BEHAVIOUR OF REINFORCED CONCRETE BEAM WITH CIRCULAR OPENING USING DIFFERENT FRACTION VOLUME OF HYBRID FIBRE

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ABSTRAK

Rasuk konkrit bertetulang dengan pembukaan yang biasa digunakan untuk memudahkan perkhidmatan penting seperti paip bekalan air, paip saliran, elektrik penghawa dingin, talian telefon dan rangkaian rangkaian komputer. Kerja eksperimen yang dibentangkan dalam penyelidikan ini bertujuan untuk menyelidiki eksperimen kelakuan rasuk dengan pembukaan bulat pada akhir rentang. Kajian ini juga dijalankan untuk mengkaji potensi serat hibrid dalam mengukuhkan rasuk konkrit bertetulang dengan menggunakan jumlah pecahan yang berlainan. Gabungan serat keluli dan serat kenaf digunakan dalam kajian ini. Kajian ini dilakukan dengan menuangkan rasuk dengan penambahan serat hibrid 0%, serat hibrid 1% dan serat hibrid 2% pada campuran rasuk konkrit bertetulang. 18 kiub semua sisi bersamaan dengan 150 mm dan 4 rasuk dimensi 400x250x1200 mm telah dipindahkan. Semua spesimen kiub telah diuji sehingga kegagalan dalam mesin mampatan. Rasuk itu dilemparkan selama 28 hari dan menjalani ujian lenturan. Semua sampel telah diuji dan keputusan dianalisis dengan menggunakan Microsoft Excel dan dibentangkan dengan bantuan jadual dan graf. Kajian menunjukkan bahawa, rasuk konkrit bertetulang dengan penambahan serat hibrid boleh mengekalkan lebih daripada 200kN beban. Walau bagaimanapun, penambahan serat hibrid dalam campuran konkrit menunjukkan kesan tidak penting dalam kekuatan mampatan. Rasuk konkrit bertetulang dengan serat hibrid menunjukkan prestasi yang lebih baik kerana tidak ada keretakan yang berlebihan sehingga strukturnya gagal. Cara kegagalan rasuk berubah dari rapuh ke cara yang lebih mulus kerana jumlah gentian keluli meningkat dalam campuran konkrit. Dari segi kemuluran, kemuluran dipertingkatkan kerana serat hibrid 1% telah ditambahkan tetapi terdapat had wujud yang serat tambahan membawa kepada kurang mulur.

ABSTRACT

Reinforced concrete beams with opening commonly used to facilitate essential services such as water supply pipes, drainage pipes, air conditioning electricity, telephone lines and computer network lines. The experimental work presented in this research is aimed to investigate experimentally the behaviour of beams with circular opening at the end of span. The research also conducted to study the potential of hybrid fibre in strengthening reinforced concrete beam using different fraction volume. The combination of steel fibre and kenaf fibre were used in this study. The study was carried out by casting beam with the addition of 0% hybrid fibre, 1% hybrid fibre and 2% hybrid fibre on the mixture of reinforced concrete beam. 18 cubes of all sides equal to 150 mm and 4 beams of dimensional 400x250x1200 mm were casted. All cubes specimens was tested until failure in compression machine. The beams were casted for 28 days and undergo flexural test. All the samples were tested and results were analysed using Microsoft Excel and presented with the aid of tables and graph. The study shows that, the reinforced concrete beam with the addition of hybrid fibre can sustain more than 200kN of load. However, the addition of hybrid fibre in concrete mix showed insignificant effect in compressive strength. Reinforced concrete beam with hybrid fibre show better performance as there is no excessive cracking until the structure had failed. Mode of failure of the beam changed from brittle to a more ductile manner as the amount of steel fibres was increased in the concrete mix. In term of ductility, the ductility is enhanced as 1% hybrid fibre was added but there is a limit exist which additional fibres lead to less ductile.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

µ	Ductility
%	Percent
mm	millimetre
MPa	Mega Pascal (pressure unit)
kN	Kilonewton
Py	Load at yield
Pmax	Maximum load
Pu	Ultimate load at failure
Vf	Volume of fraction

LIST OF ABBREVIATIONS

RC	Reinforced Concrete
FRP	Fibre Reinforced Polymer
GFRP	Glasss Fibre Reinforced Polymer
CFRP	Carbon Fibre Reinforced Polymer
KFRC	Kenaf Fibre Reinforced Concrete
PVC	PolyVinyl Chloride
OPC	Ordinary Portland Cement

CHAPTER 1

INTRODUCTION

1.1 Background of Research

Reinforced concrete is widely used for construction on a large scale due to its desirable mechanical properties. The advantage of concrete are can withstands compression, bending, tensile stress and has a high compressive strength compared to other materials. It can be used for making any size and shape for utilization in the construction including beam with openings. Beam with openings start to become popular in modern building constructions around the world. This type of beams are often provided for utility pipes and passage of ducts. These ducts are necessary in order to facilitate essential services such as water supply pipes, drainage pipes, air conditioning electricity, telephone lines and computer network lines. All of the utility pipes usually placed underneath the soffit of the beam, and were covered by a suspended ceiling thus creating a dead space (Vivek and Madhavi, 2016). In this situation, engineer cannot control the size of the beam since the support of the beam between another beams is too far. It effect the height of the floor since it does not have enough space to install a suspended ceiling. Therefore the web openings help us in reducing the height of the floor which leads to a highly economical design.

Figure 1.1 Example of RC beam with opening provided for utility pipes

Source: Sarah Jabbar (2016)

Reinforced concrete beam with openings also poses some disadvantages. An opening into beams changes their simple behaviour to a complex one and it will cause serviceability problem (Mondal, 2011). The presence of opening in the web of a reinforced concrete beam resulted too many problems in the beam behaviour including reduction in beam stiffness, excessive cracking and deflection (Chin *et al.*, 2012). The concept of using fibres as a reinforcement in the concrete mixture is not a new research. The use of fibres has been carried out from ancient times. There are various type of fibres found in the market such as glass fibres, steel fibres, carbon fibres, natural fibres (i.e. hemp, kenaf etc) and plastic fibres (i.e. polypropylene, graphite etc) (Syed Mohsin, 2012).

Recently, increasing attention has been given towards the development of green products in the field of composites. The composite materials are replacing the conventional materials, owing to its better properties like high tensile strength, high strength to weight ratio and low thermal expansion. Natural fibre composites such as kenaf composites became more attractive due to their high specific strength, lightweight and biodegradability (Naveenkumar, 2015). Amongst these types of fibre, steel fibre are widely used in the reinforced concrete structures (Lankard & Swany, 1974). Steel fibres have also demonstrated its capability in improving the structural behaviour of reinforced concrete beams. Recent studies also suggest that the addition of fibres to reinforced concrete beams with reduced shear reinforcement improves all the mechanical properties of concrete, especially tensile strength, impact strength and toughness. The resulting material possesses higher tensile strength, consolidated response and better ductility (Musmar, 2013). The addition more than one type of fibre in concrete that drives benefits from each of the individual's fibres and exhibits a synergetic response is known as hybrid fibre reinforced concrete. The focus in the present research is combination between steel fibre and kenaf fibre.

Recent investigations of kenaf fibre and steel fibre mixed and added into reinforced concrete beams (Mohsin *et al.*, 2016) it is proved that these combinations have the potential to serve as part of shear reinforcement. Fibres also improved the load carrying capacity of the beam up to 29% and 25% for beams contains 1% and 2% volume of fibre respectively. The mechanical properties of concrete are enhanced appreciably using fibres. This increases the modulus of elasticity of the concrete and reduce the chances of brittleness.

1.2 Problem Statement

The presence of opening will change simple beam behaviour into a more complex behaviour as we make a sudden change in the dimension of the beam's cross section. It will caused reduction in beam ultimate strength, excessive cracking, deflection and stiffness. Besides, the openings produces discontinuities or disturbances in the normal flow of stresses, thus leading it to stress concentration and early cracking of the beam around the opening region. The weakness of reinforced concrete beam with opening can be overcome by hybrid fibre to strengthening the beam.

Hybrid fibre is a combination of steel and kenaf fibre. Natural fibre have been used for many applications such as automotive components, aerospace parts, sporting goods and building industry (Rowell, 2008). Natural fibres such as kenaf fibre have been used as reinforcing materials for over 3000 years, in combination with polymeric materials. The natural fibre reinforced composite are lightweight and free from health hazard, reasonably strong, and hence it's have the potential to be used as material for strong components such as building materials, shipping, and automotive.

Steel fibres are widely used to enhance the performance of concrete. When steel fibres are added to mortar, Portland cement concrete or refractory concrete, the flexural strength of the composite is increased from 25% to 100% - depending on the proportion of fibres added and the mix design. Steel fibre technology actually transforms a brittle material into a more ductile one. Catastrophic failure of concrete is virtually eliminated because the fibres continue supporting the load after cracking occurs. And while measured rates of improvement vary, Steel fibre reinforced concrete exhibits higher post-crack flexural strength, better crack resistance, greater fatigue endurance, reduced maintenance cost and longer useful working life.

1.3 Objective

The aim of the research are to study the effect of hybrid fibre on the structural behaviour of reinforced concrete beam with opening.

1) To investigate experimentally the behaviour of beams with circular opening at the end of span.
2) To study the potential of hybrid fibre in strengthening reinforced concrete beam using different fraction volume.

1.4 Scope of Research

1) A total of four beams with opening at the end of the span will be tested with and without fibre mixture.
2) The reinforced concrete beam will be molded into rectangular shape with cross section of 400mm height, 150mm base and 1200mm length of span.
3) 6 cubes will be prepared to test the strength of concrete. 3 cubes will be tested for 7days and the other 3 cubes will be tested for 28 days. The dimension of each cube are 150mm x 150mm x 150mm.
4) The opening at the end of span of each reinforced concrete beam will be molded into square shape with cross section 10cm.

5) Two control beams (without fibres) which is one with opening while the other one without opening and two beams containing fibres contents 1% to 2% will be investigated.
6) Concrete will undergo slump test and a total of four beams will undergo flexure test.
7) For compressive strength test, 6 cubes will be tested in compression machine at age 7 and 28 days.
8) Four steel bar in one beam. Tensile bar = 650mm^2.
9) Strength of concrete, fck = 25MPa.
10) Strength of steel, fyk = 250 N/mm^2.
11) Size of kenaf fibre: Length = 3cm, diameter = 1mm
12) Chemical used to treat kenaf fibre: Sodium hydroxide, NaOH.

1.5 Research Significance

It is clearly stated from the problem statement that the behaviour of beam with circular opening brings a lot of problem. Durability of reinforced concrete beam is a major concerned by engineers in designing a building. Therefore, if hybrid fibre can strengthen the beam, it helps to solve the problem faced by reinforced concrete beam with opening. Hybrid fibre also can be used in construction field as a new material to strengthen reinforced concrete beam with opening which lead to a highly economical design.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Reinforced concrete beam with opening is very popular nowadays as an economic building structure and it is widely used in many types of engineering structures. Durability is the basic requirement of any concrete structure as it should be able to withstand all stresses and remain functional throughout its designed life span. But the presence of the openings caused reduction in beam strength, stiffness and caused excessive cracking and deflection (Chin *et al.*, 2014). One approach is by adding steel reinforcement (both bars and fibres), this is essentially due to its capability of enhancing the load carrying capacity and ductility of the concrete structures (Mohsin *et al.*, 2016). There are many types of fibre available for commercial use such as glass, steel, synthetic materials (e.g. polypropylene, carbon, nylon) and natural fibres such as kenaf fibre.

Fibres in concrete usually used to control plastic shrinkage cracking and drying shrinkage cracking. It increases the durability and tensile strength of the concrete. Some types of fibres produce greater impact, abrasion and shatter resistance in concrete. Fibre reinforced concrete also changes the mode of failure, control cracking propagation as well as increasing energy absorption (Mohsin *et al.*, 2016). Furthermore, recent research suggest that fibres also have the potential to serve as part of shear reinforcement in reinforced concrete structures (Mohsin, 2012)

The potential application of natural fibre in retrofitting of structure is growing up in construction industry nowadays. Among the various natural fibres, kenaf fibre have indisputable advantages over synthetic reinforcement materials. The plant's apparent high strength and light weight along with its environmental and sustainability advantages makes it a good candidate for use in structural materials. Steel fibres have also demonstrated its capability in improving the structural behaviour of reinforced concrete beam (Mohsin, 2012). Studies have shown that addition of steel fibres in a concrete matrix improves all mechanical properties of concrete, especially tensile strength and impact strength. Steel fibres can deliver significant cost savings, together with reduced material volume, more rapid construction and reduced labour costs. The combination of steel fibres and kenaf fibre known as hybrid fibre have the potential in increasing the strength of the reinforced concrete beam due to mechanical properties of steel fibres and kenaf fibre.

2.2 Reinforced Concrete Beam with Opening

2.2.1 Previous Research on Reinforced Beam with Opening

In the mid 1930's, fibre reinforced polymer has become a staple in the building industry. FRP rebar is gaining commercial value mainly because it is resistant to corrosive agents and does not let concrete rust or weaken. Famous approach by researchers towards finding material to strengthen the beams with opening is by using fibre reinforced polymer (FRP). One of the strengthening options considered is lamination of fibre reinforced polymer sheets due to its superior properties such as high tensile strength and stiffness, high resistance to corrosion, excellent fatigue performance and good resistance to chemical attack (Chin *et al.*, 2014). FRP lamination has been widely accepted by the research community and practising engineers in the construction industry as the material for strengthening and rehabilitation of common problems. There are various type of FRP such as glass fibre reinforced polymer and carbon fibre reinforced polymer. The study of behaviour of glass fibre polymer (GFRP) strengthened beams with openings using experimental investigation and numerical simulations using finite element analysis with the help of ANSYS found out that the beam capacity increased about 66-125%. According to a research conducted by Ha on the design of concrete deep beams with openings and carbon fibre laminate repair, carbon fibre laminate layers can increase the beam stiffness. The presence of CFRP sheets could increase the beam strength within 35-73% based on experimental testing carried out by El-Maaddawy and Sherif.

FRP can only be used to strengthen the beam externally. Recent experimental testing found out that steel plates can be used in strengthening the reinforced concrete beam with opening. Based on the experiment, increasing the thickness of steel plates around the shear zone openings increased the ultimate loads up to limited value depending on concrete grade beyond which the ultimate load may be constant or slightly decreased. The ultimate load of beams having rectangular opening in shear zone strengthened with steel plates with configurations used in this research slightly increased by increasing the length of horizontal steel plates. Increasing the thickness of steel plates and the length of horizontal steel plates decreases mid span deflection, inner edge deflection and difference between deflections of two opening edges.

2.2.2 Classification of Opening

Openings are frequently placed in the web area of reinforced-concrete deep beams to facilitate essential services, such as ventilating ducts, water supply and drainage pipes, network access. However, reinforced concrete beams are commonly supported on several supports and, consequently, high shear and high moment coincide within interior shear spans where failure usually occurs. Ashour and Rishi reported test results of 16 reinforced-concrete deep beams with web openings, having a shear span-to-overall depth ratio of 1.08. They concluded that web openings within interior shear spans caused more reduction to the beam capacity than those within exterior shear spans and vertical web reinforcement was more effective than horizontal web reinforcement.

Beam of circular opening with diameter less than or equal to 44% of the depth of the beam (without special reinforcement in opening zone) behave similar to the beams without opening, mode of failure is flexure at midspan, maximum compressive stress of the concrete occur at top of the beam for the ultimate load and tensile stress of the longitudinal reinforcement reaches to its yield stress before reaching to the ultimate stage of the beam. Beam circular opening with diameter more than 44% of the depth of the beam (without special reinforcement in opening zone) reduces the ultimate load capacity of the RC rectangular beams by at least 34.29%, mode of failure is shear at the opening region, maximum compressive stress of the concrete occur at the opening region of the beam for the ultimate load and tensile stress of the longitudinal reinforcement reaches to its yield stress before reaching to the ultimate stage of the beam. The circular opening has more strength than equivalent square opening with difference of 9.58% in ultimate load capacity.

2.3 Fiber Reinforced Concrete

2.3.1 Steel Fibre

Steel fibre reinforced concrete is a castable or sprayable composite material of hydraulic cements, fine, or fine and coarse aggregates with discrete steel fibres of rectangular cross-section randomly dispersed throughout the matrix. Steel fibres strengthen concrete by resisting tensile cracking (Ruano *et al.*, 2014). During recent years, steel fiber reinforced concrete has gradually advanced from a new, rather unproven material to one which has now attained acknowledgment in numerous engineering applications. Lately it has become more frequent to substitute steel reinforcement with steel fiber reinforced concrete. The applications of steel fiber reinforced concrete have been varied and widespread, due to which it is difficult to categorize. The most common applications are tunnel linings, slabs, and airport pavement. Steel fibres strengthen concrete by resisting tensile cracking. Fibre reinforced concrete has a higher flexural strength than that of unreinforced concrete and concrete reinforced with welded wire fabric. But unlike conventional reinforcement which strengthens in one or possibly two directions. Steel fibres reinforce iso tropically, greatly improving the concrete's resistance to cracking, fragmentation, spalling and fatigue. When an unreinforced concrete beam is stressed by bending, its deflection increases in proportion with the load to a point at which failure occurs and the beam breaks apart.

When steel fibres are added to mortar, Portland cement concrete or refractory concrete, the flexural strength of the composite is increased from 25% to 100% depending on the proportion of fibres added and the mix design. Steel fibre technology actually transforms a brittle material into a more ductile one. Catastrophic failure of concrete is virtually eliminated because the fibres continue supporting the load after cracking occurs. And while measured rates of improvement vary, Steel fibre reinforced concrete exhibits higher post-crack flexural strength, better crack resistance, improved fatigue strength, higher resistance to spalling, and higher first crack strength.

2.3.2 Kenaf Fibre

Kenaf known as Hibiscus cannabinus, is a plant in the Malvaceae family also called Deccan hemp and Java jute. Hibiscus cannabinus is in the genus Hibiscus and is native to southern Asia, though its exact origin is unknown. The name also applies to the fibre obtained from this plant. Kenaf fibres are reinforced with epoxy resin to form fibre reinforced polymeric composites which improves the strength of the composites. A few reserachers investigated the development of biodegradable composite materials using natural fibres and examined molding conditions, mechanical properties and interfacial bonding. They concluded that the shape, size and strength of natural fibres mainly depend on cultivation environment, region of origin and other characteristics which influence the mechanical properties of fibre composites.(Bharath, Ramnath and Manoharan, 2015)

Elsaid et al. (2011) investigated the effectiveness of using kenaf in fiber reinforced concrete. Their testing showed that though kenaf fiber reinforced concrete (KFRC) has a somewhat lower compressive strength than normal concrete, it behaves with more ductility, absorbs more energy, and better distributes cracking. The compressive strength decreased as fiber content increased because the higher fiber content mixes required a cement rich mixture. It can be concluded that KFRC could be a low-cost solution to increase durability and sustainability in certain applications**.**

2.3.3 Hybrid Fibre

The use of two or more types of fibres in a suitable combination may potentially improve the overall properties of concrete and also result in performance concrete is called hybrid fibre. The combining of fibres, often called hybridization. Hybrids based on the fibre constitutive response, in which one fibre is stronger and stiffer and provides strength, while the other is more ductile and provides toughness at high strains. Hybrids based on fibre dimensions, where one fibre is very small and provides micro crack control at early stages of loading; the other fibre is larger, to provide a bridging mechanism across macro cracks. Hybrids based on fibre function, where one type of fibre provides strength or toughness in the hardened composite, while the second type provides fresh mix properties suitable for processing (Ranjith Kumar. R, Vennila. A, 2013). Hybrid fibres can substantially improve penetration resistance, decrease crater sizes, control crack development, reduce damaged area, and improve the ductility of RC targets (e.g. beams and slabs).

2.3.4 Previous Research on Hybrid Fibre

Recently, a few Malaysian start to do a research on hybrid fibre which is involve natural fibre (kenaf fibre) and steel fibre. They study the effect of hybrid fibre on behaviour of reinforced concrete beams. Based on the research, reinforced concrete beam with fibre can increase the compressive strength for the first 3 days of experiment. However on 28th day, compressive strength of reinforced concrete beam without fibre is higher compared to the fibre reinforced concrete mixture (Mohsin *et al.*, 2016). This result are same with existing literature (Mohsin, 2012)

To summaries, addition of hybrid fibre (kenaf fibre and steel fibre) will normally increase the performance of reinforced concrete beam with opening. Hybrid fibre as crack resistance in concrete will help to reduce the crack width. Ductility is on the main concern in reinforced concrete structure. The ductility of the RC beams increases with the increases of fibre content. This is due to the fact that fibres improve the ductility of the concrete's brittle characteristics. To conclude, the addition of hybrid fibre on concrete mix in designing reinforced concrete beam with opening will satisfy the objective of this research.

CHAPTER 3

METHODOLOGY

3.1 Preparation of Concrete Ingredients

The method of preparation of concrete ingredients and the details of the constituent materials made up of concrete will be described.

Hybrid fibre reinforced concrete is design by using trial mix design method. This method is used to determine the appropriate workable mix proportions. In accordance to British method of concrete mix, the compressive strength of hardened concrete is generally considered to be an index of its other properties and the slump is controlled at the range of 75±25mm.

Table 3.1: Concrete mix details

Material	Mix 1 (V_f=0%)	Mix 2 (V_f=1%)	Mix 3 (V_f=2%)
Cement (kg/m^3)	89.17	50	50
Sand (kg/m^3)	121.25	68	68
Aggregate (kg/m^3)	225.18	126.5	126.5
Water (L/m^3)	37.45	21	21
Superplasticizer (L/m^3)	1	0.6	0.6
Steel fibre (kg)	0	4.32	8.64
Kenaf fibre (kg)	0	0.36	0.72

Figure 3.1: Slump test to measure the workability of a fresh concrete

3.1.1 Cement

The cement used in this experiment is Ordinary Portland Cement certified to MS 522-1: 2007 (EN 19-1: 2000), CEM I 42.5 N / 52.5 N and MS 522: Part 1: 2003, which is the most common cement used in general concrete construction in Malaysia when there is no exposure to sulphates in the soil or groundwater. The quality of OPC is defined by Malaysian Standard MS EN 197-1:2007, which is adopted from European Standard EN 197-1:2000.

Figure 3.2: ORANG KUAT, Ordinary Portland Cement

3.1.2 Coarse Aggregate

Construction aggregate, or simply aggregate, is a broad category of coarse to medium grained particulate material used in construction, including sand, gravel, crushed stone, slag, recycled concrete and geosynthetic aggregates. Aggregates are the most mined materials in the world. Aggregates are a component of composite materials such as concrete and asphalt concrete; the aggregate serves as reinforcement to add strength to the overall composite material. All coarse aggregate will be sieved. Only aggregate passing 20mm will be used.

Figure 3.3: Coarse aggregate

3.1.3 Fine Aggregate

Fine aggregate are basically sands won from the land or the marine environment. Fine aggregates generally consist of natural sand or crushed stone with most particles passing through a 4.75mm sieve.

Figure 3.4: Fine aggregate

3.1.4 Water

The essential material for hydration process of cement is water and also to provide workability during mixing and placing. The water used shall be clean and free from impurities. Normal tap water supply from the laboratory will be used in this research for mixing and curing of concrete. However the volume of water usual depends on the water to cement ratio (W/C) that has been set in this research.

3.1.5 Superplasticizer

Superplasticizer is the chemical admixture used in this research to overcome the issues of workability problem that arise when hybrid fibres are mixed in the concrete mix. The superplasticizer added in concrete mix is Sika Viscocrete-2199. It is specially designed for water reduction, extended workability with better flow ability. This superplasticizer meets the requirement of ASTM C 494-86. Type G and BS 5075: Part 3. It comes in aqueous solution of modified polycarboxylate based and with colors of brown liquid.

Figure 3.5: Sika Viscocrete-2199, Superplasticizer

3.1.6 Formwork

The formwork used is traditional timber formwork and engineered formwork system which used for casting of beam and cube specimen respectively. Traditional timber formwork is built in the concrete laboratory out of plywood. Plywood will be cut into required sections for casting of beam specimen with size of 150mm square side and 1200mm in length.

Figure 3.6: Plywood

Figure 3.7: Beam formwork

Steel mould are used to mold 18 cubes of 150mm X 150mm X 150mm.

Figure 3.8: Steel mould (150mm X 150mm X 150mm)

3.1.7 Steel fibre

Steel fibres are often used in construction projects of overseas countries (e.g. United Kingdom, Japan, India and more). The volume of fractions of steel fibres used ranging from 0% to 1% in this investigation. Steel fibres should be rust-free, crooked-free, and must glued together prior to mixing. All STAHLCON™ steel fibres are made from cold drawn high tensile deformed steel wires, in accordance to ASTM A820, type 1 and shall have minimum tensile strength 1100 $\pm$100 N/mm^2.

Table 3.2: Specification of STAHLCON™ steel fibre

Properties	**Detail**
Profile	STAHLCON™ HE 0.75/60
Wire (raw material)	Low carbon steel wire conforms to BS EN 10016-2
Cross section	Circular
Fibre diameter, d (mm)	0.75
Fibre length, L (mm)	60
Aspect ratio	80
Tensile strength (Mpa)	1100
Unit Weight (kg/m^3)	7800

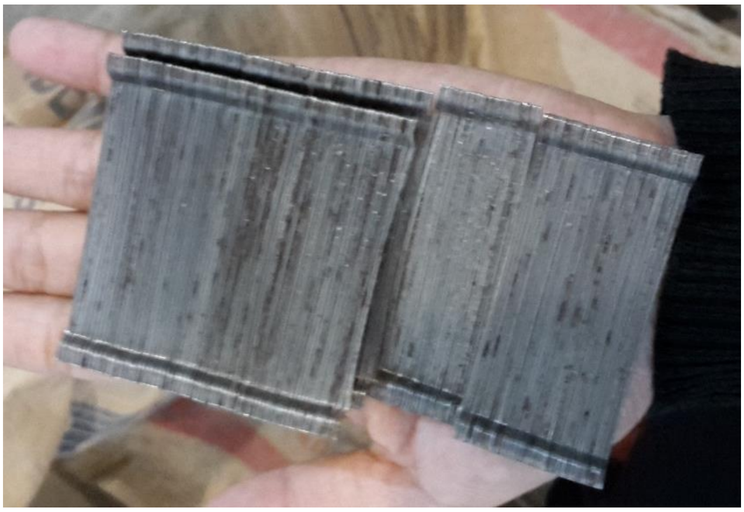


Figure 3.9: STAHLCON™ steel fibre

3.1.8 Kenaf fibre

Kenaf known as Hibiscus cannabinus, is a plant in the Malvaceae family also called Deccan hemp and Java jute. Kenaf fibre will be combined with steel fibre to produce hybrid fibre. The volume of fractions of kenaf fibres used ranging from 0% to 1% in this investigation. Diameter of kenaf fibre used is 1mm, length of kenaf fibre is 30mm, density of kenaf fibre is 0.75gm^3 and the tensile strength is 550MPa.

Figure 3.10: Kenaf fibre

3.1.9 Polyvinyl Chloride (PVC)

Polyvinyl Chloride (PVC) piping is used to make a circular opening on reinforced concrete beam. Diameter of the pipe needed to make a circular opening is 100mm.

Figure 3.11: Polyvinyl Chloride (PVC)

3.1.10 Steel bar

Steel bar or mesh of steel wires used as a tension device in reinforced concrete and reinforced masonry structures to strengthen and hold the concrete in compression. The details of steel bar for main bar and shear link as shown in Table 3.3.

Table 3.3: Detail of steel bar

Steel bar	Size
Steel bar (Y12)	12mm
Steel bar (R6)	6mm

3.2 Kenaf Treatment

Chemical used to treat kenaf fibre is sodium hydroxide, NaOH. Water is added with sodium hydroxide. Soak the kenaf fiber with the mixture of water and sodium hydroxide for 24 hour. Dry it after 24 hour.

Figure 3.12: Sodium hydroxide, NaOH.

3.3 Preparation of Reinforced Beams with Opening

The beam samples will be categorized into 3 different dosages of hybrid fibre (steel fibre and kenaf fibre) volume fractions (V_f) which were 0%, 1% and 2%. The details of the samples are shown in Table 3.4.

Table 3.4: Detail of beam samples

Beam	Composites
BEAM 1	0% of steel fibre and kenaf fibre + without opening
BEAM 2	0% of steel fibre and kenaf fibre + with opening
BEAM 3	0.5% of steel fibre and 0.5% kenaf fibre + with opening
BEAM 4	1% of steel fibre and 1% kenaf fibre + with opening

3.4 Test Procedure

In this research, the behaviour of four reinforced concrete beams with the addition of hybrid fibre will be investigated through experimentation. The potential of hybrid fibre in strengthening internally the reinforced concrete beam with opening will also be examined. Structural behaviour in term of strength, stiffness, ductility, crack propagation and mode of failure will be analysing throughout the experimental works. All the results will be compared with the control data and theoretical manual calculation.

In order to obtain the reliable results, engineering properties of all the hardened concrete will be tested in terms of compressive strength and flexural strength according to the standards of compression test (BS 1881: Part 116: 1983) and flexural test (BS 1881: Part 118:1983). 6 concrete cubes with dimension of 150mm X 150mm X 150mm will be tested on age of 7 and 28 days in the compression machine. Furthermore, four beams specimen having length of 1200mm will be tested.

Figure 3.13: Compression test machine

Figure 3.14: Flexural test machine

3.5 Data Processing Method

The result obtain from concrete compression test on cube specimens is the maximum load will be calculated for the ultimate strength and result will be generate on the graph produce by Microsoft Excel. The average ultimate strength of concrete will be based on compression test result of specimens on 7 and 28 days from the day of casting the cube. The condition of the specimen is recorded to determine the type of failure.

Concrete flexural test measures the force required to bend a beam under two point load. The load and deflection of the beam recorded will be used to determine the key result such as maximum load, ultimate load, yield deflection, ultimate deflection and ductility of the beam specimens on 28 days from the day of casting the beam. The flexural machine will automatically record the data of time, force and deflection. From the data collected, a load deflection curve will be generated by using Microsoft Excel. The cracking location will be recorded to determine the mode of failure of the beam.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The aim of this research is to investigate the behaviour of reinforced concrete beam with opening at the end of beam. Structural behaviour such as compressive strength, flexural strength, crack width and the potential use of hybrid fibre as part of shear reinforcement have been investigated. All the tests are conducted according to the methods discussed in methodology. The result and detail analysis of data from experimental works are presented as follow.

4.2 Slump Test Result

The concrete slump test measures the consistency of fresh concrete before it sets. It is performed to check the workability of freshly made concrete and indirectly, as a means of checking that the correct amount of water has been added to the mix. The slump test results for controlled beam, 1% hybrid fibre beam and 2% of hybrid fibre beam are shown in Table 4.1, Figure 4.1, Figure 4.2, Figure 4.3 and Figure 4.4.

Table 4.1: Summary of slump test results

Type of beam	Slump Height (mm)
0% hybrid fibre	75mm
1% hybrid fibre	70mm
2% hybrid fibre	70mm

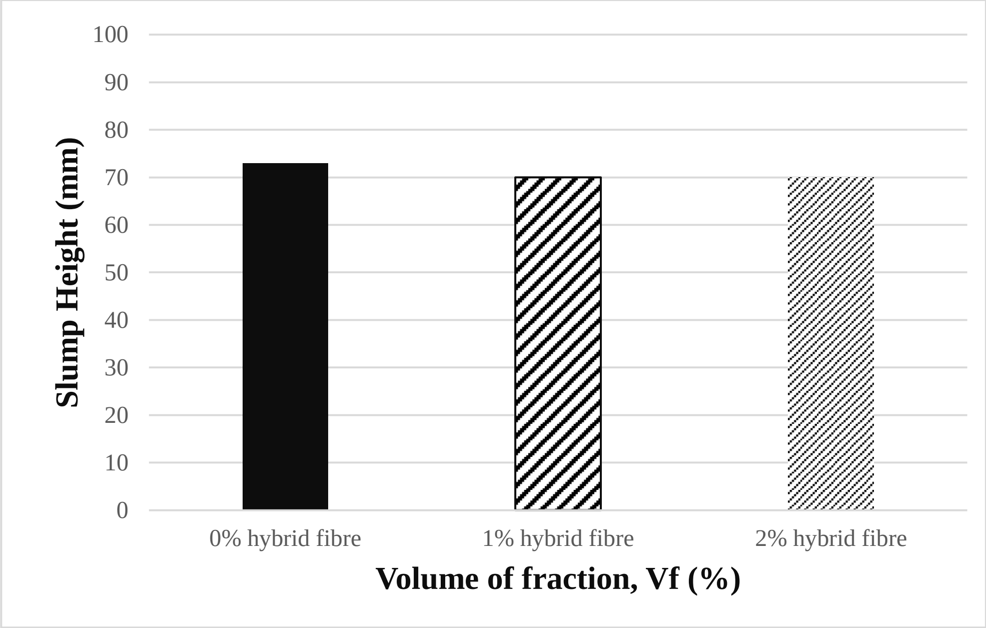


Figure 4.1: Slump Test Result

Figure 4.2: Slump Height for 0% hybrid fibre

Figure 4.3: Slump Height for 1% hybrid fibre

Figure 4.4: Slump Height for 2% hybrid fibre

Figure 4.1 shown the decreasing value of slump height of control beam to beam with hybrid fibre. The reduction maybe because of the characteristic of kenaf fibre, which was water absorbing. It absorbed water during the mixing process. In term of workability, the higher the slump value, the higher the amount of water.

4.3 Results for Cubes in Concrete Compression Test

The sample cubes with the dimension of 150 mm x 150 mm x 150 mm were tested. All cube samples were water cured for 7 and 28 days before tested for compressive strength. The results of compression strength test are shown in Table 4.2, Figure 4.5, Figure 4.6, Figure 4.7 and failure mode of sample in Figure 4.8 and Figure 4.9.

It can be observed that the concrete compressive strength is different based on the curing period. At the ages of 7 days, the compressive strength of control cube specimen (V_f = 0%) is 46.42MPa. The compressive strength has reduced to 43.29MPa with the addition of 1% hybrid fibre, which is dropped for 6.74% as compared to control cube specimen. The strength also reduced for cube which contained 2% hybrid fibre. The compressive strength has reduced to 35.56MPa. The reduction of compressive strength in concrete after added 2% of hybrid fibre is significant which the maximum decrease of 10.86MPa is (23.40%) as compared with normal concrete.

The rate of gain of concrete compressive strength is higher during the first 28 days of casting. At the ages of 28 days, the compressive strength of control cube specimen (V_f = 0%) is 53.43MPa while for the samples with addition of hybrid fibre are 50.77MPa and 40.08MPa for 1% and 2% of hybrid fibre added respectively. From the result, it shown that the maximum compressive strength of hybrid fibre reinforced concrete is 25% slightly lower than normal concrete that is 53.43MPa.

Table 4.2: Summary of cube compressive results

Volume fraction (V_f) (%)	Compressive Strength (MPa)	
	7 days	28 days
0	46.42	53.43
1	43.29	50.77
2	35.56	40.08

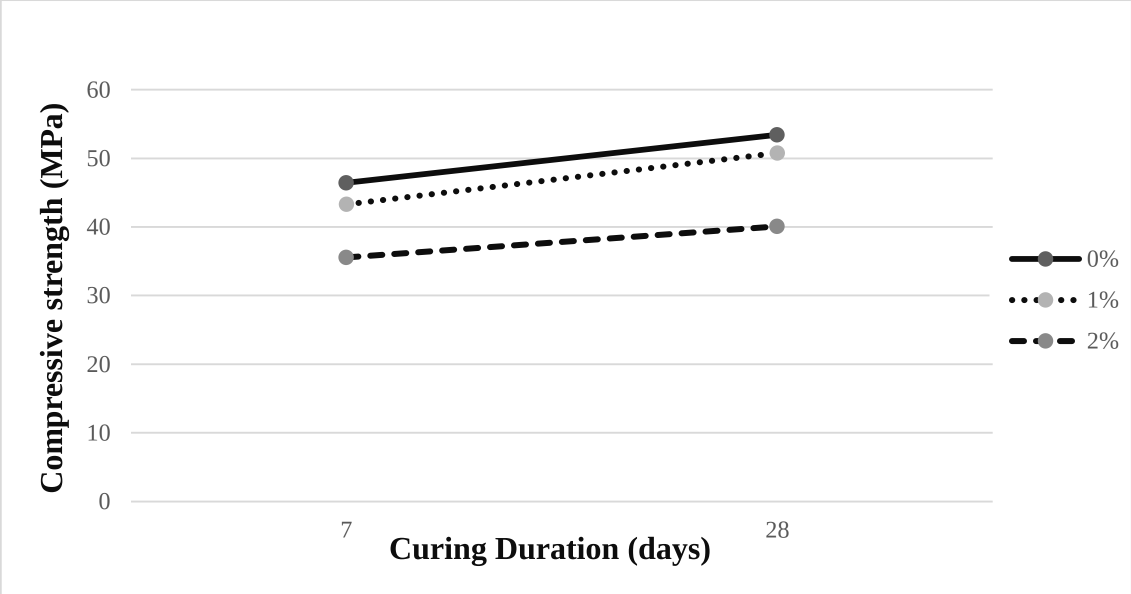


Figure 4.5: Compressive strength of cube sample

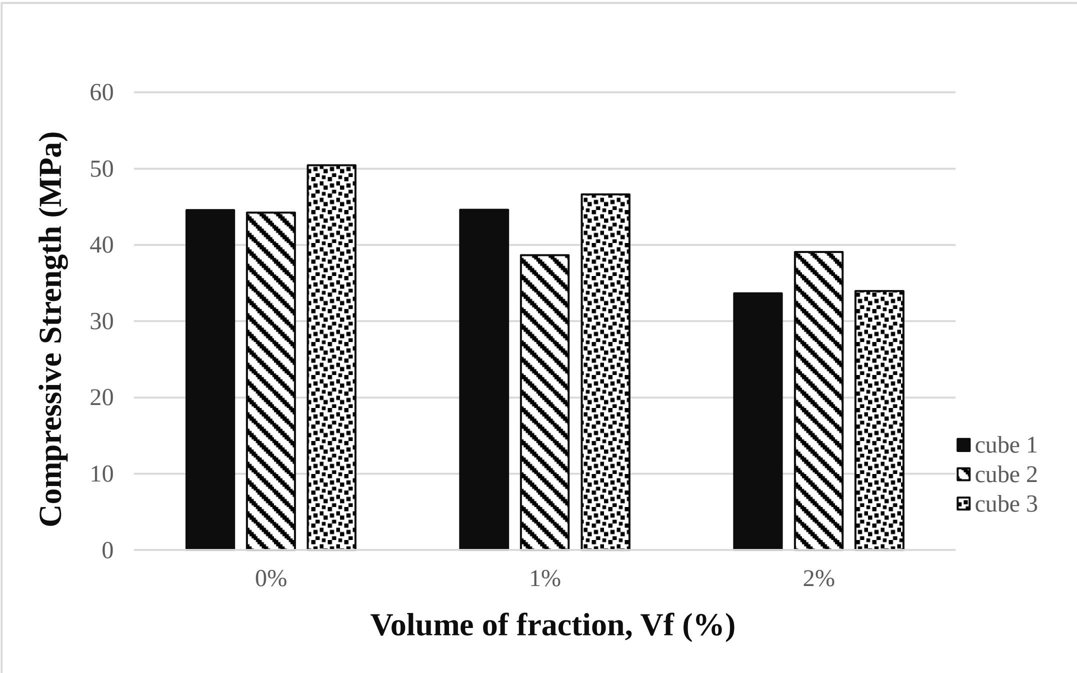


Figure 4.6: Relationship between cube compressive strength against volume fraction of hybrid fibre for 7 days.

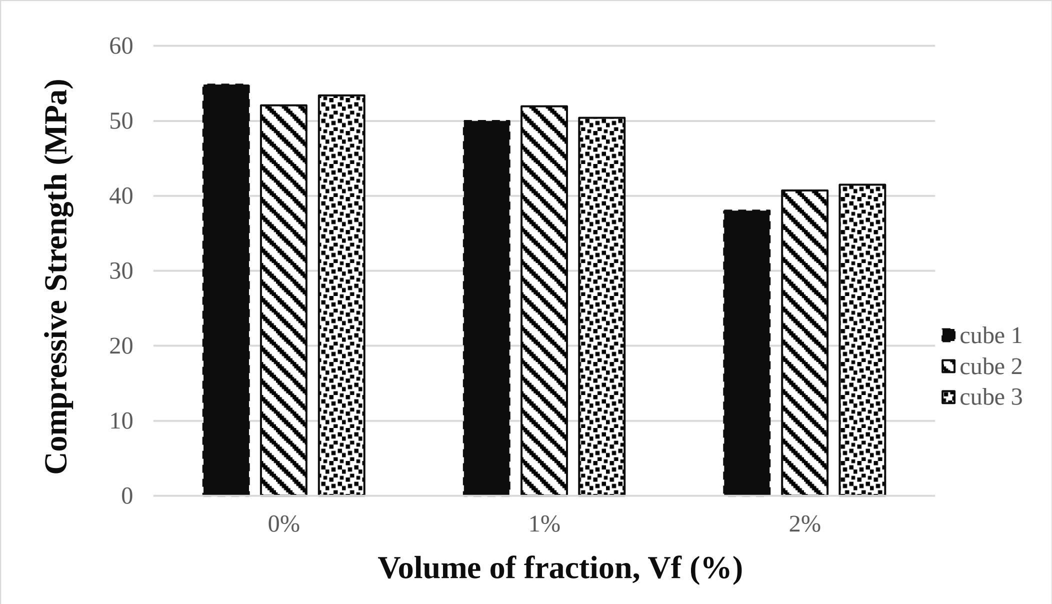
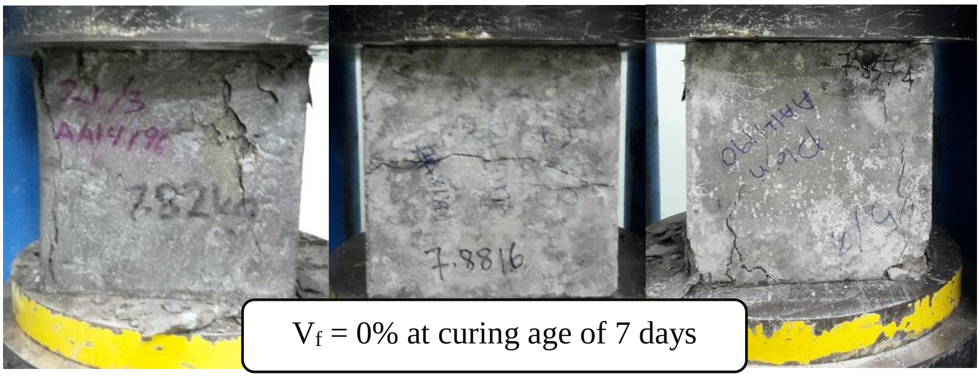
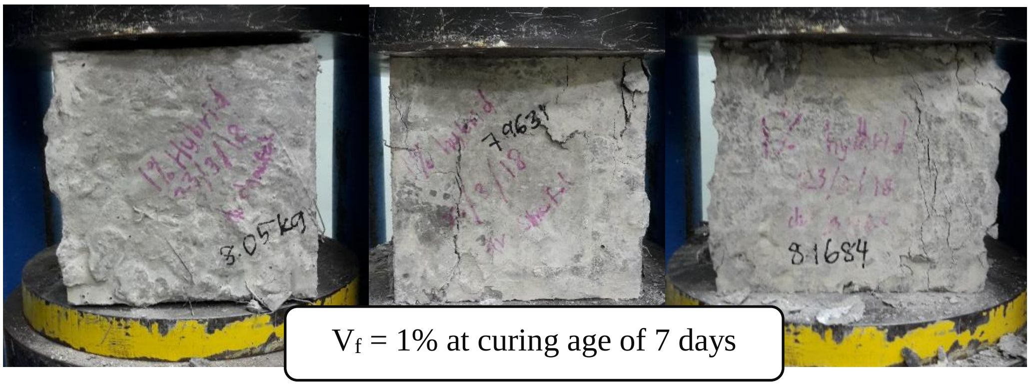


Figure 4.7: Relationship between cube compressive strength against volume fraction of hybrid fibre for 28 days.





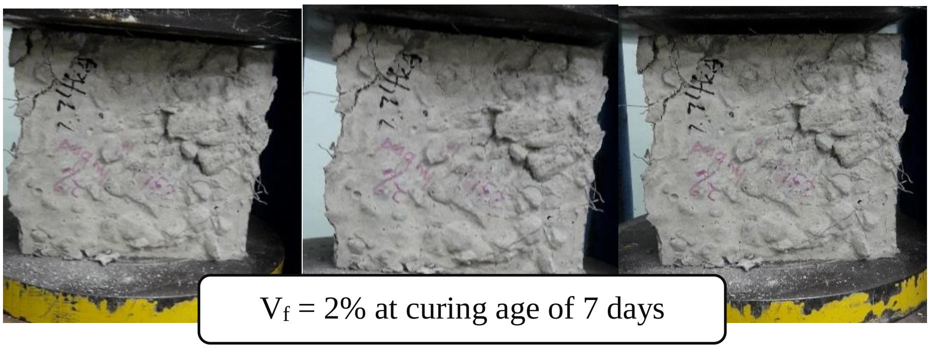


Figure 4.8: Failure mode of cube sample after compression test at curing age of 7 days.

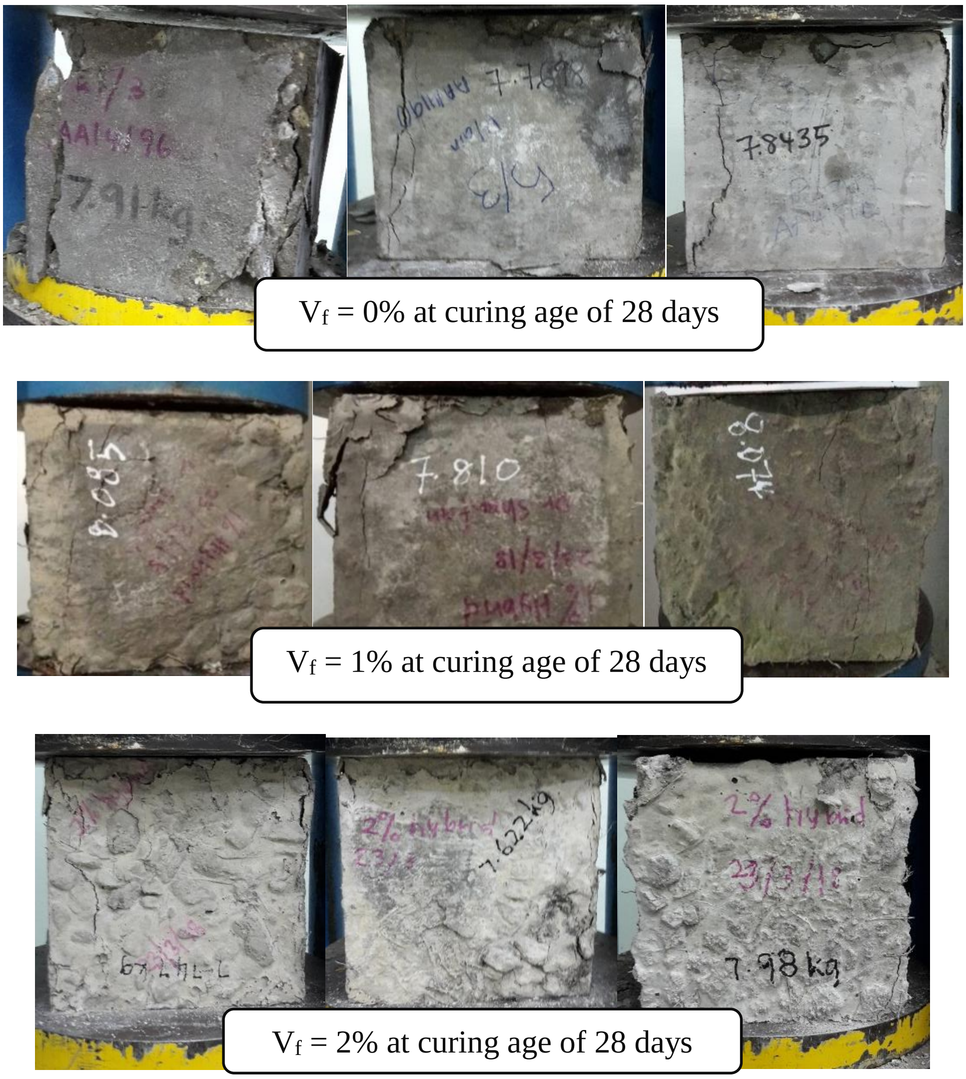


Figure 4.9: Failure mode of cube sample after compression test at curing age of 28 days.

4.4 Results for Beams in Concrete Flexural Test

The flexural test results to check the effect of adding hybrid fibres into reinforced concrete beam with opening are shown in this section. All samples are tested at the age of 28 days. In this test, all the beams are subjected to the continuously load until the beam failed. During the testing, the first crack for each beams are recorded. Comparison of load-deflection curve for control beam are shown in Figure 4.10.

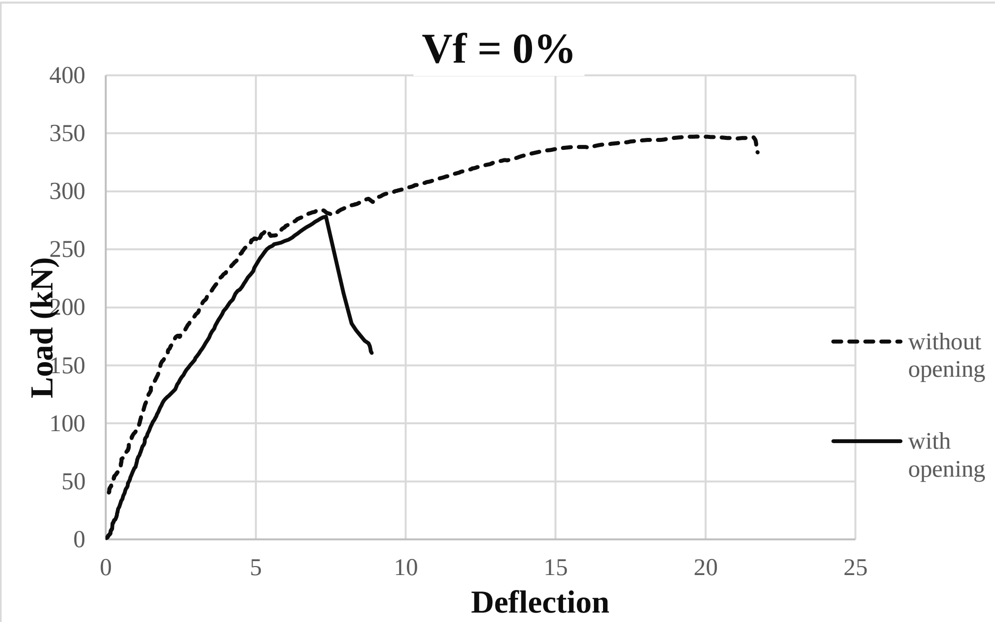


Figure 4.10: Comparison between control beam with opening and without opening

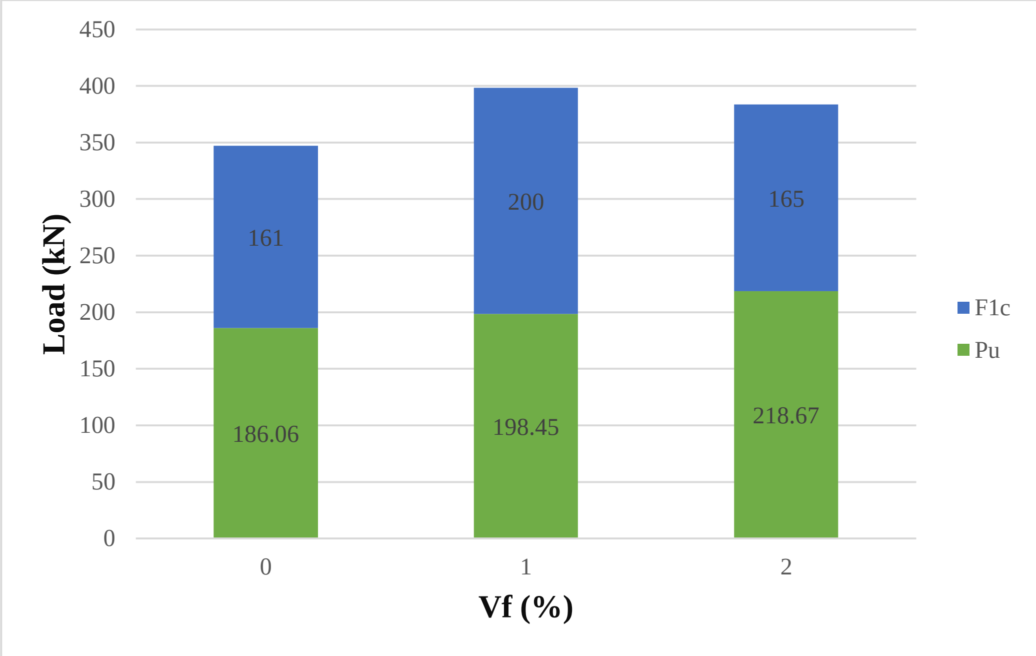


Figure 4.11: Relationship of first crack load (F_{1c}), ultimate load (Pu) against volume fraction (Vf)

Figure 4.11 shows stacked bar chart of first crack load, F_{1c} and followed by an ultimate load at failure, Pu of three beam specimens. The first crack will appear outside of the surface of the beam before failure. Beam with higher fraction volume of hybrid fibre show greater expansion than the control beam. Reinforced concrete beam with addition of hybrid fibres will show better performance as there is no excessive cracking until the structure had failed.

4.4.1 Load-Deflection Curves

All reinforced concrete beams with and without opening are tested by using flexural test machine. The load-deflection curves for beams with the addition of 0%, 1% and 2% are presented in Figure 4.12. The load at yield (Py), maximum or peak load (Pmax) and ultimate load at failure (Pu) and their respective deflections δy, δu and δ_{Pmax} are given in Table 4.3. The ductility ratio (μ) defined as $\mu = \delta u / \delta y$ is also included in the table.

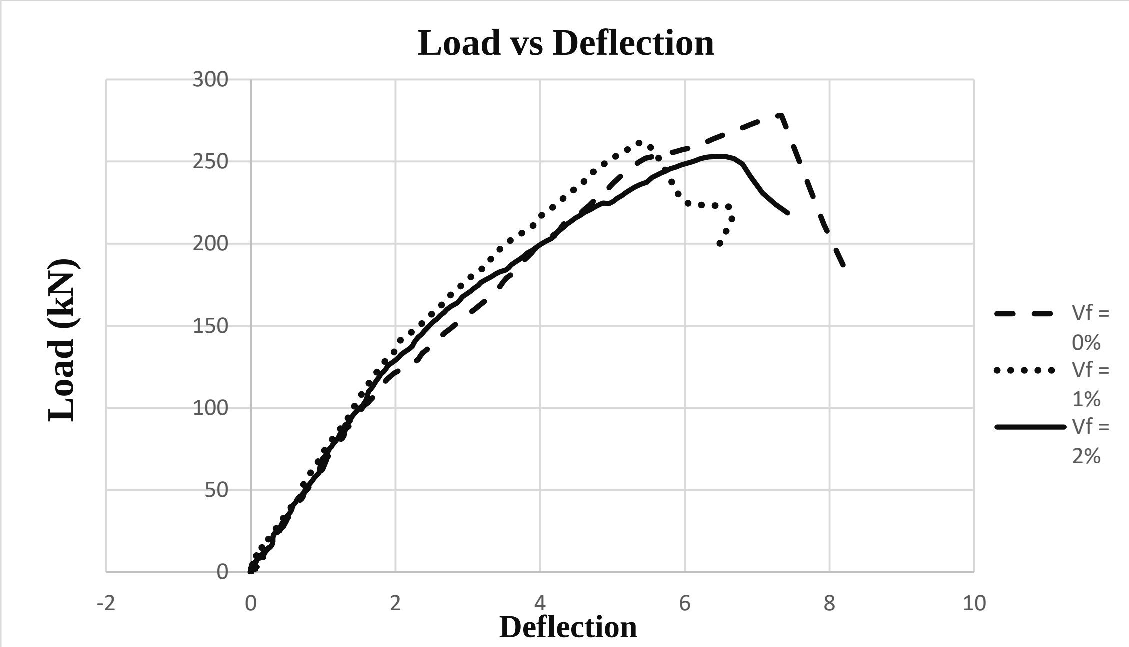


Figure 4.12: Comparison between reinforced concrete beams with different fraction volume of hybrid fibre.

Table 4.3: Summary of flexural test results

V_f (%)	Py (kN)	δy	Pu (kN)	δu	Pmax	δ_{Pmax}	μ= δu / δy
0	254.39	5.61	186.06	8.20	278.07	7.34	1.46
1	201.98	3.59	198.45	6.47	261.83	5.44	1.80
2	224.33	4.95	218.67	7.42	253.11	6.49	1.50

Reinforced concrete beam with 2% hybrid fibre achieved 218.67kN of ultimate load which is 17.53% higher than the normal reinforced concrete beam. Besides, the ultimate load of 198.45kN is obtained from reinforced concrete beam with 1% hybrid fibre which also recorded 6.66% higher than plain concrete. This explained the combination of kenaf fibre and hybrid fibre helps in enhancing the strength of beams when introduced into plain concrete.

The load carrying capacity (Pmax) of concrete are recorded for all types of beam before it failed. With the addition of 1% hybrid fibre, the load carrying capacity has reduced to 261.83kN which is dropped for 5.84% as compared to control beam. While for 2% hybrid fibre added, the maximum load also reduced to 253.11kN. This is because most of the fibres were pulled out from the matrix (as it was not fully dried and hardened) instead of fibres rupture. This phenomenon also has some effect towards the strength of the structure as higher strength was needed to rupture the fibre during the pull-out phase(Mohsin *et al.*, 2016). In term of ductility, it could be seen that reinforced concrete beam with hybrid fibre is higher than standard control beam. Therefore, it could be concluded that the addition of hybrid fibre managed to introduce a ductile characteristic into the concrete material.

4.4.2 Yield Ratio

The load at yield ratio for each beam are presented in Figure 4.13 and Table 4.4. The highest yield ratio obtained by control beam is 0.95. As for the sample contain hybrid fibre, the upward trend was observed. Based on the figure, it show that the yield ratio increases with the increase of fraction volume of hybrid fibre.

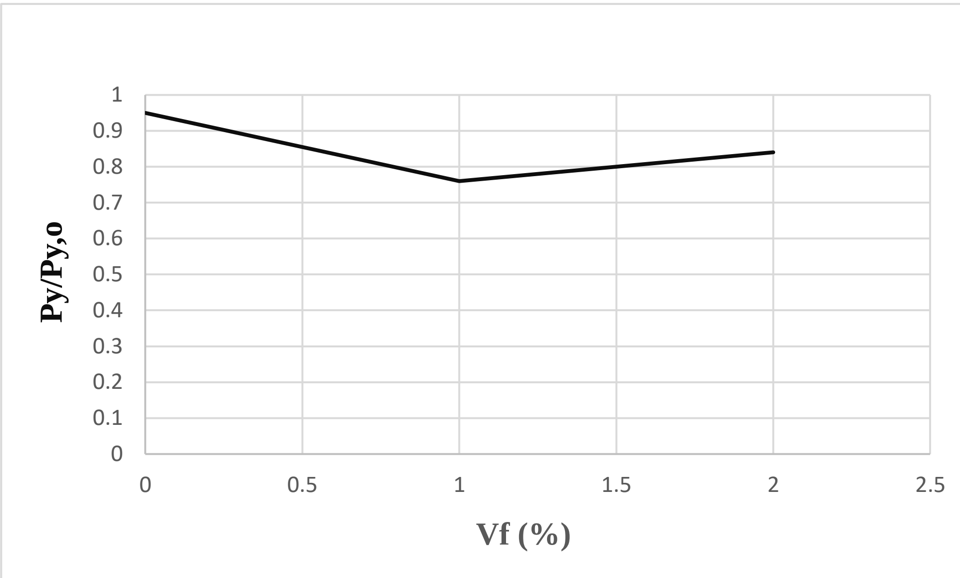


Figure 4.13: Ratio of yield load to that of the control specimen versus hybrid fibre volume fraction graph

Table 4.4: Yield load ratio

Vf	Py/Py,o
0	0.95
1	0.76
2	0.84

4.4.3 Maximum ratio

The ratio between the maximum load (Pmax) and control standard control (Pmax,o) are shown in Figure 4.14 and Table 4.5. Based on figure, the maximum load decrease with the increase of hybrid fibre.

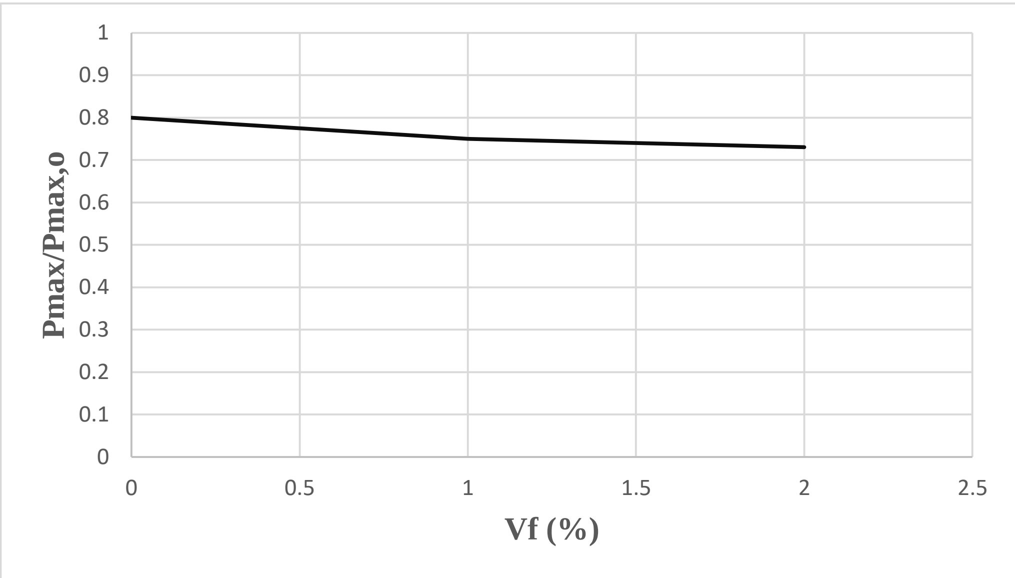


Figure 4.14: Ratio of maximum load carrying capacity to that of the control specimen versus hybrid fibre volume fraction graph

Table 4.5: Maximum load ratio

Vf	Pmax/Pmax,o
0	0.80
1	0.75
2	0.73

4.4.4 Ductility

The ductility ratio for each beam are presented in Figure 4.15 and Table 4.6. It can be concluded that ductility is enhanced as hybrid fibres are added, however there is a limit exist which additional fibres lead to less ductile. This is due to the beam becomes stiffer and deflects less and similar to the "over reinforced" behaviour associated with reinforced concrete design where too much reinforcement leads to a reduction rather than an increase in ductility.

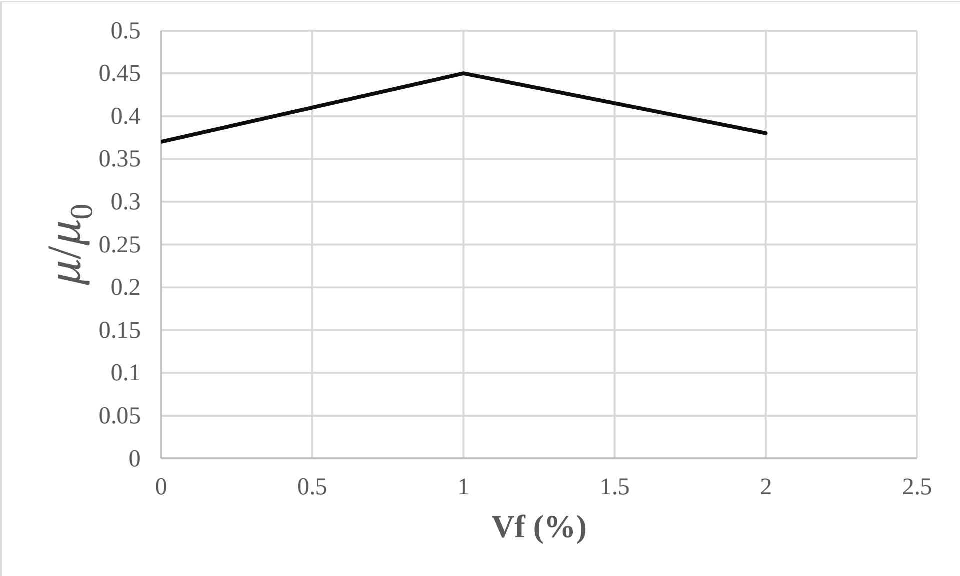


Figure 4.15: Ratio of ductility to that of the control specimen versus hybrid fibre volume fraction graph

Table 4.6: Ductility ratio

Vf	μ/μ_o
0	0.37
1	0.45
2	0.38

4.4.5 Cracking Pattern

Cracking happen when the controlled beam has start to fail. Cracking pattern for control beam without opening, beam with Vf = 0%, Vf = 1% and Vf = 2% are shown in Figure 4.16, Figure 4.17, Figure 4.18 and Figure 4.19.

Figure 4.16: Cracking pattern for control beam without opening

Figure 4.17: Cracking pattern for control beam contain 0% of hybrid fibre

Figure 4.18: Cracking pattern for beam contain 1% of hybrid fibre

Figure 4.19: Cracking pattern for beam contain 2% of hybrid fibre

Table 4.7: Mode of failure of beam

Sample	Load on 1st crack	Mode of failure
Beam without opening	261 kN	Bending
Vf = 0%	161 kN	Shear
Vf = 1%	200 kN	Shear
Vf = 2%	165 kN	Shear

From the figures above, it is apparent that most of the beams show cracking propagation between the loading and support point. During testing, it was observed that all beams with opening at the end will failed in shear mode.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

In this chapter, it conclude all the findings of the study and the results from previous chapter. The objectives of this study the effect of hybrid fibre on the structural behaviour of reinforced concrete beam with opening. Four types of beam with different fraction volume of hybrid fibre ranging from 0% to 2% were tested. All the concrete samples had subjected to water curing for 7 and 28 days before undergo compressive and flexural test.

5.2 Conclusion

Based on the results and analysis from Chapter 4, the following conclusions are drawn for the experimental works:

i. The addition of hybrid fibre containing kenaf fibre and steel fibre in concrete mix showed insignificant effect in compressive strength. The compressive strength for both sample with 1% and 2% hybrid fibre reduced 6.74% and 23.40% respectively as compared with normal concrete.

ii. The addition of hybrid fibre containing kenaf fibre and steel fibre in concrete mix obtained lower compressive strength but still achieve design strength which is 25MPa.

iii. Reinforced concrete beam with addition of hybrid fibres will show better performance as there is no excessive cracking until the structure had failed.

iv. The ultimate load for beam with hybrid fibre is higher than plain concrete. The combination of kenaf fibre and hybrid fibre helps in enhancing the strength of beams when introduced into plain concrete

v. The load carrying capacity (Pmax) for control beam is higher compared to beam with hybrid fibre. This is because most of the fibres were pulled out from the matrix (as it was not fully dried and hardened) instead of fibres rupture. This phenomenon also has some effect towards the strength of the structure as higher strength was needed to rupture the fibre during the pull-out phase (Mohsin *et al.*, 2016).

vi. Mode of failure of the beam with opening at the end is shear failure. The opening near the support causing the beam to fail in shear failure.

vii. The ductility is enhanced as 1% hybrid fibre is added but there is a limit exist which additional fibres lead to less ductile due to "over reinforced" behaviour associated with reinforced concrete design where too much reinforcement leads to a reduction rather than an increase in ductility.

viii. The reduction of strength in reinforced concrete beam with addition of hybrid fibre is due to the existing of honeycomb. Honeycomb are serious problems which not only reduces the strength of concrete but also makes the reinforcement vulnerable.

5.3 Recommendations for the Future Research

In this research, some recommendations have been identified which need to be carry out further investigation in order to provide more reliable data for better development of reinforced concrete beam with opening structures in the future works. The following idea are suggested for the present research by:

i) Studying the effect of different type of fibre on behaviour of reinforced concrete beam with opening.

ii) Considering different method in strengthening the beam (strengthen the beam externally)

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APPENDIX A
CALCULATION FOR STEEL FIBRE AND KENAF FIBRE

Cube size: 150 x 150 x 150 (mm)

Beam size: 150 x 400 x 1200 (mm)

Density kenaf fibre = 550-1400kg/m^3

Assume density (kenaf fibre) = 650kg/m^3

Density steel fibre = 7400-8100kg/m^3

Assume density (steel fibre) = 7800kg/m^3

Cube:

Volume of cube + 20% waste = 0.00405m^3

0.5% kenaf = 0.00405 x (0.5% x 650) = 0.013kg

1% kenaf = 0.00405 x (1% x 650) = 0.026kg

0.5% steel fibre = 0.00405 x (0.5% x 7800) = 0.158kg

1% steel fibre = 0.00405 x (1% x 7800) = 0.316kg

Beam:

Volume of beam + 20% waste = 0.0864m^3

0.5% kenaf = 0.0864x (0.5% x 650) = 0.28kg

1% kenaf = 0.0864x (1% x 650) = 0.56kg

0.5% steel fibre = 0.0864x (0.5% x 7800) = 3.37kg

1% steel fibre = 0.0864x (1% x 7800) = 6.74kg

Volume of beam + 20% waste = 0.0864m^3

Control beam (ingredient for 1 beam)

Coarse aggregate = 0.0864 x 1142.44 = 98.707kg

Fine aggregate = 0.0864 x 615.16 = 53.15kg

Cement = 0.0864 x 452.4 = 39.087kg

Water = 0.0864 x 190 = 16.416L

Beam with 1% hybrid fibre (ingredient for 1 beam)

Coarse aggregate = 0.0864 x 1142.44 = 98.707kg

Fine aggregate = 0.0864 x 615.16 = 53.15kg

Cement = 0.0864 x 452.4 = 39.087kg

Water = 0.0864 x 190 = 16.416L

Kenaf fibre = 0.28kg

Steel fibre = 3.37kg

Beam with 2% hybrid fibre (ingredient for 1 beam)

Coarse aggregate = 0.0864 x 1142.44 = 98.707kg

Fine aggregate = 0.0864 x 615.16 = 53.15kg

Cement = 0.0864 x 452.4 = 39.087kg

Water = 0.0864 x 190 = 16.416L

Kenaf fibre = 0.56kg

Steel fibre = 6.74kg

Volume of cube + 20% waste = 0.00405m^3

Control cube (ingredient for 1 cube)

Coarse aggregate = 0.00405 x 1142.44 = 4.627kg

Fine aggregate = 0.00405 x 615.16 = 2.49kg

Cement = 0.00405 x 452.4 = 1.832kg

Water = 0.00405 x 190 = 0.77L

Cube with 1% hybrid fibre (ingredient for 1 cube)

Coarse aggregate = 0.00405 x 1142.44 = 4.627kg

Fine aggregate = 0.00405 x 615.16 = 2.49kg

Cement = 0.00405 x 452.4 = 1.832kg

Water = 0.00405 x 190 = 0.77L

Kenaf fibre = 0.013kg

Steel fibre = 0.158kg

Cube with 2% hybrid fibre (ingredient for 1 cube

Coarse aggregate = 0.00405 x 1142.44 = 4.627kg

Fine aggregate = 0.00405 x 615.16 = 2.49kg

Cement = 0.00405 x 452.4 = 1.832kg

Water = 0.00405 x 190 = 0.77L

Kenaf fibre = 0.026kg

Steel fibre = 0.316 kg

APPENDIX B
CONCRETE MIX DESIGN FORM

Faculty of Civil Engineering & Earth Resources
Universiti Malaysia Pahang

Universiti Malaysia PAHANG

TABLE 1: CONCRETE MIX DESIGN FORM

JOB TITLE: ....

Stage	Item	Reference or Calculation	Values
1	1.1 Characteristic strength	Specified	25 N/mm2 at 28 days
			Proportion Defective (10) % k = 1.28
	1.2 Standard Deviation	Table 1.1	6 N/mm² or no data ____ N/mm²
	1.3 Margin	C1 or Specified	(k = 1.28) 1.28 x 6 = 7.68 N/mm²
	1.4 Target mean Strength	C2	7.68 + 25 = 32.68 N/mm²
	1.5 Cement type	Specified	(OPC) SRPC/RHPC
	1.6 Aggregate type : coarse Aggregate type : fine		Crushed/uncrushed Crushed/uncrushed Refer BS
	1.7 Free – water/cement ratio	Table 1.3, Figure 2	0.42 ✓
	1.8 Maximum free-water cement ratio	Specified	0.42 Use the lower value
2	2.1 Slump or Vebe Time	Specified	Slump 75 mm or Vebe time 3 s
	2.2 Maximum aggregate size	Specified	20 mm $\frac{2}{3} \times 180 + \frac{1}{3} \times 210 = 190$
	2.3 Free water content	Table 2.1	190 kg/m³ [190 kg/m³]
3	3.1 Cement Content	C3	190 / 0.42 = 452.4 kg/m³
	3.2 Maximum cement content	Specified	____ kg m³ } refer BS
	3.3 Minimum cement content	Specified	____ kg m³ }
	~~3.4 Modified free-water/cement~~ ratio		use 3.1 if < 3.2 use 3.3 if > 3.1 [kg/m³]
4	4.1 Relative density of aggregate (SSD)		____ known/assumed → sieve analysis
	4.2 Concrete density	Figure 3	2400 kg m³
	4.3 Total Aggregate content	C4 Density − cpr − cement	2400 − 190 − 452.4 ↗ 1757.6 kg/m³ [1757.6 kg/m³]
5	5.1 Grading of fine aggregate	Percentage passing (600) µm sieve	60 % → produce curve sieve analysis
	5.2 Proportion of fine aggregate	Figure 4	30.40 (35%) %
	5.3 Fine aggregate content	} C5	35% x 1757.6 = [615.16 kg/m³] m/s 2l
	5.4 Coarse aggregate content	} C5	____ x ____ = [(1142.44) kg/m³] 615.16 − 1757.6 (ignore -ve)

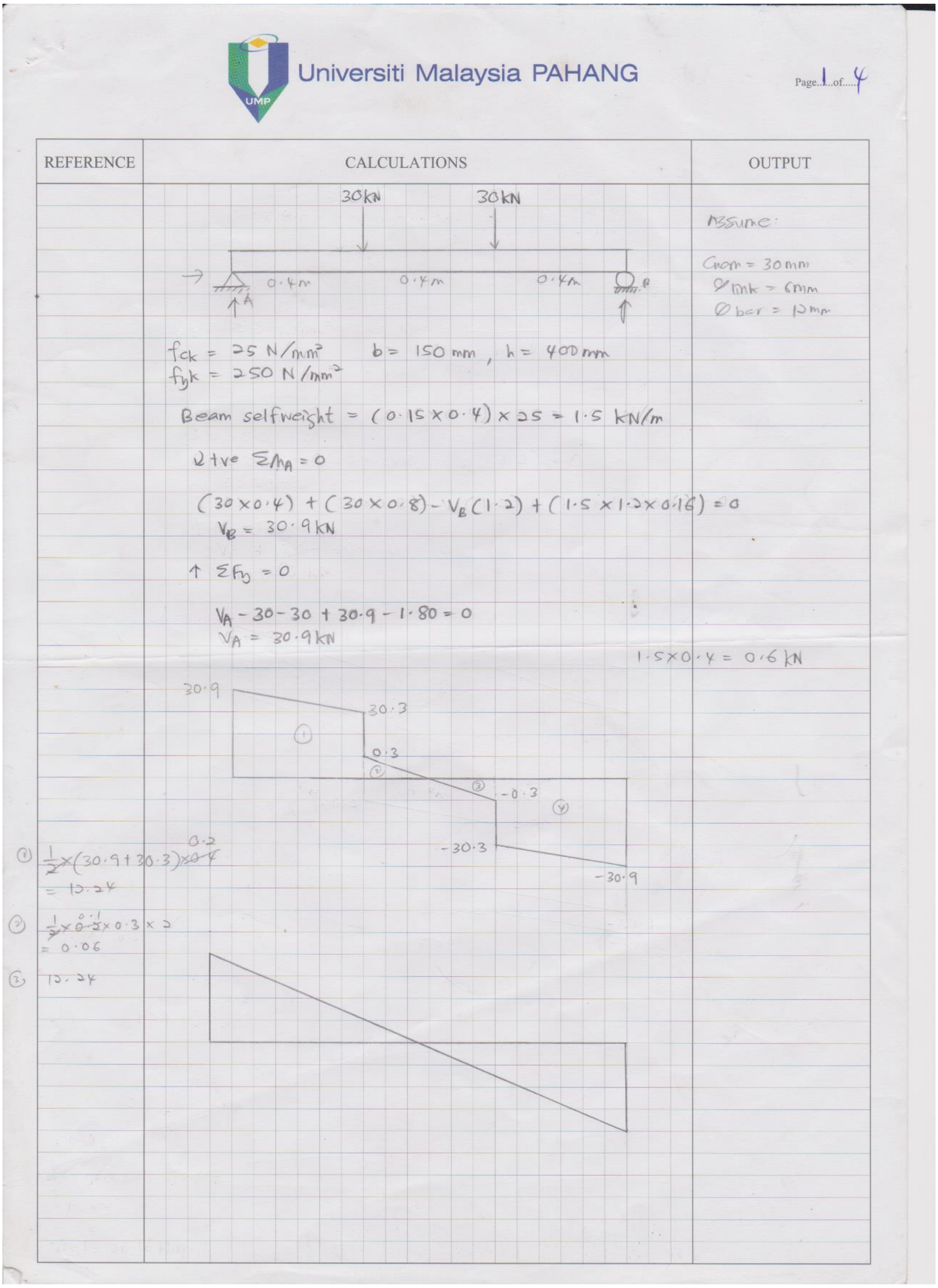
Quantities	Cement (kg)	Water (kg or L)	Fine Aggregate (kg)	Coarse Aggregate (kg) 10 mm	20 mm	40mm
Per m³ (to nearest 5 kg)	452.4	190	615.16		1142.44	
Per trial mix of ____ m³						

1 N/mm² = 1 MN m² = 1 MPa
OPC = ordinary Portland cement; SRPC = sulphate-resisting Portland cement; RHPC = rapid-hardening Portland cement.
Relative density = specific gravity
SSD = based on a saturated surface-dry basis.

22

APPENDIX C

BEAM DESIGN CALCULATION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Page 1 of 4

REFERENCE	CALCULATIONS	OUTPUT
	30kN, 30kN; A, B; 0.4m, 0.4m, 0.4m	Assume:
		C_{nom} = 30 mm
		ϕ_{link} = 6mm
		ϕ_{bar} = 12mm
	f_{ck} = 25 N/mm², b = 150 mm, h = 400 mm	
	f_{yk} = 250 N/mm²	
	Beam selfweight = (0.15 × 0.4) × 25 = 1.5 kN/m	
	+ve $\Sigma M_A = 0$	
	(30 × 0.4) + (30 × 0.8) − V_B(1.2) + (1.5 × 1.2 × 0.16) = 0	
	V_B = 30.9 kN	
	↑ $\Sigma F_y = 0$	
	V_A − 30 − 30 + 30.9 − 1.80 = 0	
	V_A = 30.9 kN	
		1.5 × 0.4 = 0.6 kN
	30.9, 30.3, 0.3, −0.3, −30.3, −30.9; ①, ②, ③, ④	
① ½ × (30.9 + 30.3) × 0.2 = 12.24		
② ½ × 0.1 × 0.3 × 2 = 0.06		
③ 12.24		

REFERENCE	CALCULATIONS	OUTPUT

MAIN REINFORCEMENT

$d = h - C_{nom} - \varnothing_{link} - 0.5\varnothing_{bar}$
$= 400 - 30 - 6 - 0.5(12)$
$= 358\ mm$

$d' = C_{nom} + \varnothing_{link} + \varnothing_{bar}/2$
$= 30 + 6 + 6$
$= 42\ mm$

Design bending moment, $M_{Ed} = 12.24\ kNm$

$$K = \frac{M}{bd^2 f_{ck}} = \frac{12.24 \times 10^6}{150 \times 358^2 \times 25} = 0.0255 < K_{bal} = 0.167$$

$$z = d\left[0.5 + \sqrt{0.25 - \frac{0.0255}{1.134}}\right] = 0.98d \geq 0.95d$$

$$A_s = \frac{12.24 \times 10^6}{0.87 \times 250 \times 0.95 \times 358}$$
$= 165.47\ mm^2$

Provide 2H 12 ($226\ mm^2$)

$$A_{s,min} = 0.26 \times \frac{2.6}{250} \times 150 \times 358$$
$= 145.21\ mm^2$

$A_{s,max} = 0.04 \times 150 \times 400$
$= 2400\ mm^2$

SHEAR REINFORCEMENT

Design shear force, $V_{Ed} = 30.9\ kN$

$$V_{Rd,max} = \frac{0.36 \times 25 \times 150 \times 358 \left(1 - \frac{25}{250}\right)}{1 + \tan 45^\circ}$$

$= 217.49\ kN$

$V_{Ed} < V_{Rd,max}$

$$\frac{A_{sw}}{s} = \frac{30.9 \times 10^3}{0.78 \times 250 \times 358 \times 2.5}$$
$= 0.177$

REFERENCE	CALCULATIONS	OUTPUT
	$\frac{A_{sw}}{s} = 0.177$	
	$A_{sw} = 57\ mm^2$	
	$s = \frac{57}{0.177} = 322\ mm$	
	Max spacing $= 0.75d = 0.75 \times 358 = 268.5\ mm$	use : H6-250
	Minimum link	
	$\frac{A_{sw}}{s} = \frac{0.08 \times 150 \times \sqrt{25}}{250}$	
	$\frac{A_{sw}}{s} = 0.24$ $A_{sw} = 57\ mm^2$	
	$s = \frac{57}{0.24} = 237.5\ mm$	
	$0.75 \times d = 0.75 \times 358 = 268.5\ mm$	use : H6-225
	$V_{min} = \frac{57}{225} \times 0.78 \times 250 \times 358 \times 2.5$ $= 44.2$	
	$\Delta F_{td} = 0.5\ V_{Ed} \cot\theta$ $= 0.5 \times 30.9 \times 2.5$ $= 38.63\ kN$	
	$A_s = \frac{38.63}{0.87 \times 250} = 0.178$	
	DEFLECTION	
	$\rho = \frac{165}{150 \times 358} = 0.003$	
	$\rho_0 = 25^{1/2} \times 10^{-3} = 0.005$	
	$\rho \leq \rho_0$	
	$\frac{l}{d} = 1\left[11 + 1.5\sqrt{25}\left(\frac{0.005}{0.003}\right) + 3.2\sqrt{25}\left(\frac{0.005}{0.003} - 1\right)^{3/2}\right]$ $= 32.21$	
	$\frac{A_{s,prov}}{A_{s,req}} = \frac{226}{165.47} = 1.37$	

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REFERENCE	CALCULATIONS	OUTPUT
	$\left(\frac{l}{d}\right)_{allowable} = 32.21 \times 1.37$	
	$= 44.13$	
	$\left(\frac{l}{d}\right)_{actual} = \frac{1200}{358} = 3.35$	
	$\left(\frac{l}{d}\right)_{allowable} > \left(\frac{l}{d}\right)_{actual}$	OK!
	<u>CRACKING</u>	
	Limiting crack width, w_{max} = 0.3mm	
	Max allowable bar spacing = 200mm	
	Bar spacing,	
	$S = 150 - 2(30) - 2(6) - 12$	
	$= 66mm < 200mm$	OK!

APPENDIX D

PHOTOS OF LABORATORY PREPARATION