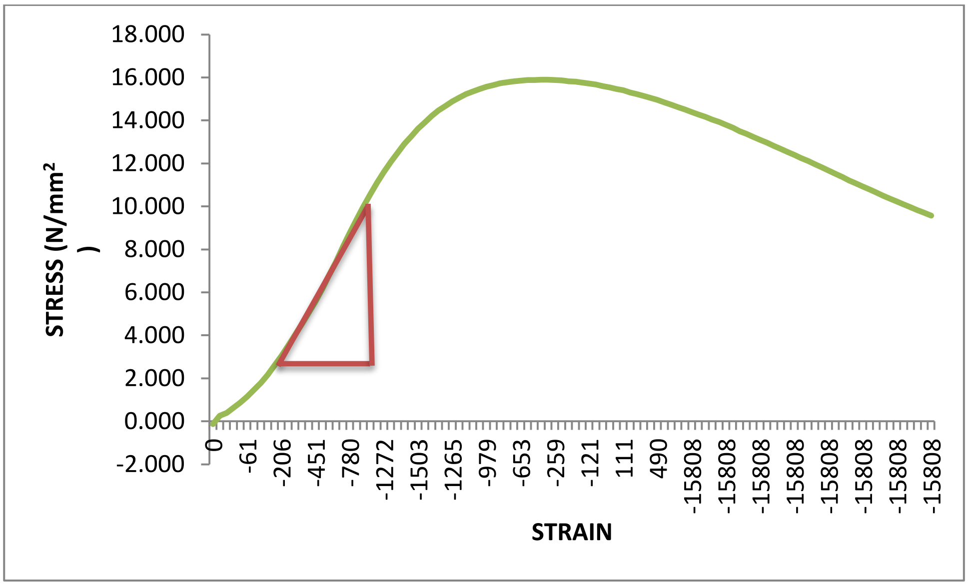


Figure 4.19: Stress versus strain (Batch 2; W/C = 6.2)

Based on the Figure 4.19, the value of Modulus of Elasticity can be calculated from the value in the graph. The value from the graph is shown in Table 4.17.

Table 4.17: Points from graph stress versus strain (Batch 2; W/C = 6.2)

POINT	VALUE
y_2	9.993 N/mm^2
y_1	2.585 N/mm^2
x_2	-961
x_1	-169

The value of Modulus of Elasticity can be calculated by using the Eq. (4.2). So, from the Eq. (4.2), the value of Modulus of Elasticity is -0.01 N/mm^2.

The data from this research are collected and the stress for this test was calculated. The stress are calculated by using the Eq. (4.1) and the value for Batch 3 of W/C = 5.8 is shown in Table 4.18.

Table 4.18: Data of load, stress and strain (Batch 3; W/C = 5.8)

TIME (sec)	LOAD (kN)	STRAIN	STRESS (N/mm2)
0	-2.559	0	-0.145
1	-1.396	0	-0.079
2	0.372	-26	0.021
3	2.419	-57	0.137
4	4.699	-93	0.266
5	7.444	-133	0.421
6	10.747	-176	0.608
7	14.655	-221	0.829
8	19.214	-272	1.087
9	24.61	-327	1.393
10	31.403	-389	1.777
11	38.288	-455	2.167
12	45.778	-528	2.591
13	53.78	-609	3.043
14	62.573	-700	3.541
15	71.738	-797	4.060
16	81.693	-902	4.623
17	92.021	-1015	5.207
18	102.21	-1142	5.784
19	112.445	-1283	6.363
20	122.726	-1440	6.945
21	133.054	-1615	7.529
22	142.87	-1806	8.085
23	151.942	-2014	8.598
24	160.363	-2234	9.075
25	167.574	-2456	9.483
26	173.901	-2673	9.841
27	179.018	-2844	10.130
28	183.252	-2835	10.370
29	186.276	-2734	10.541
30	188.695	-2588	10.678
31	190.044	-2377	10.754
32	190.882	-2277	10.802
33	191.161	-3737	10.817
34	191.254	-16207	10.823
35	191.068	-16207	10.812
36	190.463	-16207	10.778
37	189.532	-16207	10.725
38	188.044	-16207	10.641
39	186.695	-16207	10.565
40	185.02	-16207	10.470
41	183.438	-16207	10.380

42	181.391	-16207	10.265
43	179.484	-16207	10.157
44	177.251	-16207	10.030
45	175.11	-16207	9.909
46	172.691	-16207	9.772
47	170.226	-16207	9.633
48	167.62	-16207	9.485
49	164.922	-16207	9.333
50	162.084	-16207	9.172
51	159.293	-16207	9.014
52	156.502	-16207	8.856
53	153.617	-16207	8.693
54	150.686	-16207	8.527
55	147.569	-16207	8.351
56	144.545	-16207	8.180
57	141.428	-16207	8.003
58	138.404	-16207	7.832
59	135.241	-16207	7.653
60	132.263	-16207	7.485
61	129.053	-16207	7.303
62	125.89	-16207	7.124
63	122.587	-16207	6.937
64	119.33	-16207	6.753
65	116.027	-16207	6.566

From the stress and strain data in Table 4.18, the graph of stress versus strain can be plotted as shown in Figure 4.20.

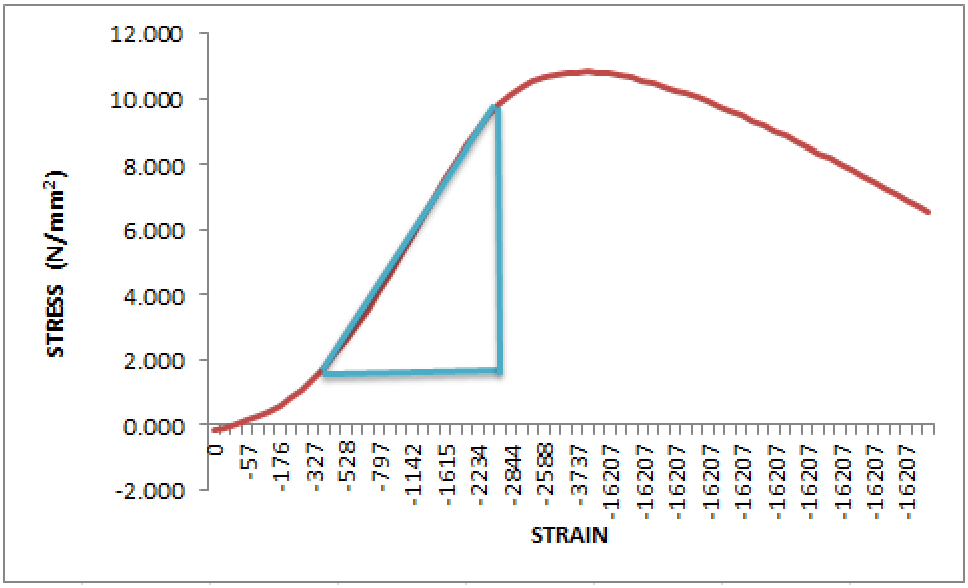


Figure 4.20: Stress versus strain (Batch 3; W/C = 5.8)

Based on the Figure 4.20, the value of Modulus of Elasticity can be calculated from the value in the graph. The value from the graph is shown in Table 4.19.

Table 4.19: Points from graph stress versus strain (Batch 3; W/C = 5.8)

POINT	VALUE
y_2	9.48 N/mm^2
y_1	1.39 N/mm^2
x_2	-2456
x_1	-327

The value of Modulus of Elasticity can be calculated by using the Eq. (4.2). So, from the Eq. (4.2), the value of Modulus of Elasticity is 0.00 N/mm^2.

The data from this research are collected and the stress for this test was calculated. The stress are calculated by using the Eq. (4.1) and the value for Batch 3 of W/C = 6.2 is shown in Table 4.20.

Table 4.20: Data of load, stress and strain (Batch 3; W/C = 6.2)

TIME (sec)	LOAD (kN)	STRAIN	STRESS (N/mm^2)
0	-2.419	0	-0.137
1	0.326	0	0.018
2	2	-34	0.113
3	4.42	-67	0.250
4	6.932	-105	0.392
5	10.235	-147	0.579
6	13.445	-195	0.761
7	16.934	-247	0.958
8	20.796	-307	1.177
9	25.262	-373	1.430
10	30.007	-442	1.698
11	34.892	-510	1.974
12	40.149	-583	2.272
13	45.639	-656	2.583
14	51.547	-729	2.917
15	57.362	-807	3.246
16	63.829	-892	3.612
17	70.202	-982	3.973
18	77.227	-1078	4.370
19	84.206	-1182	4.765
20	91.649	-1293	5.186
21	98.814	-1409	5.592
22	106.211	-1537	6.010
23	113.05	-1668	6.397
24	120.121	-1803	6.797
25	126.774	-1939	7.174
26	133.426	-2088	7.550
27	139.521	-2246	7.895
28	145.569	-2266	8.238
29	151.105	-2154	8.551
30	156.455	-2103	8.854
31	161.2	-2090	9.122
32	165.48	-2079	9.364
33	169.202	-1702	9.575
34	172.552	-1581	9.764
35	175.343	-1491	9.922
36	177.669	-1417	10.054
37	179.67	-1352	10.167
38	181.065	-1297	10.246
39	182.321	-1222	10.317
40	183.066	-1143	10.359
41	183.717	-1012	10.396

42	183.903	-886	10.407
43	184.136	-764	10.420
44	184.182	-650	10.423
45	184.136	-555	10.420
46	183.764	-483	10.399
47	183.531	-419	10.386
48	182.926	-358	10.351
49	182.368	-296	10.320
50	181.67	-203	10.280
51	180.926	-124	10.238
52	179.949	-63	10.183
53	178.832	-22	10.120
54	177.809	1	10.062
55	176.646	25	9.996
56	175.669	49	9.941
57	174.413	66	9.870
58	173.436	72	9.814
59	172.505	74	9.762
60	171.575	75	9.709
61	170.226	80	9.633
62	169.016	78	9.564
63	167.388	74	9.472
64	165.946	66	9.391
65	164.131	57	9.288
66	162.503	45	9.196
67	160.595	28	9.088
68	158.967	18	8.996
69	157.199	1	8.896
70	155.571	-16	8.804
71	153.431	-35	8.682
72	151.431	-56	8.569
73	149.244	-77	8.445
74	146.964	-101	8.316
75	144.638	-122	8.185
76	142.266	-139	8.051
77	140.033	-155	7.924
78	137.66	-166	7.790
79	135.473	-181	7.666
80	133.054	-194	7.529
81	131.007	-201	7.413
82	128.867	-210	7.292
83	126.681	-222	7.169
84	124.541	-233	7.048
85	122.308	-239	6.921
86	120.074	-248	6.795

87	118.027	-247	6.679
88	115.887	-243	6.558
89	113.887	-218	6.445
90	111.933	-211	6.334

From the stress and strain data in Table 4.20, the graph of stress versus strain can be plotted as shown in Figure 4.21.

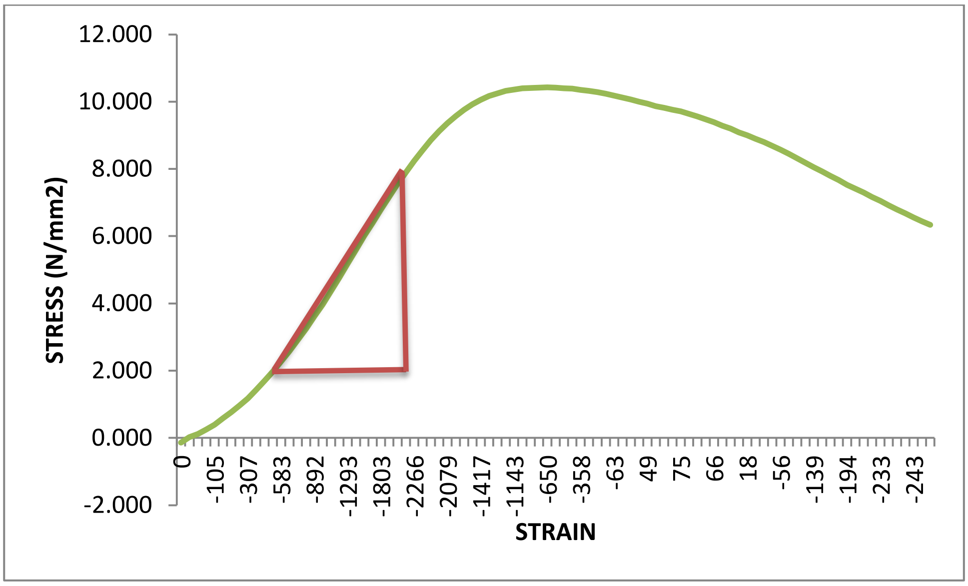


Figure 4.21: Stress versus strain (Batch 3; W/C = 6.2)

Based on the Figure 4.21, the value of Modulus of Elasticity can be calculated from the value in the graph. The value from the graph is shown in Table 4.21.

Table 4.21: Points from graph stress versus strain (Batch 3; W/C = 6.2)

POINT	VALUE
y_2	7.550 N/mm^2
y_1	1.698 N/mm^2
x_2	-2088
x_1	-442

The value of Modulus of Elasticity can be calculated by using the Eq. (4.2). So, from the Eq. (4.2), the value of Modulus of Elasticity is 0.00 N/mm^2.

4.4.2 Mode of Failure

The modulus of elasticity failure pattern in SF-OPSC indicated that OPS aggregates and steel fibers governed the failure as observed by broken cylinder specimens. The failure was due to the breakdown in the bond between the OPS aggregate, cement and steel fibers. As can be seen from the result of modulus of elasticity, the modulus of elasticity of all batch is quite same. The result of the SF-OPSC with W/C of 5.8 is quite same with the result of the SF-OPSC with W/C of 6.2. This indicated that bond between the cement, OPS aggregates and the steel fibers was not strong. Figure 4.22, 4.23 and 4.24 show the cylinder specimens before testing and after the testing for Batch 1, 2 and 3.

Before testing

After testing

Figure 4.22: Cylinder specimen for Batch 1

Before testing

After testing

Figure 4.23: Cylinder specimen for Batch 2

Before testing

After testing

Figure 4.24: Cylinder specimen for Batch 3

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be made regarding the outcomes from this research.

1. It can be concluded that the different mix designs with different W/C affecting the mechanical behaviour of SF-OPSC. The effect of different mix designs to the behaviour of SF-OPSC is determined.
2. The difference in compressive strength of SF-OPSC increased when the W/C increased by 7.84% for plain concrete, 15.45% for 50% OPS and 7.81% for 100% OPS. The difference in flexural strength of SF-OPSC increased when the W/C increased by 10.79% for plain concrete and 13% for 50% OPS while flexural strength decreased by 10.05% for 100% OPS. The difference in splitting tensile strength for plain concrete increased by 0.00% when the W/C increased but it decreased by 8.43% when the W/C increased for 50% OPS and decreased by 7.81% for 100% OPS. For modulus of elasticity, there is no significant effect from the different of W/C as the result for Batch 1 are 0.00% and it is the same for Batch 2 and Batch 3.

The following recommendations can be used to produce the high quality of concrete.

i. The coarse aggregate and fine aggregate should be sieved.
ii. For a good concrete mix, aggregates need to be clean, hard, strong particles free of absorbed chemicals or coatings of clay and other fine materials that could cause the deterioration of concrete. The OPS should be dried more longer to ensure that the OPS is really dry.

REFERENCES

Chen G.M., He Y.H., Yang H., Chen J.F., Chen Y.C. 2014. Compressive behaviour of steel fiber reinforced recycled aggregate concrete after exposure to elevated temperatures. *Journal of Construction and Building materials.* 71 (2014) 1-15.

Mannan M. A., Ganapathy C. 2004. Concrete from an agricultural waste-oil palm shell (OPS). *Journal of Building and Environment*. 39 (2004) 441 – 448.

Mo K.H., Yap K. H. Q., Alengaram U. J., Jumaat M Z. 2014. The effect of steel fibres on the enhancement of flexural and compressive toughness and fracture characteristics of oil palm shell concrete. *Journal of Construction and Building Materials*. 55 (2014) 20–28.

Oh B. H., Kim J. C., Choi Y. C. 2007. Fracture Behaviour of Concrete Members Reinforced with Structural Synthetic Fibers. *Journal of Engineering Fracture Mechanics.* 74 (2007) 243-257.

Ou Y. C., Tsai M. S., Liu K. Y., Chang K. C. 2012. Compressive Behaviour of Steel-Fiber-Reinforced Concrete with a High Reinforcing Index. *Journal of Materials in Civil Engineering.* 24 (2012) 207-215.

Shafigh P., Jumaat M. Z., Mahmud H., Abdul Hamid N. A. 2012. Lightweight concrete made from crushed oil palm shell : Tensile strength and effect of initial curing on compressive strength. *Journal of Construction and Building Materials.* 27 (2012) 252 – 258.

Shafigh P., Mahmud H., Jumaat M. Z. 2011. Effect of steel fiber on the mechanical properties of oil palm shell lightweight concrete. *Journal of Material and Design.* 32 (2011); 3926–3932.

Tadepalli P. R. 2009. Mechanical properties of steel fiber reinforced concrete beams. *Journal of Structures 2009.*

Testing Concrete, Method for Determination of Static Modulus of Elasticity in Compression. 1983. BS 1881-121:1983. British Standard Institute.

Testing Hardened Concrete, Compressive Strength of Test Specimens. 2009. BS EN 12390-3:2009. British Standard Institute.

Testing Hardened Concrete, Flexural Strength of Test Specimens. 2009. BS EN 12390-6:2009 and C1609/1609M-10. British Standard Institute.

Testing Hardened Concrete, Tensile Splitting Strength of Concrete. 2009. BS EN 12390-5:2009. British Standard Institute.

Yap S. P., Bu C. H., Alengaram U. J., Mo K. H., Jumaat M. Z. 2014. Flexural toughness characteristics of steel–polypropylene hybrid fibre-reinforced oil palm shell concrete. *Journal of Materials and Design*. 57 (2014) 652–659.

Zhang X. X., Abd Elazim A. M., Ruiz G., Yu R. C. 2014. Fracture behaviour of steel fiber-reinforced concrete at a wide range of loading rates. International Journal of Impact Engineering. 71 (2014) 89-96.

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering (Hons.) in Civil Engineering.

Signature	:	
Name of Supervisor	:	DR. NOOR NABILAH BINTI SARBINI
Position	:	LECTURER
Date	:	

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurently submitted for award of other degree.

Signature :

Name : AZMIRA BINTI AB AZIZ

ID Number : AA11129

Date :

This project is dedicated to my beloved parents, Ab Aziz and Anisah and both of my sisters, Aziham and Azura.

For their endless love, support and encouragement

ACKNOWLEDGEMENTS

I thank all who in one way or another contributed in the completion of this project. First, I give thanks to Allah for protection and ability to do work. Though only my name appears on the cover of this dissertation, a great many people have contributed to its production. I owe my gratitude to all those people who have made this dissertation possible and because of whom my graduate experience has been one that I will cherish forever.

I would like to express my sincere gratitude to my supervisor, Dr. Noor Nabilah binti Sarbini, for the continuous support of my project and research, for her patience, motivation, enthusiasm, and immense knowledge. Her guidance helped me in all the time of research and writing of this project. I could not have imagined having a better supervisor for my project.

My sincere thanks go to all my labmates and also the staff of the Concrete Laboratory, who helped me in many ways. To all my friends, thank you for your understanding and encouragement in my moments of crisis. Your friendship makes my life a wonderful experience. I cannot list all the names here, but you are always on my mind.

Most importantly, none of this would have been possible without the love and patience of my family. My family to whom this dissertation is dedicated to, has been a constant source of love, concern, support and strength all these years. I would like to express my heart-felt gratitude to my family, who has aided and encouraged me throughout this endeavor.

May Allah bless all of you.

ABSTRACT

Oil Palm Shell (OPS) is a waste lightweight aggregate originating from the palm oil industry. In this study, OPS was used as coarse aggregate. This research investigate the comparison between mix designs towards the Steel Fiber Oil Palm Shell Concrete (SF-OPSC) mechanical properties with similar concrete strength. The objectives of this study are determine the effect of different mix designs to the behaviour of SF-OPSC and study the mechanical properties of SF-OPSC. The testing specimen are cube, cylinder and prism specimens. The size of cube is 100 mm x 100 mm x 100 mm, cylinder with 150 mm in diameter and 300 mm in height and prism with the cross-section of 100 mm x 100 mm and 500 mm in length. The concrete grade that is used is 25 MPa. The tests that are conducted are compressive strength test, flexural strength test, tensile strength test and modulus of elasticity test. The type of fiber that is used is hooked end steel fiber. The volume fraction of SF is same which is 1%. The mix designs used are different in W/C; which are 0.58 and 0.62. The amount of OPS aggregate that are used in the specimen are 50% and 100%. Results shows that W/C does influenced the mechanical properties of SF-OPSC. The compressive strength of SF-OPSC increased with the increasing of W/C. While, the flexural strength increased with the increasing of W/C. Other than that, the splitting tensile strength of SF-OPSC decreased with the increasing of W/C. Finally, the W/C does influenced the modulus of elasticity of SF-OPSC.

ABSTRAK

Tempurung Kelapa Sawit (OPS) adalah sisa agregat ringan yang berasal daripada industri minyak sawit. Dalam kajian ini, OPS telah digunakan sebagai agregat kasar. Kajian ini menyiasat perbandingan di antara reka bentuk campuran ke arah Konkrit Gentian Keluli Tempurung Kelapa Sawit (SF-OPSC) sifat mekanik dengan kekuatan konkrit yang sama. Objektif kajian ini adalah menentukan kesan reka bentuk campuran yang berbeza untuk tingkah laku SF-OPSC dan mengkaji sifat mekanik SF-OPSC. Spesimen ujian kiub, silinder dan prisma spesimen. Saiz kiub adalah 100 mm x 100 mm x 100 mm, silinder dengan 150 mm diameter dan 300 mm tinggi dan prisma dengan keratan rentas 100 mm x 100 mm dan 500 mm panjang. Gred konkrit yang digunakan ialah 25 MPa. Ujian yang dijalankan adalah ujian kekuatan mampatan, ujian kekuatan lenturan, ujian kekuatan tegangan dan ujian modulus keanjalan. Jenis gentian yang digunakan merupakan gentian keluli hujung bercangkuk. Pecahan jumlah SF adalah sama iaitu 1%. Reka bentuk campuran yang digunakan adalah berbeza dari segi W / C; iaitu 0.58 dan 0.62. Jumlah OPS agregat yang digunakan di dalam spesimen tersebut adalah 50% dan 100%. Keputusan menunjukkan bahawa W/C tidak mempengaruhi sifat mekanik SF-OPSC. Kekuatan mampatan SF-OPSC meningkat dengan peningkatan W/C. Walaupun, kekuatan lenturan meningkat dengan peningkatan W/C. Selain daripada itu, kekuatan tegangan SF-OPSC menurun dengan peningkatan W/C. Akhir sekali, W/C tidak memperngaruhi kekuatan modulus keanjalan bagi SF-OPSC.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

σ	Stress
F	Force
A	Area
E	Modulus of Elasticity
ε	Strain

LIST OF ABBREVIATIONS

BS	British Standard
LWA	Lightweight aggregate
LWAC	Lightweight aggregate concrete
MPa	Mega Pascal
OPS	Oil palm shell
OPSC	Oil palm shell concrete
SF	Steel fiber
SF-OPSC	Steel fiber oil palm shell concrete
SFRC	Steel fiber reinforced concrete
W/C	Water cement ratio