

PRELIMINARY ASSESSMENT OF FIRE DAMAGED REINFORCED CONCRETE STRUCTURE AND STEEL TRUSS

M Iqbal Khiyon, Mariyana Aida Ab. Kadir*, Siti Nurul Nureda
Mohamad Zukri & Mohd Hanim Osman

¹Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Malaysia

*Corresponding Author: mariyanaida@utm.my

Abstract: The assessment of fire damaged structure is an area which considered new and have little practical experience in Malaysia. In this study the objective are to determine the concrete strength and the ultimate strength of steel truss and weight loss of the steel after exposure to fire. Non-destructive and destructive test has been tested in this study. Rebound hammer test had been done to determine the strength of the concrete beam while tensile test and corrosion test both have been done by taking samples from the steel purlin. The test conducted in this study follows the BS EN 10 002: Part 1: 1990, ISO 6892-1 and ASTM G1-90. The results from rebound hammer test, the compressive strength of the concrete beam is between 40 ± 4 N/mm² while the average ultimate strength of steel truss is between 412 N/mm² to 434 N/mm². Meanwhile, for the corrosion test, when steel is exposed in between 200 °C to 1000 °C the weight loss is 0.08% to 0.17%. This testing shows that steel has loss, its mechanical properties due to exposed to elevated temperature. By conducting a non-destructive test for concrete and destructive test for steel it shows to be practical and useful in evaluating the fire damaged reinforced concrete structure and steel truss.

Keywords: *Structure assessment, concrete, steel, fire, strength, corrosion testing*

1.0 Introduction

Building can be damaged due to several factors such as natural disasters like flood, earthquake and incidents such as fire. Fire is one of the major incidents that happened in Malaysia. Arson is increasing year by year (Fire and Rescue Department of Malaysia, 2013). In 2012 the total building fire occurred was 5477 while in 2013 the total building fire happened increased with a total of 5817. From the total of 5477 in year 2012, residential was the highest with a total of 2919 while in 2013 fire happened at residential increased with a total of 3235 (Fire and Rescue Department of Malaysia, 2013). Residential was the highest fire to happened compared to other type of building based on the fire statistical by type of building. This incidents force an engineer to think

morecreatively and innovative to design a building that can save or delay a fire happen. Fire fighter will have a problem to handle a fire exposed to high-rise building due to one floor can fully burn out while evacuation on the other floors is still taking place (Röben *et al.*, 2010). Concrete or mortar nomally have a good fire resistance (Kadir, 2013). However, reinforced concrete structure can loss it mechanical and physical properties of concrete, weight loss, aggregate cement-bond, chemical resistivity and bonding with steel reinforcement within in concrete when exposed to elevated temperature (Khalaf *et al.*, 2016 and Shoaib *et al.*, 2001). Furthermore, when this fire happens it will cause lossess in term of money and life.

An assessment of structure after a fire happen should to be done to ascertain whether a structure can be repaired or need to demolish (Yüzer *et al.*, 2004). Figure 1 below shows the flowchart for the structural assessment after the building has been damaged by fire.

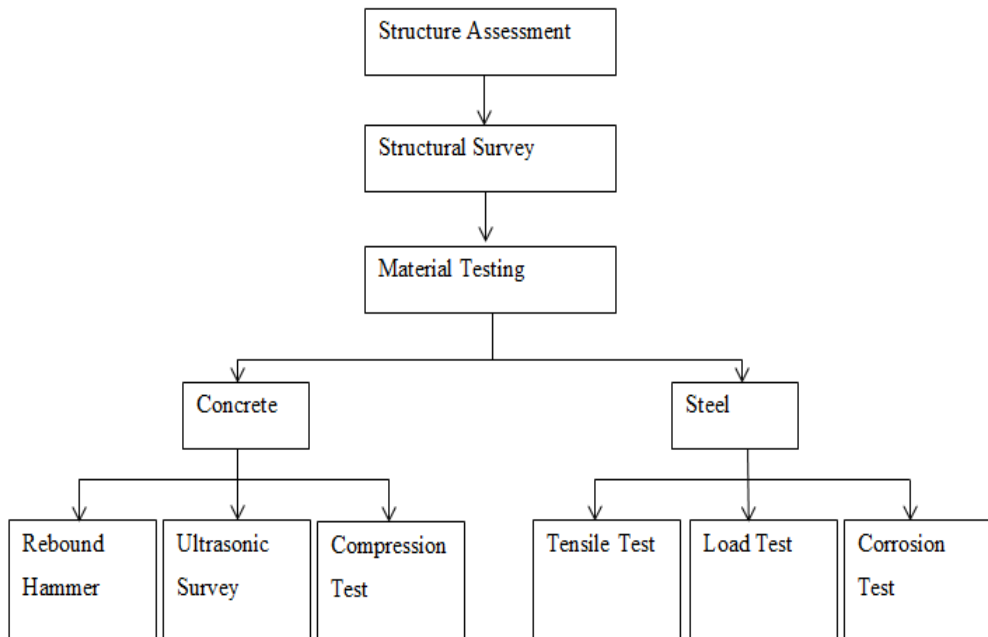


Figure 1: Flowchart for the structural assessment (Antonio Brancaccio *et al.*, 2012)

There are two main construction materials which are concrete and steel need to be evaluated when reinforced concrete structure exposed to elevated temperatures. The assesement of fire damaged concrete structure start with visual observation of physical surface of the structural element to investigate colour change, cracking and spalling (Short *et al.*, 2001). Concrete when exposed to fire, will have changes in colour will

occur (Yüzer *et al.*, 2004). The types of aggregate used is one of the reasons for concrete change in colour when exposed to elevated temperatures. Concrete will turn to red when heated to 300 °C to 600 °C (Hager, 2013) that containing silicate aggregate. Meanwhile, in temperature between 600 °C to 900 °C cement will change colour to whitish-grey and continue heating it to 900 °C to 1000 °C gives a buff colour (Hager, 2013). For limestone aggregate concrete, CaCO_3 turn into CaO at 800-900°C, and expands with temperatures (Top *et al.*, 2011). For the steel part, hot gases will contact with the steel at the beginning of fire (Ünlüoğlu *et al.*, 2007 and Yüzer *et al.*, 2004). Then, the steel will lose its yield strength, ultimate strength, modulus of elasticity and ductility (Hüsem, 2006, Shoaib *et al.*, 2001; Culfik *et al.*, 2002; Georgali *et al.*, 2005 and William *et al.*, 2008). To ascertain the damage of steel truss, visual observation is done by measuring the deflection of truss (purlin). Material testing can be done for examines several issues related to the properties of concrete and steel. This study is a preliminary assessment to determine reinforced concrete structural integrity after exposure to fire. The tests include in this study are rebound hammer for concrete while for steel the tests are tensile test and corrosion test.

2.0 Case Study: Structural Assessment of a Fire Affected Reinforced Concrete Building

This part is a case study of a preliminary structural assessment after exposing to a fire. The building is a one story reinforced concrete structure of 201.6 m² of total area and with the use of steel truss. Previously, this building is a laboratory used by the postgraduate student to do their lab work.

Based on the Malaysian Fire and Rescue Department report, the fire happened on 25 February 2014 at 1900 hrs. The laboratory was believed to be on fire for about one hour, when considering the police report, which stated that the fire had been extinguished at 2001 hrs. From the police report and local witness, the most damaged parts of the structure show to be at the back of the building. It was also reported that the root of the fire was due to the current overload in a middle circuit of the office. From the visual observation, it shows that the mainly damaged consisted in concrete cover spalling over large areas of beam and wall, over-heating of exposed steel truss and overall degradation of materials due to high concentration of dense smoke.

At that place there were a bunch of things that were affected by the fire inside the laboratory such as office partitions, windows, electrical circuit, electrical sockets and insulations. The change in colour of beam, column and wall shows the effect of the fire to building components. Moreover, rusted steel appearance all over the surfaces of the steel truss also shows that steel truss was also affected by fire. The affected conditions can be seen from the pictures illustrated in Figure 2a and Figure 2b.



(a) (b)
Figure 2: Internal views of the laboratory subjected to fire (a) From the side view of the laboratory (b) From the front view of the laboratory

An extensive experimental campaign was carried out to quantify the damaged caused by the fire and to assess the behavior of the structure. Non-destructive, tensile test and corrosion test were carried out to investigate any change in the material properties due to the elevated temperatures. This test were done to determine the strength of concrete, to find the ultimate tensile strength and metal loss of steel.

3.0 Experimental Procedure

3.1 Non-Destructive Test

The rebound hammer test or also known as Schmidt hammer was conducted to measure the uniformity of concrete, strength of the concrete, and to assess the quality of concrete in relation to standard requirements.

3.2 Test Procedure

Before the test is conduct the surface of the beam need to be cleaned from any debris or dust. After that, a grid line size 4 x 3 was drawn on the surface of the beam to mark the testing position as shown in Figure 3. Then, press the plunger on the surface of the beam and upon release it. The numbers of rebounds were recorded for each testing position. The concrete strength of the concrete beam was then determined by using the calibration chart using Chart A as shown in Figure 4.

1	2	3	4
5	6	7	8
9	10	11	12

Figure 3: Reference for testing positions from 4 x 3 grid lines

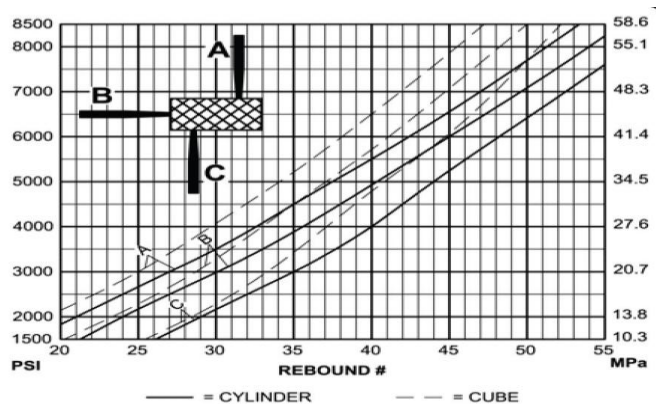


Figure 4: Calibration chart of rebound number and compressive strength

3.3 Tensile Test

The tensile test is simple, relatively inexpensive and fully standardized. The purpose of this test is to determine the ultimate strength of the steel.

3.4 Test Procedure

Six samples of coupons steel from the laboratory are used in this test. These samples are from the two purlin truss which are one of the purlin is totally exposed to fire while another one is still in good condition. Figure 5 below shows the six samples of the coupon steel where A is the samples from the least affected area and B is the most affected area due to elevated temperature. This testing follows the procedure of BS EN 10 002: Part 1: 1990 and ISO 6892-1. Figure 6 shows the coupon steel tested using DARTEC machine. The loading was applied incrementally at a rate of 0.2 kN/s until the coupon fails.

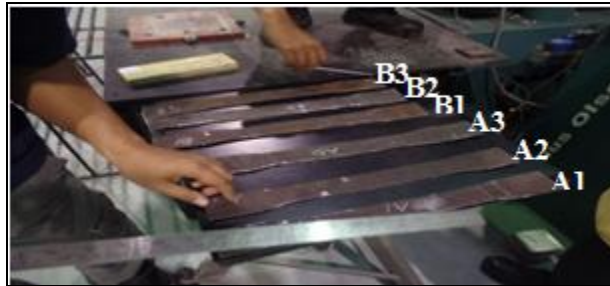


Figure 5: Samples of coupon tensile strength test



Figure 6: Coupon tensile strength test using DARTEC machine

3.5 Corrosion Test

This test was conducted to determine the weight loss of the steel when subjected to fire.

3.6 Test Procedure

Five samples from the unburned purlin were cleaned it until gets mirror surface with the dimension of the samples is 50 x 50mm. The samples are weighed before the test in the furnace with the temperature of 200 °C, 400 °C, 600 °C, 800 °C and 1000 °C. Then, the samples are clean by using chemical solution and weighing again to find the weight loss. Table 1 shows the preparation of the solution by referring ASTM G1-90 while Figure 7a and Figure 7b shows the sample before and after the cleaning process.

Table 1: Chemical used in the cleaning process of the corrosion coupon steel

Weight	Chemical
100ml	hydrochloric acid
2gram	antimony trioxide (SB_2O_3)
5gram	stannous hydroxide ($SnCl_2$)
5gram	sodium hydroxide (NaOH)

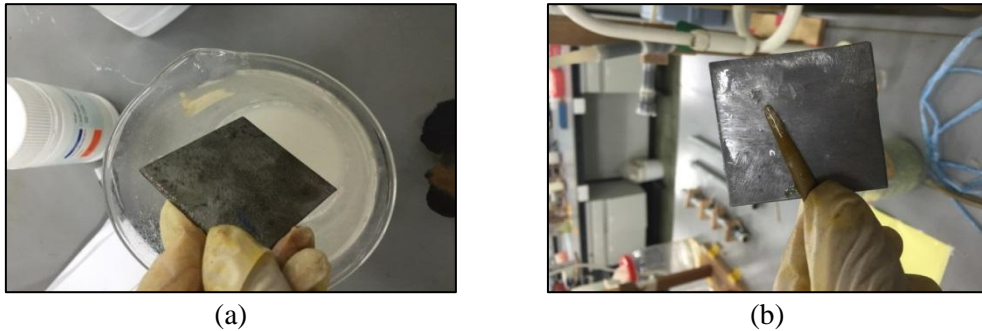


Figure 7(a) Sample before test in the solution (b) Sample after test in the solution

4.0 Result and Discussion

4.1 Rebound Hammer Test

The test results show that the compressive strength for the concrete beams is 40 ± 4 N/mm² based on the Table 2 below. The value is sufficient for design a house.

Table 2: Results for the rebound hammer test

Beam	Point	Rebound hammer												Ave	Estimate f_{cu} (N/mm ²)
		1	2	3	4	5	6	7	8	9	10	11	12		
1	1	36	36	32	33	36	37	38	38	35	34	36	36	36	38
	2	42	38	34	36	38	38	34	40	32	38	34	37	40	
	3	38	40	34	34	36	36	36	34	34	38	36	35	36	38
	4	34	40	33	38	36	38	32	36	35	36	38	36	36	38
2	1	34	40	38	32	30	42	36	36	34	42	34	42	37	40
	2	37	38	34	36	37	34	36	44	36	42	40	40	38	41
	3	34	36	32	36	34	36	40	35	34	38	32	33	35	36
	4	40	40	38	37	38	36	36	38	44	38	36	36	38	41

4.2 Tensile Test

From the Table 3 below, the ultimate strength is in ranged 395 to 503 N/mm² for samples less affected by fire and for most affected samples by fire is in the ranged 384 to 426 N/mm. For the less affected samples by fire, the average ultimate strength is 434 N/mm² while the average ultimate strength for the most affected samples by fire is 412 N/mm².

Table 3: Summary of the result for the tensile test

Specimen	Thickness, t (mm)	Width, b (mm)	Ultimate strength, R_m (N/mm^2)	Yield strength, R_c (N/mm^2)	R_m/R_c
A1	3.47	36.10	503	413	1.22
A2	3.52	39.43	395	298	1.33
A3	3.48	40.80	403	311	1.30
B1	3.41	41.63	426	332	1.28
B2	3.45	42.75	425	339	1.25
B3	3.56	43.05	384	300	1.28

Note:

A: Least affected by fire

B: Most affected by fire

4.3 Corrosion Test

Table 4 below shows the summary results of the chemical test while Figure 8 shows the graph of the weight loss of the coupon steel against temperature.

Table 4: Summary of the results of the chemical test

Temperature	Original weight	Weight after test	Percentage loss
200 °C	59.47g	59.42g	0.08%
400 °C	63.51g	63.46g	0.08%
600 °C	59.35g	59.28g	0.12%
800 °C	59.56g	59.48g	0.13%
1000 °C	65.31g	65.20g	0.17%

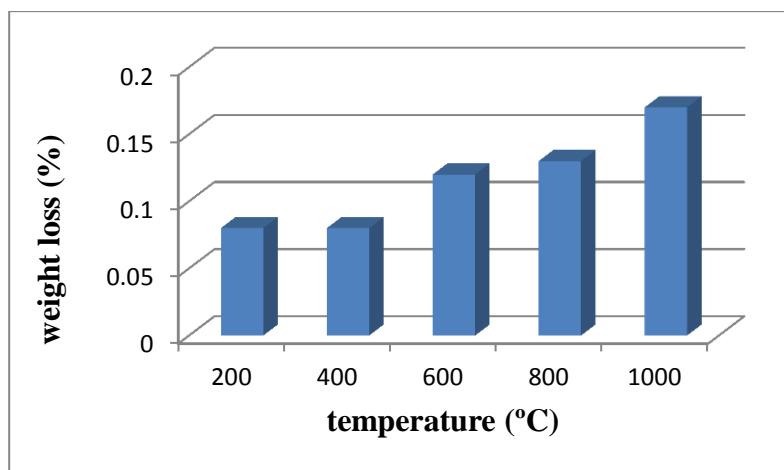


Figure 8: Weight loss of steel versus temperature

5.0 Conclusion and Recommendation

Structural assessment of laboratory building is a preliminary assessment to determine the damage of the building after expose to fire. Even though the testing involved in this study not cover all the structure assessment testing, but this research has provided a valuable information regarding the performance of the reinforced concrete and steel structure when exposed to fire to a certain temperature. The non-destructive test and destructive test such as rebound hammer, tensile test and corrosion test was conduct in this research. For the concrete is shown that the fire happens is not very affected the concrete elements. For the steel truss based on the tensile test it shows that the steel has loses its ultimate strength when exposed to a certain temperature and by done the corrosion testing it prove that when steel is exposed to a high temperature corrosion does happen. This test can be improved by performing another method such as concrete core testing, ultrasonic testing, load testing and also increase the number of samples to get more accurate data.

6.0 Acknowledgement

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