MECHANICAL BEHAVIOUR OF CONCRETE ADDED WITH BAMBOO FIBRE

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ABSTRACT

The rapid population growth around the world has caused the housing demands to increase rapidly. More infrastructures and buildings are required in order to facilitate the expanding population. This phenomenon has caused the demands on construction materials such as concrete to increase as well. Concrete has many advantages including low cost, high availability, low maintenance, high compressive strength and durability, concrete's low tensile strength requires it to be reinforced with high tensile strength materials. The addition of natural fibre into fresh concrete can increase the ductility of the concrete matrix. This study aims to investigate the workability, compressive strength, and flexural strength of concrete added with bamboo fibre. The addition of bamboo fibre is divided into three different percentages namely 0.5%, 1.0% and 1.5% based on the volume of the concrete mixture. The slump test was carried out to determine the workability of the concrete, while the compression test and flexural test were performed to determine the compressive strength and flexural strength, respectively. The workability and compressive strength decreased when more bamboo fibre was added into the concrete, yet the flexural strength increased when more bamboo fibre was added. In conclusion, this study presents an experimental investigation on the mechanical behaviour of bamboo fibre reinforced concrete.

ABSTRAK

Pertumbuhan penduduk yang rapid di seluruh dunia telah menyebabkan permintaan atas perumahan meningkat dengan pesat. Lebih banyak infrastruktur dan bangunan diperlukan bagi memudahkan bilangan penduduk yang semakin berkembang. Fenomena ini telah menyebabkan permintaan ke atas bahan pembinaan seperti konkrit turut meningkat. Konkrit mempunyai banyak kelebihan termasuk kos yang rendah, ketersediaan yang tinggi, penyelenggaraan yang rendah, kekuatan mampatan dan ketahanan yang tinggi, manakala kekuatan tegangan konkrit yang rendah memerlukan ia diperkukuhkan dengan bahan yang mempunyai kekuatan tegangan yang tinggi. Penambahan serat semula jadi ke dalam konkrit boleh meningkatkan kemuluran matriks konkrit. Kajian ini bertujuan untuk menyiasat kebolehkerjaan, kekuatan mampatan dan kekuatan lenturan konkrit selepas ditambah dengan serat buluh. Penambahan serat buluh dibahagikan kepada tiga peratusan yang berbeza iaitu 0.5%, 1.0% dan 1.5% berdasarkan jumlah isi padu campuran konkrit. Ujian kemerosotan telah dijalankan untuk menentukan kebolehkerjaan konkrit, manakala ujian mampatan dan ujian lenturan telah dijalankan untuk menentukan kekuatan mampatan dan kekuatan lenturan masing-masing. Kebolehkerjaan dan kekuatan mampatan menurun apabila lebih banyak serat buluh telah ditambah ke dalam konkrit, namun kekuatan lenturan meningkat apabila lebih banyak serat buluh telah ditambah. Kesimpulannya, kajian ini membentangkan siasatan secara ujikaji ke atas tingkah laku mekanikal konkrit bertetulang serat buluh.

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LIST OF SYMBOLS

%	Percentage
m^3	Cubic metre
mm	Millimetre
N/mm^2	Newton per millimetre square
kg	Kilogram
N	Newton
°C	Degree Celsius
w/c	Water to cement ratio
mm^2	Millimetre square
μm	Micrometre
MPa	Mega Pascal
±	Plus-Minus

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
B0	0% of Bamboo Fibre
B05	0.5% of Bamboo Fibre
B10	1.0% of Bamboo Fibre
B15	1.5% of Bamboo Fibre
BS	British Standard
CEM I	Portland Cement Type I
EN	European Standards
FA	Fly Ash
HBC	High Belite Cement
MS	Malaysia Standard
OPC	Ordinary Portland Cement
SF	Silica Fume
YTL	YTL Corporation Berhad

CHAPTER 1

INTRODUCTION

1.0 BACKGROUND

The rapid population growth around the world has caused the housing demands to increase rapidly. More infrastructures and buildings are required in order to facilitate the expanding population. This phenomenon has caused the demands on construction materials such as concrete and steel rebar to increase as well. Ghavami (2005) stated that the present energy crisis provoked by the industrial over-growth has resulted in the increasing anxieties about environmental degradation and managing the energy resources still available. The concept of environmentally friendly technology has inspired the researchers to do more in protecting the environment. Therefore, there is an intense on-going search for non-polluting renewable materials which helps to improve the concrete performance.

Concrete is essentially a mixture of cement, aggregates and water. It is widely used in construction industry because all the raw materials required are widely available and are of low cost. Concrete is very strong in compression but it has a very low tensile strength. To improve its tensile strength, various fibres such as steel fibre, glass fibre, natural fibre, and synthetic fibre are also used to improve the properties of concrete, mainly enhancing the tensile strength.

Ghavami (2005) also proposed that the selection of materials especially in this era of industrialization is based mainly on the price, availability and the type of facility used for production or processing. Bamboo appears to meet the requirement as it reaches its full growth in just a few months and reaches its maximum mechanical resistance in just few years. Bamboo is considerably cheap because according to Ghavami (2005), it is rich in tropical and subtropical regions around the world.

1.1 PROBLEM STATEMENT

Concrete is one of the most commonly used materials in construction around the world. Although it has many advantages including low cost, high availability, low maintenance, high compressive strength and durability, concrete's low tensile strength requires it to be reinforced with high tensile strength materials. Typically, in the construction industry, steel, in the form of rebar, is used to reinforce concrete, but the cost of rebar in many developing countries including Malaysia is relatively high compared to the average income. Therefore, minimal rebar is often used by developers to reinforce concrete homes and buildings, leading to unsafe structures.

Studies were carried out in order to enhance the concrete's tensile strength itself in the respect of reducing size of steel rebar to be used to reinforce concrete, while restricting the structure failure. Adding various fibres which possessed high tensile strength into the concrete was found to be a way to enhance the concrete's tensile strength.

Inspired by a vision of sustainability, bamboo fibre was selected as the additive in this study because bamboo has an economical advantage as it reaches its full growth in just a few months. Moreover, bamboo exists in abundance in Malaysia. Thus, utilizing bamboo fibre as an additive in concrete tends to become a considerable solution to promote safer structure while minimal rebar is used.

1.2 RESEARCH OBJECTIVES

The main aim of this study is to determine the possibility on increasing the flexural strength of conventional concrete by adding various quantities of bamboo fibre as an additive. The other objectives of this study are stated as follow:

i. To determine the workability of the concrete added with bamboo fibre which is 0.5%, 1.0% and 1.5% of mixture volume.
ii. To determine the compressive strength of the concrete added with bamboo fibre which is 0.5%, 1.0% and 1.5% of mixture volume.
iii. To determine the flexural strength of the concrete added with bamboo fibre which is 0.5%, 1.0% and 1.5% of mixture volume.
iv. To compare the workability, compressive and flexural strength between normal concrete and concrete with additive (bamboo fibre)

1.3 SIGNIFICANCE OF STUDY

The adoption of agriculture fibres such as bamboo fibre as an additive in concrete, enhancing concrete's tensile strength would bring significant impacts to the construction industry. The low tensile strength of concrete is always been a concern whenever the concrete is used. Therefore, introducing bamboo fibre as an additive in concrete to enhance the tensile strength would help to minimize the adoption of steel rebar, as well as reduce the construction cost. In terms of novelty, the success of this study will help to understand the behaviour of the concrete when bamboo fibre is added.

1.4 SCOPE OF WORK

There are several scopes covered in this study, as listed below:-:

i. The grade 30 concrete are designed using bamboo fibre, crushed granite, river sand, Ordinary Portland cement, and tap water.
ii. The dimensions of cube and beam chosen for compressive test and flexural test are 150 mm x 150 mm x 150 mm and 100 mm x 100 mm x 500 mm respectively. The specimens are tested at the curing age of 7^{th}, 14^{th} and 28^{th} days referencing

the BS 1881: Part 116 (compressive strength) and ASTM C78 / C78M – 15a (flexural strength).

iii. The bamboos from the same source are used in this study, which it means to be the same type of bamboo.

iv. The bamboo fibre used is 40 mm long and approximately 2 mm thick.

v. The proportions of bamboo fibre added into the concrete were namely 0.5%, 1.0%, and 1.5% of the concrete volume.

1.5 EXPECTED OUTCOME

The expectations were listed as follow when the concrete is added with bamboo fibre:

i. The workability of the concrete will decrease when more bamboo fibre is added into the concrete, yet the degree of workability shall lie in the acceptable range, i.e. 75 ± 25 mm.

ii. The flexural strength of the concrete with bamboo fibre addition will be higher than the normal concrete

iii. The flexural strength of the concrete with bamboo fibre addition will increase along with the volume of bamboo fibre added into the concrete.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

This chapter reviews the past relevant literatures, which include the characteristics of materials and the research methodology. Besides, the past researches on fibres added into concrete and the characteristics of bamboo are also discussed.

2.1 CONCRETE

Concrete is an artificial product, commonly used in the construction. Concrete is highly demanded in construction as its low cost, low maintenance, high compressive strength and durability had made it advantageous. Typically, concrete is a composite material which is made from cement, gravel, sand, and water. Admixtures are sometimes added into the concrete mixture. The materials are mixed in appropriate proportions to produce concrete as per designed depending on the requirement of the structures. In tradition, the composition of concrete is simple. However, the modern concrete is of complex mix, with intention to ensure the durability and longevity of concrete (Branston, 2006).

2.1.1 Durability of Concrete

Durability of concrete is one of the requirements under predicted exposure condition during its service life span. One of the examples influencing the durability of concrete is permeability which is caused by the ingress of water, carbon dioxide, oxygen, sulphate, chloride, and other harmful substances (Neville and Brooks, 1987). This is due to the micro and macro-cracks and voids developed during concrete production (Gambhir, 2008). Different grade of aggregate would affect the permeability of concrete. Gap-graded aggregate would result in higher permeability. Besides, a uniform graded aggregate results in lower permeability in concrete production (Mobasher and Mitchell, 1988). Helmuth (1994) found that the increases of size of the aggregate will cause permeability increases in concrete production. The factors which reduce the penetration of the concrete protecting the reinforcement from ingress of external moisture and to prevent reinforcement from corrosion are low water to cement ratio, good compaction, adequate curing and an adequate concrete cover (Neville and Brooks, 1987).

2.2 CEMENT

Cement is the main component in producing concrete. Nawy (2008) propose that Portland cement is by far the most important member of the family of hydraulic cements which is the cement that hardens through chemical reaction with water.

According to Portland Cement Association (2010), Portland cement is a closely controlled chemical combination of calcium, silicon, aluminium, iron, and small amounts of other ingredients to which gypsum is added in the final grinding process to regulate the setting time of the concrete. In the combination of cement products, lime and silica make up about 85% of the mass and the common materials used in its manufacture are limestone, shells, and chalk or marl combined with shale, clay, slate or blast furnace slag, silica sand and iron ore.

There are many types of cement in the market, such as Portland pozzolan cement, Portland blast-furnace slag cements, expansive cements, high-alumina cement and etc.

Nawy (2008) stated that the usage of different types of cement depends on its distinct characteristics. Ordinary Portland cement (OPC) is one of the most common cement used around the world in this modern era. OPC, a hydraulic binder obtained from limestone and clay, is traditionally used for buildings and structures. According to Sui et al. (2004), high belite cement (HBC) has better strength when cured after 7 days and results in higher late strength as compared to OPC. However, HBC concrete exhibits higher compatibility with concrete admixtures, freeze-thaw resistance, permeability resistance, carbonation resistance, less shrinkage and better workability, under low water to cement ratio (0.25).

2.3 WATER TO CEMENT RATIO

Water is another important component in producing concrete. The ratio of water to cement (w/c) is the key factor to determine the concrete strength. Nawy (2008) states that concrete with lower w/c ratio yields with higher strength, while higher w/c ratio yields with a lower strength. The increment on w/c ratio would result in lower temperature, and minimize the shrinkage problem. However, the increase of the w/c ratio would tend to corrode the reinforcement bar (Masood et al., 2003). In addition, Nawy (2008) suggested that the w/c ratio also affects the workability and consistency of the concrete during production.

2.4 AGGREGATE

Oxford dictionary defined aggregate as sand or broken stone that is used to make concrete or for building roads, etc. In civil engineering, aggregate is defined as a mass of crushed stone, gravel, sand, and etc, predominantly composed of individual particles, but in some cases, including clay and silts (Nawy, 2008). Aggregate is mainly used as an underlying material for foundations and pavements. Also, aggregate is one of the main components in concrete in which it contributes 70% to 80% of volume in concrete, thus it has large influences on the concrete properties (Alexander and Mindess, 2005).

The role of aggregate in concrete mixture is to provide better dimensional stability, durability and wear resistance. Absence of the aggregates would cause the large castings of neat cement paste to be self-destruct upon drying. Production of natural aggregate is cheaper than producing Portland cement, thus the introduction of aggregate into concrete makes concrete to be more economical. Of course, the aggregates in composition of concrete should be clean and free from impurities, such as clay, salt, dirt or other matter (Nawy, 2008).

2.4.1 Coarse Aggregate

Coarse aggregate normally occupies 2/3 of total volume of aggregate in concrete. The shape and surface texture of coarse aggregate would affect the concrete strength. Experiments showed that compression strength of concrete with rough surface aggregate has 10% difference compared to the smooth aggregate (Perry & Gilliot, 1977). Alexander (1989) also agreed that the shape and texture of coarse aggregate have the direct effect on the concrete strength. Mehta and Monteiro (1997) suggested that only 15% of elongated and flat aggregate are allowed in producing concrete. This is due to the elongated and flat aggregate would reduce the compressive strength and thus increase the cement consumption in concrete production. Figure 2.1 shows the favoured shape of coarse aggregate to be used in concrete which is angular and slightly cubic while Figure 2.2 shows the (a) flat and (b) elongated aggregates which is not favoured in concrete production.

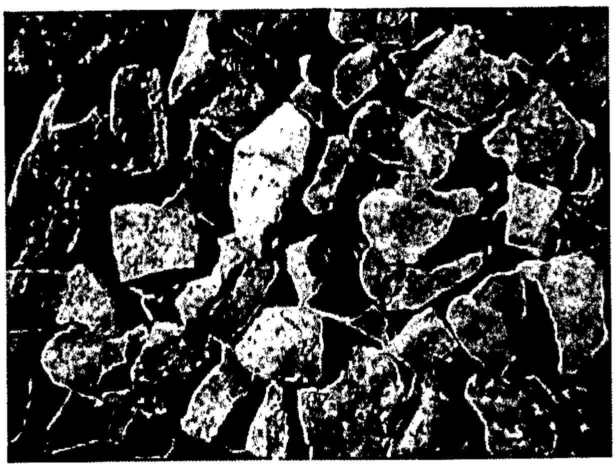
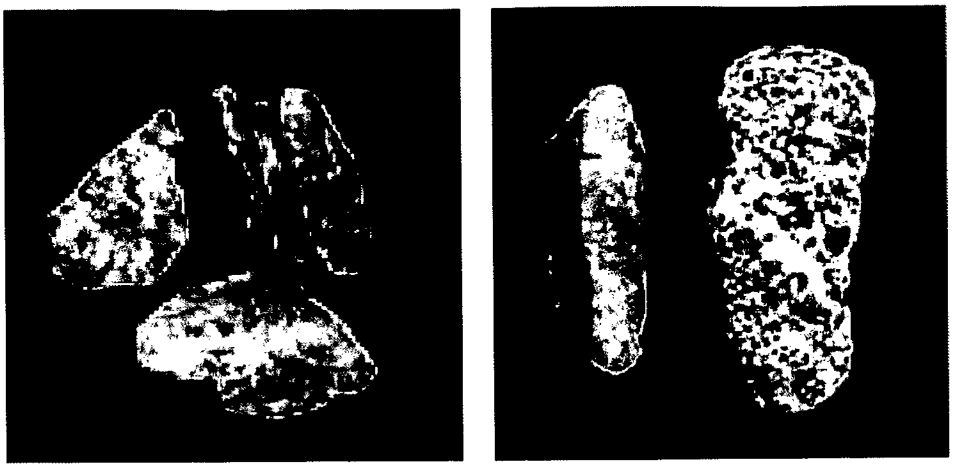


Figure 2.1: Angular and cubic shape aggregate



(a) (b)

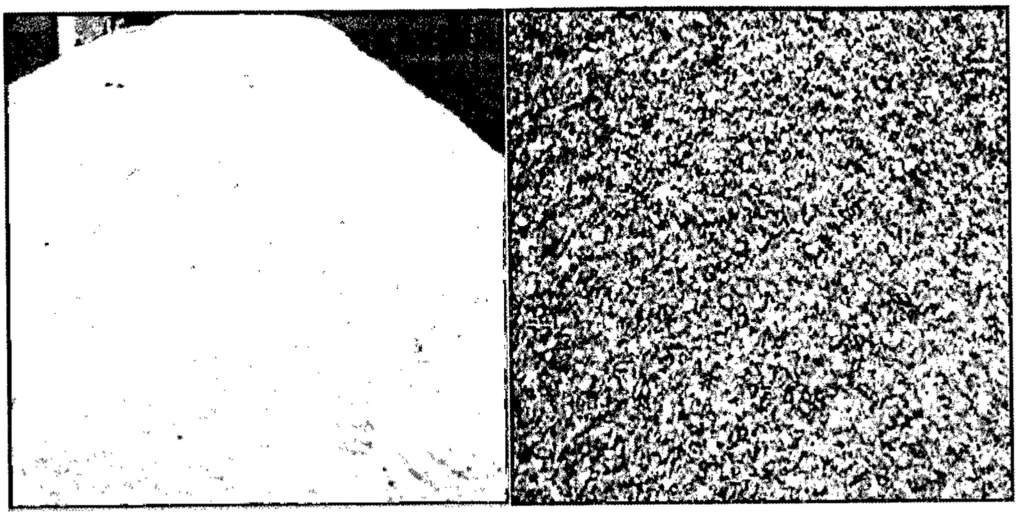
Figure 2.2: Not-to-be-favoured aggregate; (a) flat shape; (b) elongated shape

In addition, Popovics (1998) suggested that the concrete strength is dependent on the size of aggregate. Also, Washa (1998) stated that the concrete mixture with optimum aggregates size will produce better workability as well as reduce the shrinkage and creep in concrete. Taylor (1983) suggested that the nominal size of the coarse aggregate is 20 mm. This was further proven by the experiments carried out by Oh et al. (2002). The result showed that the size of 19 mm aggregate served higher strength as compared to 25 mm aggregate.

2.4.2 Fine Aggregate

According to Nawy (2008), fine aggregate consists of natural or manufactured particles ranging in size from 150 mm to 4.75 mm while Taylor (1983) suggested that the particles which passed through a 5mm sieve size is considered as fine aggregate. In concrete production, the size of fine aggregate is acceptable ranging between 4.75 mm to 75μm in which Chang et al. (2001) proposed that the finer aggregates have better positive effect on the properties of fresh concrete and hardened concrete.

Nawy (2008) also stated that the fine aggregate serves to mitigate the particle interlocking action when the fine and coarse aggregate are blended so that the fine aggregate is more than enough to fill in the voids within the coarse aggregate. Hudson (1999) proposed that using river sand in concrete is much better than using crushed stone sands. This is due to rounded and smooth surface of the river sand in which it works better for workability. Figure 2.3 shows the two different types of fine aggregate mentioned by Hudson (1999).



(a) (b)

Figure 2.3: Types of fine aggregate; (a) river sand; (b) crushed stone sand

2.5 CURING PROCESS

In achieving desired concrete strength and durability, concrete shall undergo curing process in which the concrete is protected from loss of moisture and kept within a reasonable temperature range. Steady hydration would result low level of permeability, high resistance to abrasion, reduction of plastic shrinkage, high concrete strength and quality (Newman and Ban, 2003). Curing process can be classified into two types: dry-air curing and water curing.

Dry-air curing is a curing method wherein the concrete cubes are left in open air to be cured at room temperature. Meanwhile, according to Kholia et al. (2013), water curing methods were divided into two groups: water adding technique and water retaining technique. Kholia et al. stated that the most often used curing method in the construction industry is the saturated wet covering method, which is one of the water adding technique. In this method moisture retaining fabrics such as burlap cotton mats and rugs are used as wet covering to keep the concrete in a wet condition during the curing period.

Study performed by Safuddin et al. (2007), the obtained experimental results indicated that the dry-air curing is not an efficient method to achieve good strengthen properties of concrete. Besides that, that water curing is the most effective method of curing as it produced highest level of compressive strength, dynamic modulus of elasticity and ultra-sonic pulse velocity, and lower level of surface absorption because of improved pore structure and lower porosity resulting from greater degree of hydration and pozzolanic reaction without any loss of moisture from the concrete specimen.

Zhang and Zhang (2006) were involved in the study of hydration of cement and pore structure of concrete cured in the tropical environment. The results obtained showed that the water curing at 20 °C had higher degree of cement hydration and lower capillary in the concrete as compared to the dry-air curing.

2.6 COMPRESSIVE STRENGTH

Compressive strength of concrete was defined as the resistance of concrete to resist compressive loads. The compressive strength of concrete was determined by using compression test, also known as cube test as illustrated in Figure 2.4. The compressive strength was calculated by force per unit area. The ultimate load, *w* was divided by the cross-sectional area subjected to the load. The cube test is normally conducted according to BS 1881: Part116: 1983 or ASTM C 39 – 03.

Figure 2.4: Compression test / Cube test

2.7 FLEXURAL STRENGTH

Flexural strength or modulus of rupture of the concrete is a measure of a concrete beam or slab to resist deformation under load. Flexural strength of the concrete is usually about 10 to 20% of the concrete's compressive strength. The flexural strength is expressed in MPa and it can be determined using 2 methods: third-point loading (referring to ASTM C 78) and center-point loading (referring to ASTM C 293). The methods are illustrated in Figure 2.5 and Figure 2.6.

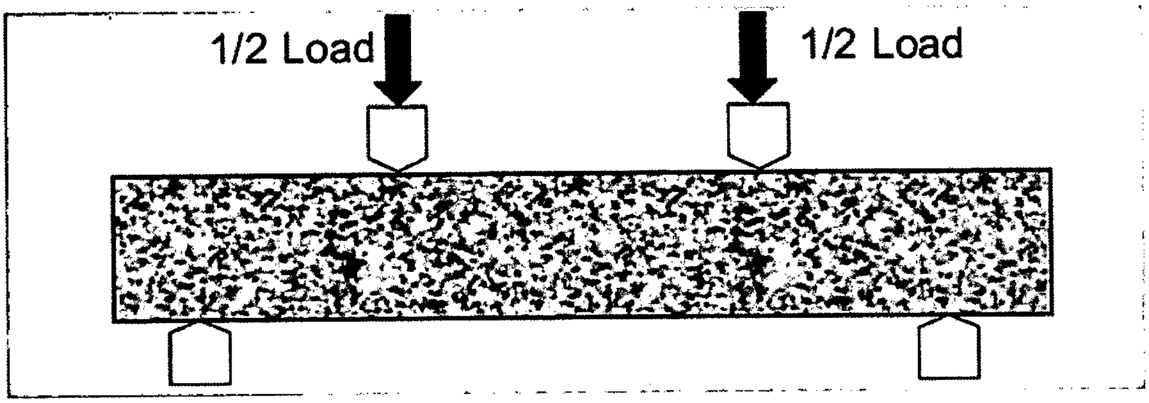


Figure 2.5: Third-Point Loading (ASTM C 78)

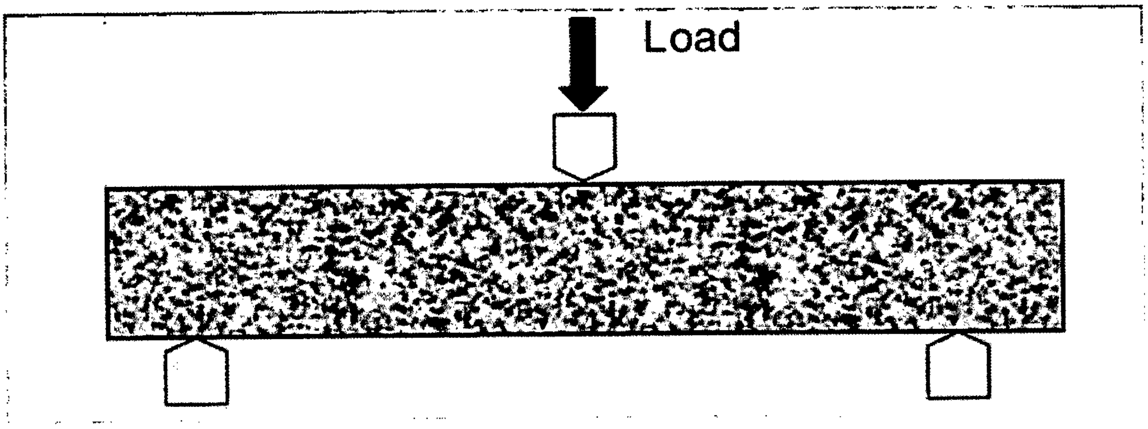


Figure 2.6: Center-Point Loading (ASTM C 293)

In the Third-Point Loading method, which is shown in Figure 2.5, half of the load is applied at each one third of the span length from the end. The maximum stress is presented over the center 1/3 portion of the beam. On the other hand, the Center-Point Loading method, which is shown in Figure 2.6, the entire load is applied at the middle of the span. The maximum stress is presented only at the center of the beam.

2.8 FIBRES REINFORCED CONCRETE

Torgal and Jalali (2011) said that promoting the use of concrete reinforced with vegetable fibres could be a way to improve concrete durability and also sustainable construction. Adding the short-fibre reinforcement in low volumes (less than 2-3%) can increase the fracture toughness of concrete that will help to control the width of crack that form due to the volume changes in concrete (Raoufi and Weiss, 2011). Besides, Shah and Weiss (2006) stated that when concrete cracks, fibres help to bridge a crack and transfer load across the crack. As such, fibre reinforcement will limit the extent of restrained shrinkage cracking by limiting the width of the crack that forms in concrete elements.

In the examination of SEM micrograph, of the composite fracture surfaces, Ni (1995) showed that the samples containing the weaker fibre had produced the expected higher population of broken fibres than samples containing the stronger fibres. Ni (1995) also suggested that the fibre strength was particularly important to composite toughness but not as important to the strength.

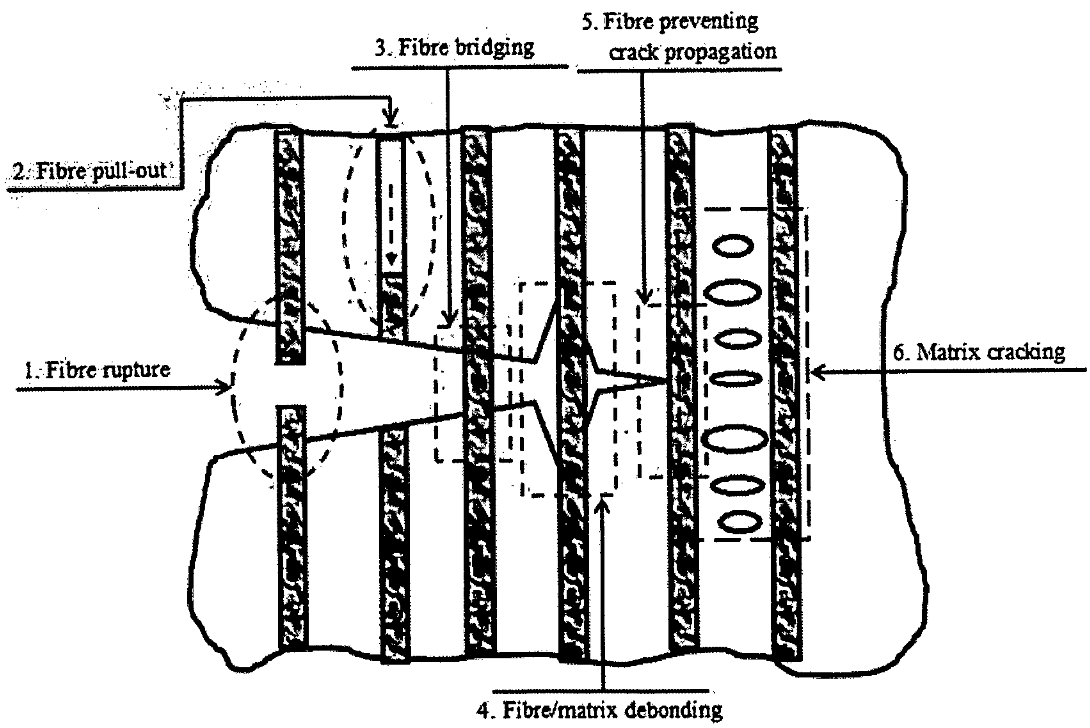


Figure 2.7: The mechanical behaviours of fibre in concrete.

Source: Zollo 1997