STUDY ON THE CONCRETE BEAM DEPTH REDUCTION BY USING STEEL FIBRE UNDER FLEXURAL LOAD

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ABSTRACT

Nowadays, the construction of high rise building was gradually increased as the demand of property increase. Construction of high rise building required large structural components to support the load. Therefore, the deep beam of the building will decrease the space of the interior building and not economically efficient because reduce the space of building. The experimental work presented herein was aimed to study on the concrete beam depth reduction by using steel fibre under flexural load. The hooked end steel fibres with aspect ratio of 80 were used. The dosage of steel fibres in concrete mix was based on the volume fraction of V_f = 0.4% (30kg/m^3). There were three tests such as compressive test, flexural test and modulus of elasticity carried out in this research. In order to determine the mechanical properties of the specimens, a total of 6 cylinders concrete which divided into 3 control cylinder, V_f = 0 % and 3 steel fibre cylinders and a total of 49 beams with different depth were casted. The dimension of the beam were 100mm for width and 500mm for length while the depth of steel fibre reinforced concrete (SFRC) beam various from 50mm, 60mm, 70mm, 80mm, 90mm, 100mm and 100mm of control beam which was plain concrete, V_f = 0%. Each of the depth casted for 7 beams. The dimension of cylinder concrete with 110mm in diameter and 200mm in height. The results indicate that the compressive strength of SFRC increase about 27.66% compared to the control specimen. Meanwhile, the concrete which included steel fibre highly enhanced the flexural of SFRC. The load for depths of 100mm SFRC beams was able to exceed all of the control beam while the 90mm depth of SFRC beams able to reach the load of the control beams. The result of modulus of elasticity was increased compare to control specimen. In conclusion, SFRC beam include steel fibre able to increase the compressive strength, flexural strength and modulus of elasticity.

ABSTRAK

Pada masa kini, pembinaan bangunan tinggi secara beransur-ansur meningkat kerana permintaan daripada peningkatan hartanah. Pembinaan bangunan tinggi diperlukan komponen struktur besar untuk menyokong beban. Oleh itu, rasuk dalam bangunan itu akan mengurangkan ruang bangunan dalaman dan tidak cekap dari segi ekonomi kerana mengurangkan ruang bangunan. Kerja-kerja eksperimen yang dibentangkan di sini adalah bertujuan untuk mengkaji pada rasuk pengurangan kedalaman konkrit dengan menggunakan gentian keluli bawah beban lenturan. Yang ketagih gentian keluli akhir dengan nisbah aspek 80 telah digunakan. Dos gentian keluli dalam campuran konkrit adalah berdasarkan kepada pecahan isipadu V_f = 0.4% (30kg/m^3). Terdapat tiga ujian seperti ujian mampatan, ujian lenturan dan modulus keanjalan yang dijalankan dalam kajian ini. Untuk menentukan sifat-sifat mekanik spesimen, sebanyak 6 silinder yang dibahagikan kepada 3 kawalan silinder, V_f = 0% dan 3 silinder gentian keluli dan sebanyak 49 rasuk dengan kedalaman yang berbeza telah dibaringkan. Dimensi rasuk adalah 100mm untuk lebar dan 500mm untuk panjang manakala kedalaman gentian keluli mengukuhkan konkrit (SFRC) rasuk pelbagai dari 50mm, 60mm, 70mm, 80mm, 90mm, 100mm dan 100mm kawalan rasuk yang konkrit biasa, V_f = 0%. Setiap kedalaman dibaringkan selama 7 rasuk. Dimensi konkrit silinder dengan diameter 110mm dan 200mm tinggi. Keputusan menunjukkan bahawa kekuatan mampatan SFRC meningkat kira-kira 27.66% berbanding dengan spesimen kawalan. Sementara itu, konkrit yang termasuk gentian keluli meningkatkan lenturan SFRC. Beban untuk kedalaman 100mm rasuk SFRC dapat melebihi semua rasuk kawalan manakala kedalaman 90mm SFRC rasuk dapat mencapai beban daripada rasuk kawalan. Hasil modulus keanjalan telah meningkat berbanding dengan mengawal spesimen. Kesimpulannya, SFRC rasuk termasuk gentian keluli dapat meningkatkan kekuatan mampatan, kekuatan lenturan dan modulus keanjalan.

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LIST OF SYMBOLS

%	Percent
±	Plus-Minus
®	Registered
TM	Trade Mark
mm	Millimeter
cm	Centimeter
kN	Kilo newton
MPa	Mega Pascal
GPa	Giga Pascal
kg	Kilogram
kg^{-1}	Per kilogram
m^3	Cubic meter
kg/m^3	Kilogram per cubic meter
m^2/ kg	Square meter per kilogram
N/mm^2	Newton per square millimeter
V_f	Volume Fraction
L_f	Length of steel fibre
d_f	Diameter of steel fibre
λ	Aspect Ratio
f_t	Tensile Strength
n_f	Number of fibres per kg
mins	Minutes
°C	Degree Celsius

LIST OF ABBREVATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British Standard
CB	Control Beam
FRC	Fibre Reinforced Concrete
FM	Fineness Modulus
JSCE	Japanese Society of Civil Engineers
PVC	Polyvinyl chloride
SFRC	Steel Fibre Reinforced Concrete
W/C	Water Cement Ratio
et al.	And others

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

High-rise buildings investment projects represent a component of the country's economy power and a sign of advantage to the country. Malaysia was one of the countries which involved in the progress to establish high rise investment projects. Within this few years, the development of high rise building can be clearly observed especially at Kuala Lumpur, Penang and Johor. The main building construction material was concrete. Concrete had been widely used as it can be casted in different types of shape such as rectangular, circular and hollow shape. Concrete have long service life compare to timber, steel and others materials. Although, concrete able to withstand high compressive strength but it was quasi-brittle material and easily cracked as it was weak in resisting external forces when small stress applies (Z. Wang, Yang, & Wang, 2011). Since, concrete was weak in tensile strength, it will cause sudden tensile failure without warning. In order to improve the weakness of concrete, many types of fibres had been widely used from the past history. The sun-baked bricks reinforced with straw were used to build the Aqar Quf near Baghdad and horsehair for reinforce masonry mortar. Besides that, asbestos fibres had been used for few 100 years, but due to health hazards occur from asbestos fibres, others types of fibres had been replaced (Wafa Labib and Nick Eden).

The first research on the potential of steel fibres to replacing reinforcement rode had been analysed at United States during early 1960s. After that, more details of the research development had been carried out and also applied on industry (Wafa Labib and Nick Eden). Glass fibre, synthetic fibre, natural fibre and steel fibre can be easily found at market. The mechanical and physical properties were difference for each type of fibre material.

For glass fibre, it had been applied in concrete since late 1950s. However, the ordinary glass fibres, such as borosilicate E-glass fibres, were affected by the cement paste which contain of alkali. Later on, more research and development was focus on producing glass fibres with containing zirconia which able to resist alkali. Hence, it had become the commercialized product and had been widely used in the United States. Currently, the glass fibres reinforced concrete were used for the production of architectural cladding panels for exterior used, many plant manufactured products and pre-packaged surface bonding products were used in housing applications (ACI Committee 544, 2001).

For synthetic fibres such as nylon and polypropylene had been used to mix with concrete but it were not successful as using steel or glass fibres. It was man-made fibres produce from research and development in the petrochemical and textile industries. In recent research, it was find out that synthetic fibre were able to use in construction elements because thin products produced with synthetic fibres able to retain integrity when support high ductility. Nowadays, synthetic fibre reinforces concrete widely used for slabs on grade, floor slabs and stay-in-place forms in multi-story buildings (ACI Committee 544, 2001).

Although there was not much research and development for natural fibre compare to other types of fibre, but recently research and development of natural fibre had been gradually increase. Natural fibre was one of the popular types of fibre which can be easily found from the market. It can be get at low cost and the manpower knows how to apply the technique by using natural fibre. Nowadays, natural fibres can manufacture thin sheet high fibre content fibre reinforces concrete (ACI Committee 544, 2001).

Steel fibres had been widely used compared to others types of fibre in reinforced concrete structures (Heng, R.Y. 2014). The addition of steel fibres or other types of fibre to concrete was unable to prevent cracking but to control the size of cracks of concrete (Wafa Labib and Nick Eden). Discrete fibres in concrete slabs or pavements were able to change the mechanical properties such as tensile, flexural, ductility, ultimate strength and toughness of the concrete. Many researches carried out study about the behaviour of steel fibre reinforced concrete under impact resistance compare to unreinforced concrete. The tensile and flexural strength of concrete improve by addition of steel fibre.

1.2 PROBLEM STATEMENT

Plain concrete was brittle and poor in tensile strength. The tensile and compressive strength of concrete were not proportional. Typically, plain concrete had the tensile strength from 8% to 15% of its compressive strength. It was easily to get first crack appear when the concrete was applied by high load, hence it will loses the service load. The concrete structure with collapse as it lack of post-peak resistance. The weakness of concrete can be traditionally overcome by adding reinforcing bar or prestressing steel. However, the usage of reinforcing bar or prestressing steel was not environmental friendly. When produced cement and steel, the process involved will emitted carbon dioxide and other types of gas which will cause air pollution. Therefore, by reducing the usage of cement and steel, the rate of global warming and water level rising will decrease.

Steel fibres can be added into concrete mix to minimize the usage of steel while maintain the integrity of concrete structure. Some investigation had been carried out; the reducing of the amount of shear links can be achieved especially in the joint area of reinforced concrete frames when mixed with steel fibre. The investigations showed that applying steel fibres instead of shear reinforcement giving structural benefits such as reducing the construction cost.

The construction of high rise building required large structural components to support the load acting on the structural members. Normally, the design engineer will design the structure with large components to make sure it was able to sustain high load. Therefore, the structural members such as slab, beam and column will be designed in the larger size. The larger size of the structural components will decrease the spatial of the building and also increase the cost of project.

Beam was the structural member which functions as resisting bending when load applied, therefore it play an important role in structural building. The purpose to carry out this research was to study the reduction depth of concrete beam by putting steel fibre to achieve the efficiency of economical and increase the interior space of the building.

1.3 OBJECTIVE

The objectives of this research are:

i. To determine the flexural load of beam specimens containing steel fibre
ii. To determine the optimum depth can be achieved by steel fibre in strengthening the flexural strength of the concrete.

1.4 SCOPE OF RESEARCH

The research was limited to the following matter as the steel fibres of STAHLCON® HE0.75/60 with hooked-end with amount of 0.40% of concrete volume were used in this research. The depth of steel fibre reinforced concrete beam were various from 50mm, 60mm, 70mm, 80mm, 90mm and 100mm, while the width and length was fixed to 100mm and 500mm respectively. The concrete design used referred to the characteristic of 30MPa using Ordinary Portland Cement (Type 1).

For compressive strength, the total of 6 cylinder specimens had been casted. Three control concrete cylinders and three steel fibre concrete cylinders used to test for the compressive strength at age of 28 days. For flexural test, a total of 49 beams had been casted. The depth from 50mm, 60mm, 70mm, 80mm, 90mm and 100mm had been casted for total of 42 steel fibres concrete beam, while control beam with depth of 100mm casted for 7 beams. All of the beam specimens tested by flexural machine at age of 7, 14 and 28 days. 2 beam specimens tested at age of 7 and 14 days while 3 specimens tested at age of 28 days. All of the control specimens were mixed without adding of steel fibre, V_f = 0%. The results obtained had been compared with the control beam to find out the optimum depth of steel fibre reinforced concrete.

1.5 RESEARCH SIGNIFICANCE

Steel fibre reinforced concrete (SFRC) was concrete which consist of materials such as cements, fine aggregate, coarse aggregate and discontinuous discrete steel fibres. Nowadays, ductility of concrete was considered by engineers in structural design. The SFRC will fail after the steel fibre breaks or was pulled out of the concrete when tension force applied. Since, the combination of concrete with steel fibres, it increase the mechanical properties of concrete in term of strength and durability. Through the experiment, the optimum depth of steel fibre reinforced concrete beam was determined and it was able to reduce the depth by comparing with control beam. Hence, the addition of steel fibre able to apply in construction field as it shortens construction time, indirectly reduce the construction cost.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Concrete without shear reinforced could sudden failed when shear stress subjected on it. However, the addition of fibre into concrete which known as fibre reinforced concrete was able to improve the concrete properties in all directions. Since, the size of fibre was small; it was dispersed randomly in the concrete during mixing. Fibre reinforced concrete was cement-based composite materials. The addition of fibre into concrete was able to increase flexural-tensile strength, spitting resistance, impact resistance, frost resistance and good in permeability.

There was many types of fibre can be found at market such as steel, plastic, glass and natural fibre. Each types of the fibre had its own characteristics properties. The cross section can be in circular, triangular or flat shape. The term of “toughness”, “tensile strength” and “cracking deformation” characteristics was able to improve when fibre mixed into concrete matrix. Before considered fibre reinforced concrete as a workable construction material, the cost of the materials of fibre must economically than exist reinforce system.

In summary, the combination of fibre with concrete improved the mechanical properties of concrete such as crack resistance and increase in toughness. There were several important factors which needed by fibre to improve mechanical properties of concrete such as mechanical properties of fibre, bonding properties, amount of fibre and distribution of fibre inside the concrete.

2.2 STEEL FIBRE

2.2.1 Overview of Steel Fibre

Steel fibre was the most widely used for structural and non-structural purposes which were used as a replacement for conventional steel fabric reinforcement. The physical properties and mechanical properties of the steel fibres were differences for different composition of steel fibre. By comparison with others types of fibre such as glass, synthetic and natural fibre, steel fibre able to strengthen and increase the ductility of the concrete. (Tantary, M. A . and Akhil , J.,2012)

Nowadays, steel fibres had been widely used in Malaysia. The application of steel fibres in Malaysia currently at industrial or residential flooring such as at jointed or join-less slab on grade and suspended slab on piles, shotcrete application, overlays, floor topping, precast products, segmental lining, cellar walls, blast-proof structures, safety vaults and etc. Some of the example of project which using steel fibres were SMART Tunnel, Hydroelectric at Ulu Jerai, Pahang, LCCT Expansion at Sepang Selangor, etc. ("Stahlcon Steel Fibre Technical Pamphlets," 2012).

In this research, steel fibres had been chosen to add into concrete. The reason using steel fibre because it can saves time and reduces construction costs as there was no labour needed to lay the welded wire fabric or reinforcement bar. It also improves the mechanical performance of concrete.

2.2.2 Physical Properties of Steel Fibre

In recent years, the shape of steel fibres had been carrying out on research and development to achieve improved fibre-matrix bond characteristics. It was aim to improve the dispersibility of steel fibre in the concrete mix. According to BS EN 14889-1, the manufacture of steel fibres can be divided into five general types based on the product used and was shown at Table 2.1. (ACI Committee 544, I.R, 1996):

Table 2.1: Steel Fibres Classification

Group	**Type**
I	Cold-drawn wire
II	Cut sheet
III	Melt-extracted
IV	Shaved Cold Drawn Wire
V	Milled from Block

Based on the Japanese Society of Civil Engineers (JSCE), steel fibres can be classified into different shape of its cross section. It can be in square, circular and crescent section. Generally, there were mixtures of composition likes carbon steel, low carbon steel, stainless steel and with some alloy constituents in the steel fibres. The fibre strength, stiffness, and the ability of the fibres to bond with the concrete were important. The bonding between steel fibre and concrete were depends on the aspect ratio of steel fibre. Normally, the aspect ratios range from about 20 to 100, while the length dimensions range from 6.4 mm to 76 mm. It was small enough to disperse randomly in an unhardened concrete mixture (ACI Committee 544, I.R, 1996).

For steel fibres, there were various types and shapes such as straight, hooked, crimped, double duoform, ordinary duoform, paddled, enlarged ends, irregular and indented shapes shows at Figure 2.1, while the cross section of steel fibres were showed at Figure 2.2. Several factors such as shape, aspect ratio and fibre content must be considered as it will affect the performance of steel fibres (Khaloo & Afshari, 2005; Robins, Austin, & Jones, 2002; Sharma, 1986; Trottier & Banthia, 1994). The consideration between the bonding of steel fibres and concrete was important as it will increase the mechanical properties of concrete. From research, hooked-ends fibre provides better bonding than straight steel fibre (Heng, R.Y., 2014).

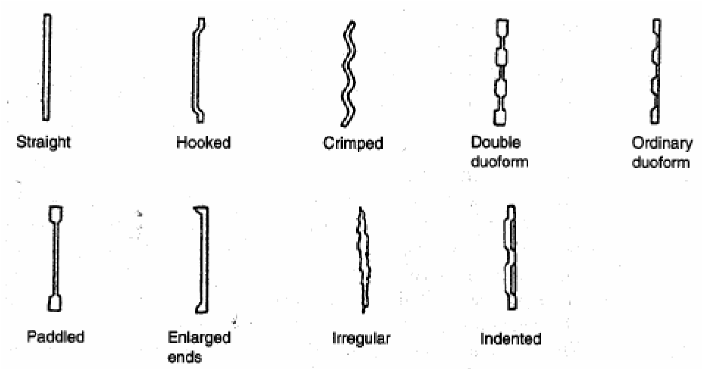


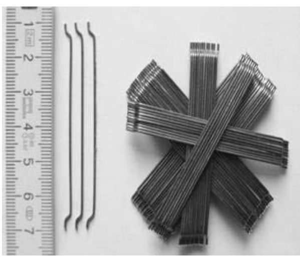
Figure 2.1: Examples of the shapes for steel fibres

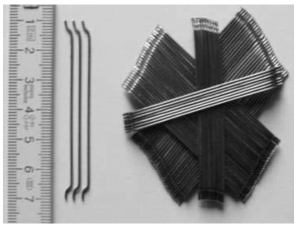
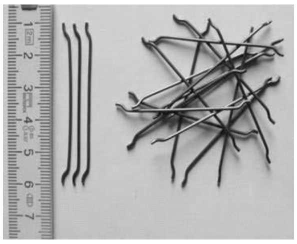
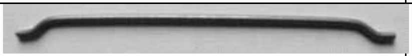
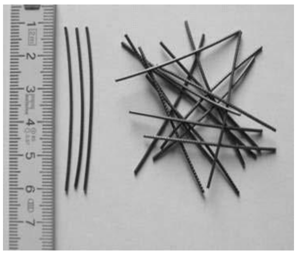
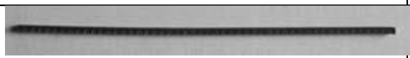
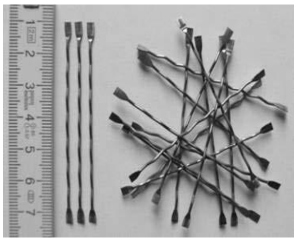
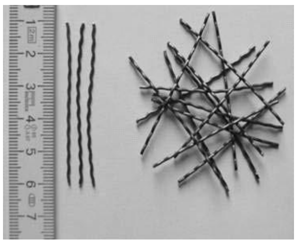
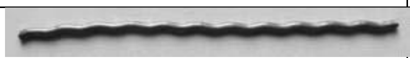
Figure 2.2: Steel fibre cross sections

Sources: Knapton, 2003

According to the research carried out by Klaus Holschemacher and Torsten Muller, it was focused on the influence of steel fibre type and amount on flexural tensile strength, fracture behavior and workability of SFRC. There were total of six different type of steel fibres had been used to study the influence of fibre type on hardened properties of steel fibre reinforced concrete. The overview of tested steel fibres shows at the Table 2.2.

Table 2.2: Overview of tested steel fibres

Variant	Illustration	Geometry	Variables
1			l_f = 60mm
		Form : straight	d_f = 0.75 mm
		Surface : plane	λ = 80
		End anchorage : hooked ends	f_t = 1050 N/mm^2
		Allocation : glued	n_f = 4600 kg^{-1}

2			l_f = 60mm
		Form : straight	d_f = 0.90 mm
		Surface : plane	λ = 67
		End anchorage : hooked ends	f_t ≥ 1000N/mm^2
		Allocation : glued	n_f = 3200 kg^{-1}
3			l_f = 50mm
		Form : straight	d_f = 1.05 mm
		Surface : plane	λ = 48
		End anchorage : hooked ends	f_t = 1000 N/mm^2
		Allocation : separate	n_f = 2800 kg^{-1}
4			l_f = 50mm
		Form : straight	d_f = 1.00 mm
		Surface : plane	λ = 50
		End anchorage : none	f_t ≥ 1100 N/mm^2
		Allocation : separate	n_f = 2900 kg^{-1}
5			l_f = 60mm
		Form : corrugated	d_f = 1.00 mm
		Surface : plane	λ = 60
		End anchorage : end paddles	f_t = 1100 N/mm^2
		Allocation : separate	n_f = 2450 kg^{-1}
6			l_f = 50mm
		Form : corrugated	d_f = 1.00 mm
		Surface : plane	λ = 50
		End anchorage : none	f_t ≥ 1100 N/mm^2
		Allocation : separate	n_f = 2850 kg^{-1}

All of the six types of steel fibre were then casted with three different fibre content varied from 20, 30 and 40 kg/m^3. The result of Load-Deflection Curves of the research for 20, 30 and 40 kg/m^3 was show at Figure 2.3, 2.4 and 2.5 respectively.

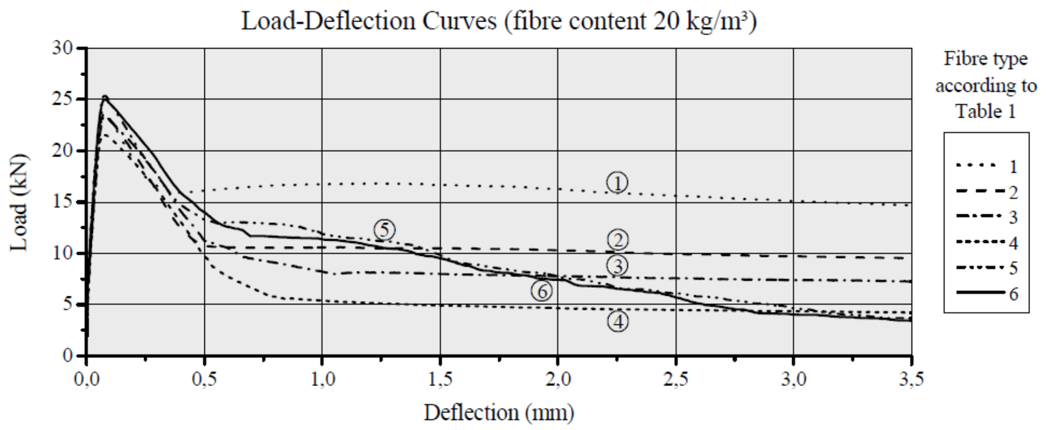


Figure 2.3: Average load-deflection curves for different fibre types.

Fibre content: 20 kg/m^3.

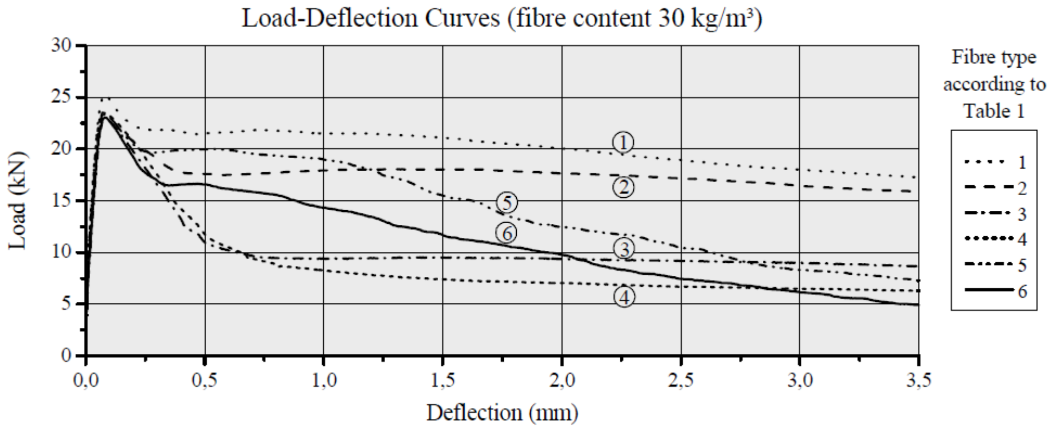


Figure 2.4: Average load-deflection curves for different fibre types.

Fibre content: 30 kg/m^3.

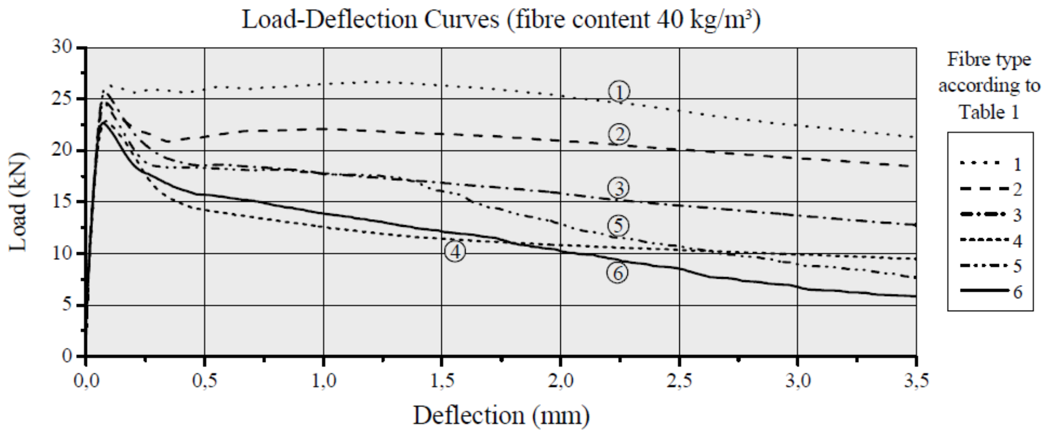


Figure 2.5: Average load-deflection curves for different fibre types.

Fibre content: 40 kg/m^3.

From the result shows at figure above, after first crack occur due to reduction of the load bearing capacity, steel fibre of type 1, 2, 3 and 4 referred to Table 2.2 shows a roughly constant load level with increasing deflection. The reason of causing this was slow pull-out of the fibres out of the concrete matrix. However, the steel fibre type 5 and 6 with different amount of fibre content show a distinct load decrease after passing the maximum load. This was affected by the pull-out of the fibre which caused a sudden failure of the concrete matrix.

In summary of the research, the fibre types from 1, 2, 3 and 4 were categories under ductile material behavior. However, the reached load level of steel fibre type 4 without hook ends always lay below steel fibre of 1 to 3 with hooked ends. The lower loss of strength with increasing deflection was determined by steel fibre types from 1 to 4 when compare with corrugated fibres 5 and 6. The corrugated fibre types were not showing ductile material behavior after an initial high post crack load capacity. All in all, the geometry of the fibres affect the shape of the post crack load-deflection curve, while the reached load level after the crack load was defined predominantly by the fibre content.

From the research by Klaus Holschemacher and Torsten Muller, it can conclude that, steel fibre with hook-end fibre was stronger than without hook-end fibre, while the steel fibre with corrugated shapes were not suitable to use because it did not show ductile material behavior. In this research, the steel fibres with hook-end from TIMURAN Engineering had been used to mix with the concrete. It provides the standard size which was use in Malaysia. The products of STAHLCON steel fibre provide two types of products which were HE 0.75/60 and HE 0.55/0.35. The hooked-end steel fibre which made by cold drawn wire with HE 0.75/60 had been using in our research as it was more suitable to apply in industrial or residential flooring.

2.2.3 Mechanical Properties of Steel Fibre

According to the journal of Shahiron Shahidan 2009, the table at Table 2.3 showed the mechanical properties of steel fibre for all type of steel fibre. This result of properties of steel fibre had been proved in previous research. The experimental work and designing steel fibre in concrete had been carrying out. The modulus elasticity of steel fibre was higher; it was similar to the modulus elasticity of steel reinforcement. Besides that, the yield strength of the steel fibre was high enough to resist crack propagation at the concrete bonding; hence it results in high value of yield strength. Furthermore, steel fibres were protected from corrosion by the alkaline from the cementitious matrix (ACI Committee 544).

Table 2.3: Mechanical Properties of Steel Fibre

Steel Fibre (Hooked end)	
Density	7.85 g/cm^3
Modulus of Elasticity	205 GPa
Poison Ratio	0.29
Yield Strength	1275 MPa
Tensile Strength	1100 MPa

2.3 STEEL FIBRE REINFORCED CONCRETE (SFRC)

Steel fibre able to enhances the post-cracking behavior of concrete. The mixtures of concrete which contain steel fibre were able to resist the formation of cracks when external load applied on it (Lim & Oh, 1999). Plain concrete was weaker than steel fibre reinforced concrete, when high load applied on it the concrete will immediately fail when first crack form. However, the addition of steel fibre reinforced concrete able to turn plain concrete into ductile concrete, therefore it was able to enhance the properties of concrete such as strength and durability. For durability of ductile concrete, since it was able to arrest the first crack therefore higher flexural strength was able to cater by the steel fibre reinforced concrete.