PERFORMANCE OF CONCRETE FILLED HOLLOW SECTION WITH FIBROUS FOAMED CONCRETE SUBJECTED TO AXIAL COMPRESSION LOAD

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ABSTRACT

The use of a concrete-filled section as a column has been widely used due to its structural elements. However, most recent studies have only focused on three types of concrete: normal, high-strength and lightweight aggregate. Foamed concrete has received significant attention due to its potential as a structural construction material. However, the mechanical properties of foamed concrete have to be improved due to its brittle behaviour. Adding 40% of Rice Husk Ash (RHA) as sand replacement, 0.8% of steel fibre and 0.4% of polypropylene fibre (volume fraction of total concrete) to foamed concrete can improve the mechanical properties of modified fibrous concrete. A sum of 60 specimens with the sizes of 100(b) mm x 100(h) mm x 350(*l*) mm and thicknesses of 2 mm and 4 mm were tested. The highest result for bond strength and of ultimate strength is CFHS-RHA-SF for both 2 mm and 4mm thicknees. The bond strength was 0.171 MPa and 0.482 MPa for 2 mm and 4 mm. Meanwhile, the results ultimate strength for 2 mm and 4 mm was 464kN and 991kN. The results showed that the differences in the percentage between the experiment and the theoretical analysis ranged from 10% to 58%. This was due to the coefficient for concrete that provided based on Eurocode 2 is used for normal concrete. The failure mode for all specimens showed outward bulging at the top of the specimens. Additionally, quantitative analyses were carried out using finite element software (ANSYS) with various thicknesses of 2 mm, 4 mm, 6 mm, 8 mm and 10 mm. The results of the FEM analysis were similar to the results of experimental work in terms of the ultimate strength and failure mode. The empirical equations for ultimate strength of CFHS with modified fibrous foamed concrete proposed in this study showed good agreement with the experimental results.

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ABSTRAK

Penggunaan bahagian berisi konkrit sebagai tiang telah digunakan secara meluas kerana elemen strukturnya. Walau bagaimanapun, kebanyakan kajian terkini hanya tertumpu kepada tiga jenis konkrit: agregat biasa, kekuatan tinggi dan ringan. Konkrit berbuih telah mendapat perhatian yang ketara kerana potensinya sebagai bahan binaan struktur. Walau bagaimanapun, sifat mekanikal konkrit berbuih perlu diperbaiki kerana kelakuannya yang rapuh. Menambah 40% Abu Sekam Padi (RHA) sebagai pengganti pasir, 0.8% gentian keluli dan 0.4% gentian polipropilena (pecahan volum jumlah konkrit) kepada konkrit berbuih boleh meningkatkan sifat mekanikal konkrit gentian diubah suai. Sejumlah 60 spesimen dengan saiz 100(b) mm x 100(h) mm x 350(*l*) mm dan ketebalan 2 mm dan 4 mm telah diuji. Keputusan tertinggi untuk kekuatan ikatan dan kekuatan muktamad ialah CFHS-RHA-SF untuk ketebalan 2 mm dan 4mm. Kekuatan ikatan ialah 0.171 MPa dan 0.482 MPa untuk 2 mm dan 4 mm. Sementara itu, keputusan kekuatan muktamad untuk 2 mm dan 4 mm ialah 464kN dan 991kN. Keputusan menunjukkan bahawa perbezaan peratusan antara eksperimen dan analisis teori adalah antara 10% hingga 58%. Ini disebabkan oleh pekali untuk konkrit yang disediakan berdasarkan Eurocode 2 digunakan untuk konkrit biasa. Mod kegagalan untuk semua spesimen menunjukkan bonjolan luar di bahagian atas spesimen. Selain itu, analisis kuantitatif telah dijalankan menggunakan perisian unsur terhingga (ANSYS) dengan pelbagai ketebalan 2 mm, 4 mm, 6 mm, 8 mm dan 10 mm. Keputusan analisis FEM adalah serupa dengan hasil kerja eksperimen dari segi kekuatan muktamad dan mod kegagalan. Persamaan empirikal untuk kekuatan muktamad CFHS dengan konkrit berbuih gentian diubah suai yang dicadangkan dalam kajian ini menunjukkan persetujuan yang baik dengan keputusan eksperimen.

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LIST OF SYMBOLS

N_u	Ultimate Strength (Theoretical analysis)
N_e	Ultimate Strength (Experimental result)
A_s	Area of steel section
A_c	Area of concrete
f_{sk}	Characteristic of steel
f_{cu}	Compressive strength
f_{ck}	Characteristic of concrete
F_b	Bond strength
P_o	Perimeter of concrete infill
L	Length
b	base
h	height
t	thickness

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LIST ABBREVIATION

HSS	Hollow Steel Section
CFHS	Concrete Filled Hollow Section
RHA	Rice Husk Ash
FC	Foamed Concrete
SF	Steel Fiber
PF	Polypropylene Fiber
b/t	base/thickness
CFST	Concrete Filled Steel Tube
NWC	Normal Weight Concrete
LWC	Light Weight Concrete
CFT	Concrete Filled Tube
D/t	Diameter/thickness
SI	Strength Index
C/S	Cement/Sand
F/C	Foam/Cement
W/C	Water/Cement
LVDT	Linear Variable Differential Transformer
FEM	Finite Element Modelling

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Hollow steel section (HSS) is widely used for structural construction in square, rectangular or circular shapes. HSS offers advantages over other structural steel sections in terms of structural elements. However, the local buckling problem has become a concern among researchers. When HSS is exposed to heat or fire, the result can be catastrophic, causing HSS to bend. This situation can be prevented by filling the hollow section with concrete in order to avoid inward local buckling that can cause HSS to bend.

Concrete-filled hollow section (CFHS) consists of a steel tube with a concrete core cast inside. Furthermore, CFHS columns are governed by stability and failed by local buckling. According to Vinay *et al.* (2015), concrete cores can prevent steel tubes from buckling and improve compressive stability enormously. In addition, CFHS has become popular in structural applications due to this composite structure that utilises the compressive strength of concrete, and the steel tube contributes to the strength as a ductile material.

According to Hafiz (2016), the change in length under axial compression load of short column of CFHS was not affected. However, in certain building, the construction of short columns is required. This is due to either ground conditions or the requirement of intermediate beam. Chen, Wang, Roeder and Ma (2017) studied the strength of CFHS and

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found that, the results of the CFHS experiments were inconsistent due to the confinement effect and the contribution of the steel sections.

The studies on CFHS with normal concrete or high-strength concrete showed the concern of the dead weight of the structure. Therefore, past research has proposed and promoted lightweight concrete filled with CFHS to minimise the self-weight of structure (Ghannam, 2014; Fu *et al.*, 2011). Previous research also found that lightweight concrete with CFHS was more ductile than normal concrete and high-strength concrete (Chu, 2014). Moreover, an experimental study by Mouli and Khelafi (2007) showed that the bond strength of lightweight concrete as an infill in steel section was higher than CFHS with normal concrete.

Foamed concrete is a type of lightweight concrete. Due to many advantages offered by foamed concrete, this research aims to study its usage as an infill material. Foamed concrete fits the title of Green Concrete, defined as the production of concrete by using less water to optimise energy, conserving natural resources, generating less water and providing healthier spaces for occupants (Moon *et al.*, 2015). Furthermore, the term 'modified fibrous foamed concrete' can be defined as a foamed concrete that includes Rice Husk Ash (RHA) as sand replacement and fibre. According to recent research by Hadipramana *et al.* (2015) and Ganiron Jr (2013), RHA can be used as sand replacement that contributes to the increment of strength in foamed concrete. Recent research by Rahman *et al.* (2015) proved that foamed concrete with a density range of 1400 kg/m^3 to 1600 kg/m^3 could achieve high compressive strength around 6.4 MPa to 14 MPa. Besides, by adding fibre in foamed concrete and incorporating 40% of RHA as sand replacement and fibre, the strength could achieve up to 30 MPa (Rum *et al.*, 2017; Jaini *et al.*, 2017).

1.2 Problem statement

CFHS is one of the methods to increase the strength and resistance of local buckling. The most commonly used CFHS is structural columns. Moreover, the compressive strength of the concrete contributes to the delay of the steel-hollow section failure. So far, there has been little discussion on CFHS with modified fibrous foamed concrete. Current studies

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only focus on CFHS with high-strength concrete and normal concrete (Chen *et al.*, 2017; Bedage & Shinde, 2015; Chu, 2014).

Lightweight concrete could be used as an alternative to normal weight concrete in an attempt to reduce the dead weight of the concrete infill. The steel section filled with foamed concrete did not show an increase in the ultimate strength of CFHS due to low compressive strength compared to normal concrete. The study on the ultimate strength of lightweight concrete in the steel section is still ongoing. Currently the equation to analyse ultimate strength is based on equation in Eurocode 4 (BS EN 1994, 2007). Therefore, in this research, coefficient equation for CFHS with fibrous foamed concrete is proposed.

1.3 Aim and Objective

The aim of this research is to investigate the performance of concrete-filled columns with lightweight concrete using foamed concrete containing fibre and RHA as sand replacement. Therefore, the objectives of this research are as follows:

i. To determine bond strength at the interface between steel section and concrete core and the ultimate strength of CFHS

ii. To validate the efficiency of CFHS with foamed concrete containing fibre and RHA as sand replacement as infill using the finite element method

iii. To modify the empirical formula for ultimate strength prediction for CFHS with fibrous foamed concrete

1.4 Scope of research

This research involves experimental work to investigate the performance of CFHS for modified fibrous foamed concrete. The modified fibrous foamed concrete contains Portland cement, fine aggregates, water, superplasticizer, foam agent, 40% of RHA as sand replacement and fibre. There are two types of fibre were used as additional material,

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which are polypropylene fibre and steel fibre. The density of modified fibrous foamed concrete was 1600 kg/m^3.

The material properties were determined with a good mix design to produce a good strength of foamed concrete containing fibre and RHA as sand replacement. The material properties were obtained to determine the optimum percentage used in modified foamed concrete. 54 cube specimens of 100 mm x 100 mm in size and 18 cylinder specimens of 150 mm x 300 mm in size were prepared to determine the compressive strength and Young's Modulus of Elasticity. These material properties were used as data input in parametric study. All specimens were casted with polypropylene fiber or steel fiber of 0%, 0.2%, 0.4%, 0.6%, 0.8% and 1.0% of volume fractions of total weight of modified foamed concrete were added in foamed concrete, respectively.

Overall, 54 specimens of CFHS short columns with modified fibrous foamed concrete were prepared in total. Modified fibrous foamed concrete contained foamed concrete with 40% of RHA as sand replacement and fibre. The optimum percentage for steel fibre was 0.8%, and polypropylene fibre was 0.4%. The sizes of the square hollow section specimens were 100 mm (b) x 100 mm (h), with the length of the stub of 350 mm and thicknesses of 2 mm and 4 mm, respectively. In order to study on bond strength of CFHS. the top end of the specimens was prepared with a gap of 50 mm for the CFHS. Then, during testing the 50 mm gap at the top were placed as the bottom of specimens. The load was applied to the inner concrete in order to determine bond-slip failure between the inner concrete and the outer steel section. Meanwhile, the specimens of CFHS were subjected to compression load to determine the ultimate strength of CFHS. After the testing was done, the most critical failure mechanism of specimen was cut and removed to observe the damage to the concrete cores for bond strength failure mechanism, while for ultimate strength is a failure mode.

Furthermore, a quantitative analysis was performed using finite element software (ANSYS). The material properties of the steel sections and modified fibrous foamed concrete were obtained in the experimental work. The ultimate strength of CFHS with modified fibrous foamed concrete was modelled similar with the size of the experimental specimen with thicknesses of 2 mm and 4 mm. Then, the results of the FEM analysis for

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2 mm and 4 mm were verified with the experimental results. Further parametric study was performed by increased thickness of steel section to 6 mm, 8 mm and 10 mm, respectively. Result from parametric study was analysed and the coefficient equation used to multiply with predicted the ultimate strength of CFHS with modified fibrous foamed concrete was proposed.

1.5 Overview of thesis

The research methodology represents the procedure of this research. The details of methodology regarding the experimental study of the performance of CFHS with fibrous foamed concrete are as follows:

i. **Literature review**

   Previous studies on various types of CFHS with different thicknesses and types of concrete as infill were reviewed.

ii. **Material preparation for experimental work**

   The study requires the establishment of accurate required strength of fibrous foamed concrete with RHA as sand replacement and procedure methodology based on the standard procedure in order to obtain accurate experimental results.

iii. **Specimen Testing**

   Cube specimens were tested under compression test. Meanwhile, cylinder specimens were tested for tensile and Young's Modulus of Elasticity. Stub specimen was subjected to static load.

iv. **Theoretical analysis**

   The prediction of the experimental results of CFHS with fibrous foamed concrete was based on the code of practice.

v. **Finite element modelling**

   Finite element modelling was used to validate the experimental result. This study was also conducted to modify the equation to determine the strength of lightweight CFHS.

vi. **Results analysis and discussions**

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The results analysis and discussions were conducted to ensure the accuracy and persistence of the designed experimental work. The comparison of experimental results and the theoretical analysis was done to ensure the validity of the results obtained. However, an analytical approach was used to ensure an integration between literature and the results.

1.6 Conclusion

This research only focuses on the CFHS for short column size 100 mm (b) x 100 mmn(h) x 350 mm (*l*) with steel sections' thicknesses of 2 mm and 4 mm, respectively. The density of the modified fibrous foamed concrete is 1600 kg/m^3.

Practically, the modified fibrous foamed concrete was prepared with Portland cement, fine aggregates, water, superplasticizer, foam agent, RHA and fibre. In addition, 40 % of RHA was used as sand replacement. The optimum percentages of fibre as addititonal materials were 0.8% and 0.4% for steel fibre and polypropylene fibre, were obtained during experimental work. This research does not focus on the behaviour of the foamed concrete containing fibre as additional materials and RHA as sand replacement. Furthermore, this research also does not focus on the material of modified fibrous foamed concrete.

The main interest of this research is to evaluate the ultimate strength of CFHS with modified fibrous foamed concrete subjected to axial compression load. This experimental research also investigates the effects of the CFHS bond strength on the ultimate strength of CFHS.

Finite element modelling was conducted using ANSYS software to obtain the ultimate strength of CFHS with modified fibrous foamed concrete and the failure mode of the specimen. The specimen size was similar to the size used in the experimental work, with thicknesses of 2 mm, 4 mm, 6 mm, 8 mm and 10 mm, respectively. The results of FEM were verified with the results of the experimental work of thickness 2 mm and 4 mm.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides literature review on concrete-filled hollow section (CFHS) and lightweight concrete. A depth of knowledge on the experimental work and analysis is discussed in order to determine the performance of CFHS with fibrous foamed concrete containing fibre and RHA as sand replacement.

2.2 Concrete Filled Hollow Section (CFHS)

The use of CFHS has been prevalent due to its significant improvement in axial capacity without an increase in the cross-sectional area required (Testo & Lam, 2011). In other words, the use of CFHS provides a basic advantage in structural efficiency where the danger of local buckling is reduced if the steel section is encased in concrete. Moreover, CFHS is a structural member that efficiently combines the tensile strength and the ductility of the steel with the compressive strength of the concrete. Chan *et al.* (2015) stated that the concrete infill contributes to strength and ductility.

2.2.1 Strength of CFHS

Concrete-filled tubes are effective structural components due to their strength to size efficiency and facilitation of rapid construction (Bagherinejad *et al.*, 2015). The concrete

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filled in hollow steel section provides compressive strength and flexural stiffness to the section and prevents local buckling. However, the tube walls, in most cases, do not offer significant confinement to core concrete beyond the yield load of the composite column. The confinement of the concrete infill improves its strength and prevents spalling that may occur in a traditionally reinforced concrete component under lateral loading, such as an earthquake (Bagherinejad *et al.*, 2015). Hence, unreinforced CFHS with high-strength concrete is cheaper for column construction (Shim, Kim & Park 2018) Moreover, the combination of the economic aspect and constructional advantage shows that CFHS with high-strength concrete can be a practical option for a range of structural applications. However, it contributes to the increase of the dead load of structural members. Therefore, research on CFHS has been extended using lightweight concrete.

Lightweight concrete offers a lower density between 400 kg/m^3-1600 kg/m^3, reducing a dead load of structural members. In other words, any densities can also be obtained from about 600 kg/m^3 to 1700 kg/m^3 by adjusting the foam or mortar ratio (Guan, 2010). Thus, normal aggregate concrete can be replaced by lightweight aggregate concrete due to its low specific gravity and thermal conductivity. The thermal conductivity of lightweight concrete and the low specific gravity producing lighter structures seem to be good reasons for using lightweight concrete in composite construction. Hence, lightweight concrete has good mechanical properties (Lo, Tang & Cui, 2022). Thus, the strength and brittleness of lightweight concrete can be improved.

2.2.2 Ductility of CFHS

Figure 2.1 shows that the pattern of the load-displacement curve of the CFHS with lightweight concrete and various thickness behave similar. Specimen were a square hollow section, S1LW saiz 150 mm (b) × 150 mm (h)×4.8 mm (t), S2LW saiz 150 mm (b)× 150 mm (h)× 4.8 mm (t) and S3LW saiz 50 mm (b)× 50 mm (h)× 1.6 mm (t), while S1NW saiz 150 mm (b) × 150 mm (h)×4.8 mm (t), S2NW saiz 150 mm (b)× 150 mm (h)× 4.8 mm (t) and S3NW saiz 50 mm (b)× 50 mm (h)× 1.6 mm (t). 'N' is for normal concrete and 'L' is for lightweight concrete. From the result, it was found that the load carrying capacity of composite columns filled with lightweight concrete is more sensitive to the

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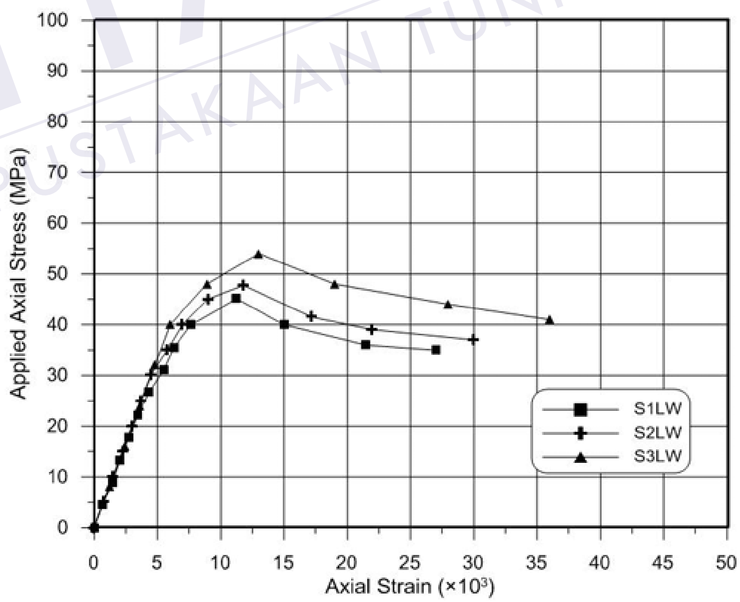
size effect than those filled by normal concrete. Also, it was observed that the column ductility was also inversely affected by the size of the tested Concrete Filled Steel Tube (CFST) column specimens.

Chu (2014) proved that the rectangular CFHS had the least ductility, while those with circular sections showed the greatest ductility behaviour. When the square CFHS specimen was compared with the normal concrete circular specimen, the results showed a higher strength of the axial load but fewer ductility behaviours in the circular specimen and the opposite behaviours in the square specimen. Bastami, Mousavi and Abbasnejadfard (2022) reported that the ductility of CFHS with high-strength concrete columns was considerably possible in the column design due to the increase in the compressive strength of concrete with more brittle unloading characteristics. In other words, it reduced the ductility of CFHS. When the load was increased to 70% - 80% of the ultimate capacity, the steel tube enteed the yield stage, and local buckling could be observed on the steel tube (Fu *et al.*, 2020). As the compressive load was increased, the buckle of the tube became more severe until the failure was reached.



a) Axial Stress versus Axial strain for square specimens with Light weight concrete (LW)

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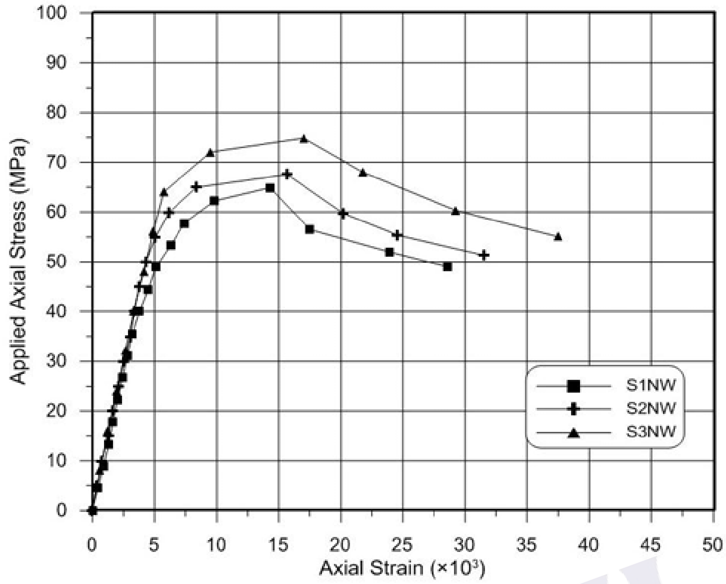

b) Axial Stress versus Axial strain for square specimens with normal concrete (NW)

Figure 2.1 : Compare of various cross section between lightweight concrete and normal concrete (Saleh, 2020)

Additional steel fibre was suggested by Tokgoz and Dundar (2010) to enhance the strength of the CFHS. They proved that the addition of steel fibre in core concrete has a considerable effect on the behaviour of CFHS. The result of their study shown in Figure 2.2 is between CFHS with normal concrete (52 MPa) and CFHS with normal concrete and additional steel fibre (59 MPa). It is shown in Figure 2.2 that CFHS column specimens with steel fibre concrete behave in a ductile manner. According to Tokgoz and Dundar (2010), steel fibre in core concrete (Exp-Fiber) improved the ductility and deformation behaviour of CFHS columns compare with normal concrete as concrete core (Exp-Plain). This proved that the addition of steel fibre into concrete contributed little effect on the ultimate strength capacity of CFHS columns.

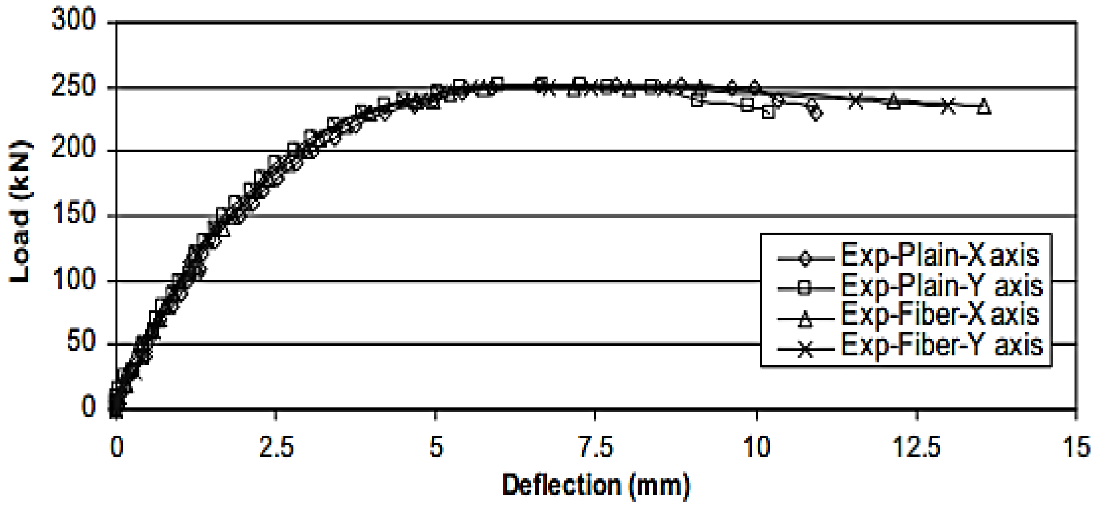

Figure 2.2 : Experimental Load-Deflection Curve for specimen size 100 mm x 100 mm x 4 mm (Tokgoz & Dundar, 2010)

2.2.3 Failure mode

Figure 2.3 shows the failure mode for the stub column filled with recycled aggregate. It can also be observed that the concrete core suffers the same damage as the steel section. This may be due to the larger portions of resistance provided by the thicker steel section and better confinement of the concrete provided by the steel section (Chen *et al.*, 2017). Figure 2.4 shows the CFHS stub specimen filled with normal concrete strength of 60 MPa is tested under full compression load. The failure mode of the specimens showed an outward bulging at the top, bottom and mid-height of stub specimens as shown in figure below. According to Jayaganesh *et al.* (2015), the steel section in the outer limit directly carried the applied load and provided confinement to the inner concrete core. Hence, it avoided the damage to the inner concrete core and led to the bulging of the steel section.

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