STUDY OF FIRE DAMAGED CONCRETE STRUCTURE

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ABSTRACT

This study is under the field of Structural Forensic which is investigating the damages and any deterioration on concrete structure. This study is focused on the effect of fire temperature on concrete in terms of changes in colour, physical and strength of concrete. Based on the changes observed, the range of temperature that the concrete structure has been exposed can be identified. The temperature is identifying so that the damages of concrete can be classified into which class. After the class of damage is identified, the method of solution that suitable for a particular damage can be determined. This study is fully based on the literature review from sources such as journal, article etc. that have acknowledged the validity of the content and meet the stated purpose of the study. The methods that used for this study is literature review and analysis of literature. These both methodologies have few stages. The methodology of analysis is the important one because of the Analysis Chapter is the critical part of this study to develop results that fulfill the objectives outlined. From the comparison analysis of selected sources, the result is a summary table that could be use as a reference for solution any fire damaged cases. To prove the usable of that table, a real life case study is analyzed using that table created. The result from analysis is then comparing to the real solution that know from the interviewed to the involved company. This study was succeeded to develop one table that can use as a reference for temperature identifying that caused the damages on concrete. One of the methods to determine the damages on concrete is by observation.

ABSTRAK

Kajian ini merupakan satu kajian di bawah bidang Forensik Struktur yang menyiasat permasalahan seperti kerosakan dan kemerosotan sesebuah struktur konkrit. Untuk kajian ini, ia menfokuskan kepada kesan suhu kebakaran terhadap konkrit seperti perubahan warna, fizikal dan kekuatan konkrit. Berdasarkan perubahan yang diperhatikan, linkungan suhu yang telah terdedah kepada struktur konkrit terlibat dapat dikenalpasti. Suhu kebakaran perlu dikenalpasti untuk menentukan kelas keberadaan kerosakan pada struktur konkrit tersebut. Selepas mengetahui kelas kerosakan, cara penyelesaian yang sesuai untuk kerosakan tersebut dapat ditentukan. Kajian ini adalah berdasarkan kepada ulasan karya-karya seperti jurnal, artikel, majalah dan lain-lain yang diakui kesahihan kandungannya dan menepati tujuan kajian yang telah dinyatakan. Kajian ini menggunakan kaedah kajian literasi dan analisis literasi. Kedua-dua metodologi ini melibatkan beberapa peringkat. Metodologi analisis adalah yang terpenting kerana Bab Analysis adalah bab yang kritikal untuk menghasilkan satu keputusan yang dapat memuaskan objektif kajian ini. Daripada analisis perbandingan sumber-sumber yang terpilih, hasilnya adalah sebuah jadual ringkasan yang dapat dijadikan rujukan untuk penyelesaian terhadap permasalahan kerosakan struktur konkrit yang terbakar. Sebagai pembuktian kebolehgunaan jadual tersebut, satu contoh kes kajian sebenar dianalisis menggunakan jadual tersebut. Hasilnya adalah sama jika dibandingkan dengan cara penyelesaian sebenar yang diketahui melalui proses temubual dengan syarikat yang terlibat. Kajian ini berjaya menghasilkan sebuah jadual yang dapat digunakan sebagai rujukan untuk menentukan suhu yang menyebabkan kerosakan-kerosakan Salah satu kaedah untuk menentukan kerosakan-kerosakan tersebut adalah melalui pemerhatian.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Structural forensic is a method of investigation about the structural damages, defects or failures. This study focuses on the concrete structure that damaged because of fire. Fire is an element that can be a friend to human, but fire also capable to destroy though the strongest concrete. Unfortunately, as durable as concrete is, when it is exposed to fire it can be rendered structurally unstable. The properties of concrete are deteriorate after it exposed or subjected to high temperature such as fire. Of particular importance are loss in compressive strength, loss of elastic modulus, cracking and spalling of the concrete reduced yield strength, ductility and tensile strength of the steel, and the loss of bond between them (N.R Short, J.A Purkiss, S.E Guise, 2001).

Concrete is naturally fire-resistant and concrete structures are generally capable of being repaired after a fire, even a severe one. In the 1980s, Tovey and Crook summarised the information gathered from over 100 fire damaged structures. They concluded that, almost without exception, the structures performed well during and after the fire. Most of the structures were repaired and returned to service. When structures were demolished and replaced, it was generally for reasons other than the damage sustained during the fire.

This study focuses on the concrete structure that damaged because of fire. Fire is an element that can be a friend to human, but fire also capable to destroy though the strongest concrete. Unfortunately, as durable as concrete is, when it is exposed to fire it can be rendered structurally unstable. The properties of concrete are deteriorate after it exposed or subjected to high temperature such as fire. Of particular importance are loss in compressive strength, loss of elastic modulus, cracking and spalling of the concrete reduced yield strength, ductility and tensile strength of the steel, and the loss of bond between them (N.R Short, J.A Purkiss, S.E Guise, 2001).

A practical and efficient way to analyse the damage and the appropriate method to repair any fire damaged concrete structure will be identify through this study of forensic structural. Forensic structural or civil engineer perform autopsy on components or full-sized buildings, bridges and other engineered constructed facilities/infrastructure in order to determine the cause and extent of failure. A secondary purpose is to determine methods of repair, rehabilitation or replacement (Nguee Chin Seng, 2006). The concerned meaning repair here is to return the strength of a structural element so that back to initial strength.

1.2 PROBLEM STATEMENT

Concrete is one of the best fire-resistant and high strength products found in the construction of buildings and flatwork. Nevertheless, intensive heat not only affects concrete, it can weaken it to the level where the only solution is demolition and replacement.

However, fire occurs in structure with a wide range of different construction system which uses different type of materials for their structural members. Hence, the forensic investigator must understand the effect that heating has on the variety of different construction materials.

After all, the repair technique of fire damaged concrete structure will determine. The solution must be suitable with the damage. The repairing is possible to save the cost than to rebuild or construct new for the damaged structure. Concrete structures known for a good fire resistance and have very often a very high residual strength. It is often both technically and economically possible to repair and reuse a concrete structure after fire (Yngve Anderberg, 2009).

1.3 OBJECTIVE

At first, the assessment of the fire damaged concrete structure is carried out to propose the solution or an appropriate repair method or to decide whether demolition of elements or the whole structure is more appropriate

Other than that, the aim of this study is to identify the effect of fire on concrete. The concrete structure was affected in term of its properties such as loss of pre-stress, residual deformations, cracking and loss of material by spalling, detailing and connection failure especially between steel and reinforced concrete member and other else. To get that result, the data from various source will be interpret.

After that, classify the level of damage, how bad the damage that occurred. The level of damage is depending on the level of temperature. To recognize the temperature level, it can be determined by looking at the appearance (colour) and condition (at the surface) of the concrete after fire. The changing of colour are shows the degree of temperature. Then, the damage of concrete can relate directly to the character of temperature.

1.4 SCOPE OF STUDY

The field of structural forensic is such a wide study. However for this study, it is only cover for three scopes that will fulfil the objectives. The first one is focus on the damaging effects on concrete to make a process of temperature identifying become easy. There are many effects that will occur when concrete exposed to fire. However, this study only covers the effects in terms of colour changes, physical damages and strength loss.

Other than that, this study will covers about the solution method that can be identify accordingly to the class of the damage. The resulting solution method is only for the general method. This is because of the method will briefly explain in the chapter of literature review. Then the last scope of this study is to cover about the method of assessing. The method of assessing is depend on how many class is available.

1.5 SIGNIFICANT OF STUDY

There is a fact that after fire incident most concrete buildings structure are capable of being repaired which can appreciably reduce the costs and time lost in rebuilding. When talk about the fire, for sure it related to temperature. So the temperature identifying is important to find out what class of the damage occurred.

The expected result that get from this study a bit or more will being a reference for any problem encountered about the fire damaged structure especially for concrete. Furthermore, it will ease any problems either the way to identify the level of damage then to relate it with the techniques of repair that suitable and possible for the damages.

1.6 EXPECTED OUTCOME

The outcome that expected from this study are hopefully this study can provide or being a guideline to assess the fire damage concrete. The way to assess the fire damage cases can carry out in the simple form such as table or graph, so that for any cases future, this study could be use as a reference to make the process of assessment or identifying the details of fire cases become easier.

Besides, this study could outline the method about how the various degree of temperature affected the structural concrete. Lastly, this report will come out with the best solution fire damaged cases due to any consideration. When the outcome that expected is achieved, means that the objective this study also achieve.

1.7 CONCLUSION

As overall, this chapter is a preliminary stage for completing this study. This chapter is important as a guideline to ensure the outcome is by following the objectives that have been outlined.

The objectives of this study are clearly stated. By completing this study, it can be a one of the simple references for temperature identifying according to the effect that occurred on concrete in terms of its colour, physical and strength. The solution for any cases is could identify directly when the class of damages based on the range of temperature is known.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will come out with the detail discussion that taken the objective of this study ad a guide. Firstly, this study will come out with types of damage that formed due to fire. There are too many damages of concrete that would occurred after burning. So, this chapter will state as much as possible the types of damage either damage on the properties of concrete, or damage on its features.

After that, proceeds to the issue how the temperature of fire changes the visual appearance. At many time fire is generally experienced are formed localised that is part of the structure is damaged. However, still ensure the joint of structure is intact.

Furthermore, the main objective of this study that is to determine the repair technique of fire damaged concrete structure. This subtopic is come out with few papers, journal articles, which discussed the methods that usually used for the damages that identified.

However, there are certain cases that are no possible to reuse the structure. This case has considered when the fire is exposed too heavy, greater deformation or deflection easy to form. When the damages on structure are too much, that is also required to replace.

2.2 DAMAGES

2.2.1 General

Damages on concrete after exposing to fire are too general. Typically, fire damaged concrete need a specific identification to ease the repairing process. The damages usually identify by observation on its visual appearance. However, the different temperature of fire gives the different effect on visual. Three types of change are usually responsible.

The first one is cracking and micro cracking in the surface zone. This is usually sub-parallel to the external surface and leads to flaking and breaking away of surface layers. Cracks also commonly develop along aggregate surface – presumably reflecting the differences in coefficient of linear expansion between cement paste and aggregate. Larger cracks can occur particularly where reinforcement has affected by the increase in temperature.

Next is alteration of the phases in aggregate and paste. The main changes occurring in aggregate and paste relate to oxidation and dehydration. Loss of moisture can be rapid and probably influences crack development. The paste generally changes colour and various colour zones can develop. A change from buff or cream to pink tends to occur at about 300°C and from pink to whitish grey at about 600°C.

Lastly is dehydration of the cement hydrate. Cementitious paste with considerable shrinkage cracking, honeycombing and generally concrete becomes friable, very porous and easily broken down at the temperature greater than 600°C

2.2.2 Classification of Damages

Classification is based on the temperature of the fire damage. When concrete is exposed to fire, concrete colour will change. If the concrete change from the white or grey to pink, orange or red then it usually indicates that it has significant damage is more than likely the structure is not strong. Change in colour is an indication that the fire is the optimum temperature to alter the physical properties of concrete. Classification of the extent of damage can be determined by observing the appearance (colour) and conditions (the surface) of concrete after a fire. This list of observations on the proposed inspection would provide a useful and additional input to estimate the intensity of the fire.

Concrete can sustain various degrees of damage depending on the severity of the fire and the high temperature levels reached. The effects of high temperature fire on concrete structures are such as the reduction in compressive strength and micro cracking within the concrete microstructure (Andrew-Phaedonos, 2011). Besides, colour changes consistent with strength reductions, reduction in the modulus of elasticity, various degrees of spalling, loss of bond between concrete and steel, and possible loss of residual strength of steel reinforcement and tension in pre-stressing tendon are also effect of fire with high degree of temperature.

2.3 EFFECTS OF FIRE TEMPERATURE

The following sections outline about the changes that occurred on concrete after heating on fire. The concrete are changes inner and outer. To know how the temperature affecting the concrete is by the following section.

2.3.1 Concrete Strength and Elastic Modulus

After cooling to ambient temperatures it has been observed that the strength of concrete may be further reduced from its strength at high temperature. Effectively during the cooling period a further loss of strength takes place because of continuing disintegration of the microstructure.

Concretes containing certain synthetic lightweight aggregates, such as sintered pulverised-fuel ash are though to offer good fire resistance, provided that the concrete is dry. However, poor performance has been observed in conditions were the concrete is saturated at the time of the fire.

The cement type and cement blend also influence behaviour of concrete in fire. Modern concretes often include a pozzolanic mineral addition in the binder such as fly ash (pulverised-fuel ash or POFA) ground granulated blastfurnace slag (GGBS). Their use is generally thought to give a slight improvement in heat resistance owing to the fact that they reduce the amount of calcium hydroxide (portlandite) within the hydrated binder. However, in the case of microsilica, its use significantly increases the risk of spalling due to the fact that it leads to very low permeability to the hardened concrete.

For temperatures up to 300°C, the residual compressive strength of structural quality concrete is not significantly reduced, while for temperatures greater than 500°C the residual strength may be reduced to only a small fraction of its original value. Consequently, the design methodology in the Eurocode discounts the strength of concrete exposed to temperatures higher than 500°C.

On the basis of the uncertainties regarding the assessment of the residual strength of concrete discussed above, this report recommends a more conservative approach, discounting the residual strength for concrete exposed to temperatures above 300°C.

2.3.2 Mineralogical and Colour Changes

Heating concrete causes a progressive series of mineralogical changes that can be investigated by petrographic examination to determine the maximum temperature attained and deduce the depth to which the concrete has been damaged. A compilation of the changes undergone by Portland cement concrete as it is heated is presented in Table 2.1, which is based on Ingham, 2007.

Table 2.1: Mineralogical and strength changes to concrete caused by heating

Heating Temperature	Mineralogical Changes
70-80⁰C	Dissociation of ettringite,causing its depletion in the cement matrix.
105⁰C	Loss of physically bound water in aggregate and cement matrix commences causing an increase in the capillary porosity and minor microcracking.
120-136⁰C	Decomposition of gypsum, CaSO4·2H2O causing its depletion in the cement matrix.
250-350⁰C	Pink/red discolouration of aggregate caused by oxidation of iron compounds commences at around 300°C. Loss of bound water in cement matrix and associated degradation becomes more prominent.
450-500⁰C	Dehydroxylation of portlandite, Ca(OH)2 causing its depletion in the cement matrix. Red discolouration of aggregate may deepen in colour up to 600°C. Flint aggregate calcines at 250-450°C and will eventually change colour to white/grey. Normally isotropic cement matrix exhibits patchy yellow/beige colour in cross-polarised light, often completely birefringent by 500°C.
600-800⁰C	Decarbonation of carbonates; depending on the content of carbonates in the concrete, e.g. if the aggregate used is calcareous, this may cause a considerable contraction of the concrete due to release of carbon dioxide, the volume contraction will cause severe microcracking of the cement matrix.
800-1200⁰C	Complete disintegration of calcareous constituents of the aggregate and cement matrix due to both dissociation and extreme thermal stress, causing a whitish grey colouration of the concrete and severe microcracking. Limestone aggregate particles become white.
1200⁰C	
1300-1400⁰C	

Source: Ingham (2007)

The colour of concrete can change as a result of heating, which is apparent upon visual inspection. In many cases a pink/red discolouration occurs above 300°C, which is important since it coincides approximately with the onset of significant loss of strength due to heating. Any pink/red discoloured concrete should be regarded as being suspect and potentially weakened.

In addition to the maximum temperature reached, the actual heat-induced concrete colour changes depend on the mineralogy of aggregate present in the concrete. Colour changes are most pronounced for siliceous aggregates and less so for limestone, granite and sintered pulverised-fuel ash lightweight aggregate (which shows very little colour change). Striking colour changes are produced by flint (chert).

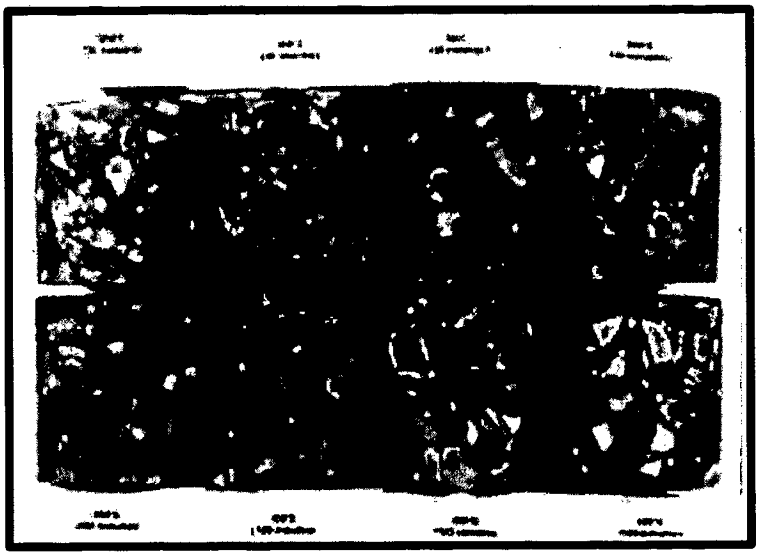

Figure 2.1 Appearance of flint aggregate concrete cores which have been heated for ½ hour (upper row) and 2 hours (lower row), at the temperatures indicated.

Source: Ingham 2007

The pink/red colour change is a function of (oxidizable) iron content and it should be noted that as iron content varies, not all aggregates undergo colour changes on heating. Concrete which has not turned pink/red is not necessarily undamaged by fire. Also, due consideration should always given to the possibility that the pink/red colour may be a natural feature of the aggregate rather than heat-induced. In concrete containing aggregate that does not undergo colour change or is naturally pink/red, other mineralogical and physical indicators should be used for determining the presence of fire-damage. It should also be noted that the cement paste can also be discoloured by carbonation and this should not be confused with heat-induced discolouration.

According to article, titled Assessment of fire damaged concrete using colour image analysis; the damages can be identified by visual observation. The degree of fire that concrete structure exposed has identified based on the colour or visual appearance changes. If the colour of concrete change into pink or red means that, the structure has exposed to the temperature 300°C until 600°C. Fire with temperature 600°C to 900°C will changing the colour of concrete into whitish grey, and buff for 900°C to 1000°C.

The changing in colour can be a good sign to know what is actually happen to the concrete while burning. The discolorations of pink or red shows that iron compound in fine or coarse aggregate dehydrate or oxidise. The deterioration is occurs when the colour of concrete turn into pink or red.

2.3.3 Cracking

At high temperatures, the unrestrained thermal expansion of steel reinforcement is greater than that of most concretes. This can lead to bursting stresses and cracking around the steel in heavily reinforced members. Experience suggests that such cracks concentrate at positions where, incipient cracks due to drying shrinkage, flexural loading, etc. were present. In addition, the thermal incompatibility of aggregates and cement paste causes stresses which frequently lead to cracks, particularly in the form of surface crazing.

2.3.4 Spalling

Moreover, the damages that can be identifying through the visual observation are such as crazing, cracking and spalling (loss of material). According to journal of assessment of fire damaged concrete structure and the corresponding repair measure, the typical damages that can be identify due to fire are loss of prestress, the residual deformation, cracking loss of material by spalling, detailing and connection failure between steel-RC and at supports, also change visual appearance such as sooty and coloured surface.

Spalling of the concrete will occur when the intensity of fire is such that moisture trapped within the concrete microstructure, achieve bursting pressure, due to the generation-superheated steam, sufficient to crack and spall the concrete. According to the Technical Note: Fire damaged Reinforced Concrete (2011), few factors can increase the spalling due to the thermal shock, strain differences and pressure causing micro-cracking and further strength losses such as unequal rate of thermal expansion between the aggregates, cementitious paste and reinforcing steel, and water quenching during fire suppression

Three main types of spalling can be recognised. Explosive spalling (see Figure 2.2) occurs early in the fire (typically within the first 30 minutes) and proceeds with a series of disruptions, each locally removing layers of shallow depth. Aggregate spalling, also occurring in the early stages, involves the expansion and decomposition of the aggregate at the concrete surface causing pieces of the aggregate to be ejected from the surface.

Figure 2.2 Explosive spalling

Source: Camberley 1990

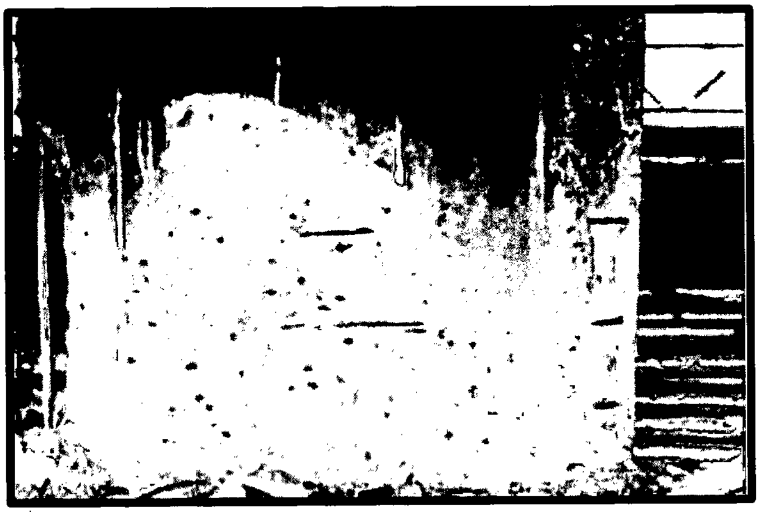

Figure 2.3 'Sloughing off'

Source: Camberley 1990

Sloughing off or corner spalling (see Figure 2.3), occurs in the later stages of the fire when temperatures are lower. It occurs chiefly in beams and columns, as tensile cracks develop at planes of weakness such as the interface between the reinforcement and the concrete.

As this type of spalling occurs in the advanced stages, the concrete is already significantly weakened and thus there are no implications for structural performance. Due to the lateness of the onset of this type of spalling, the interior concrete and the reinforcement are unlikely to have been subjected to high temperatures, even though the latter is often exposed.

Figure 2.4 Spalling of a slab soffit owing to fire-damage of embedded plastic reinforcement bar spacers.

Source: Camberley 1990

Spalling of concrete surfaces can be caused by the deterioration of materials embedded in concrete other than reinforcement bars. Ingham and Tarada indicate that plastic reinforcement bar spacers are one of the more commonly encountered examples of this (see Figure 2.4).

Further loss of concrete may also take place after the fire has been extinguished and as the concrete cools. In such cases this concrete has remained in place long enough for the rise in temperature of internal concrete and reinforcement to be restricted.

2.3.5 Soot and Smoke Deposit

Black soot and smoke deposits on concrete components is direct by-product of an intensity of fire. These can be seen during fire burning whereas the soot can also be seen while the intensity of fire is abating.

2.4 TESTING

There are several techniques available to help in the diagnosis of the condition of reinforced concrete on site and laboratory-based. Techniques carried out on site include a visual inspection, non destructive testing and removal of samples of concrete and reinforcement, which can then be inspected and / or tested in the laboratory. Guide to the chosen test method suitable for investigating the fire damaged concrete as provided in Table 2.2.

2.4.1 On site Inspection

It may not be sufficient to take the 'sounding' on the broken concrete to determine the level of deterioration. 'Rings' concrete sound and 'dull thud' weak material easily distinguished. This test can be effectively done with a hammer and chisel. Removing concrete with a hammer and chisel can therefore be used to determine the depth of the pink-red layer. Figure 2.5 shows red-pink discolouration on the soffit of a fire damaged slab.