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# The Deflection Behavior of High Temperature Exposed-Reinforced Concrete Beam

[1*]Setyowati E W ,[2**] Soehardjono A
[1] *Lecturer of Civil Engineering, Faculty of Engineering, Brawijaya University, Malang, Indonesia*
[2] *Professor of Civil Engineering ,Faculty of Engineering,Brawijaya University, Malang,Indonesia*

**ABSTRACT**
The high temperature exposure that induces the concrete's microstructure changes, will eventually cause the changes of physical and mechanical nature of the concrete's structure while also change the behavior of the reinforced concrete beam. This research studied the deflection behavior of the reinforced concrete beam that had been burned in high temperature and the correlation of this act towards the changes in the concrete's microstructure and the maximum deflection of post-burn reinforced concrete beam. The study used 28 days old of 36 reinforced concrete beams (150 mm x 200 mm x 750 mm) with 25 mm thick concrete cover that had been burned under various temperatures (400$^o$C ; 600$^o$C ; 800$^o$C), compared with unburned control. Afterwards, the flexibility test was done towards the reinforced concrete beams to identify the level of deflection and maximum deflection of each beam.The recent evaluation microstructure test showed that the physical and mechanical characters are in equal with the behavior of post burn reinforced concrete beam .The test result showed that high temperature exposure will change the deflection behavior of reinforced concrete beam. The concrete beam exposed by 400$^o$C temperature, in general, have less deflection value. This result was supported by the examination data of the concrete's microstructure that showed positive result. On the other hand, 600$^o$C exposure led to the destruction of the concrete's microstructure that reduce the concrete's strength and increase the beam's deflection. In 800$^o$C exposure, the microstructure examination showed the lost of portlandite phase, the cement's characteristic nature, thus drastically reducing the strength of concrete's materials. Similarly, the steel's strength was also reduced, leading to further reducement of reinforced concrete's beam strength.
***Keywords:*** *Deflection, Reinforced Concrete Beam, High Temperature*

## I. INTRODUCTION

Fire damage is a substantial hazard need to be evaluated in designing building's structure. Eventhough concrete has been known as a subtle material with high resistancy towards high temperature, the fire damage can cause changes in the structure of reinforced concrete beam thus need more planning concern and evaluation.The exposure of the high temperature towards concrete's materials will change the concrete's microstructure that will lead to the shift of physical andmechanical nature of the concrete [1].

The structure behavior, especially crack and deflection behavior that is included in the standard for structure damage, and the reduce of strength, were also changed. SNI and international standard have established the regulation for maximum deflection limit for reinforced concrete beam. However, there is no deflection limitation standard for high temperature exposed-reinforced concrete beam post-fire damage until now. The construction behavior of reinforced concrete beam needs to be evaluated to determine the suitability for use and rehabilitation. Therefore, it is important to test and observe the behavior of concrete beam, especially the deflection behavior of the reinforced concrete beam post high temperature exposure.

## II. STUDY LITERATURE

**The Structure of Reinforced Concrete Beam**

As per definition, reinforced concrete beam is part of the building structure that consists of concrete materials combined with steel materials and shaped as structure element. According to the nature and characteristic of each material, concrete and steel, the structure is planned for strength by employing the composite action between those two materials. Steel material has characteristic of high tensile strength and therefore will contribute to the structure tensile strength. On the other hand, normal concrete material will give high contribution for the structure pressure strength.

The guidelines for the reinforced beam structure plan are based on the standard for all structure, such as ACI and SNI that often used in Indonesia for various structures.[2][3]

The deflection case in reinforced concrete beam showed that high temperature force on a beam will cause deformation and add stretch . Base of composite structure's plan about deformation of deflection, the composite's act in a structure is an interaction of all elements towards the force as a unity.

There are various degrees of the combined act, which are massively depend on the characteristic nature of steel and concrete materials.In a condition where the damage occur on each or both materials, the degree of the combined act of two materials will change, dependently.

The steel material in reinforced concrete beam structure has an important role in supporting the composite's strength, as also under high temperature exposure. Inaddition, the steel material that easily affected by temperature changes has great importance and this material will even become the source that can change the power and the act of steel and concrete composites.

**The effect of temperature change on steel behavior**

The nature and characteristic of steel are easily affected by temperature changes thus we need to understand this behavior change determine the welding procedure and burn effect. Under temperature more than 200$^{o}$C, the tensile-stretch curve start to become un-linier. On temperature between 800$^{o}$C and 1000$^{o}$C, steel will lost 65% of its strength, and on 675$^{o}$C steel will lost 75% of its strength [4].

**The high temperature effect on concrete**

In general, concrete has high resistancy against high temperature. However, due to the unique character of concrete which has a lot of variables to retain the same strength, many efforts need to be done to improve the comprehensive power of concrete up to more than 70 MPa that been categorized as high strength concrete (HSC) that still need to be evaluated for its application as fire resistant-concrete (Kodur et al)

For reinforced concrete, the high temperature will change the physical, mechanical, and chemical nature of the steel and concrete materials as a result of the changes of the microstructure, that, as a whole, reduce the strength and change the structure behavior (the crack behavior of the reinforced concrete beam). The changes and damages that occur on the microstructure of the concrete will affect the physical and mechanical nature of the concrete, while also bring huge impact on the behavior of the reinforced concrete beam (RC beam). One of the most important concrete's behavior is the crack behavior as crack is one indication of structure damage and failure [1].

Due to the chemical bond changes, the resulted compound from hydration process will become dehydrated thus reduce the strength of the cement paste as the binding material of concrete. The reaction between pozzolan and CH, named as "pozzolanic reaction", is more effective to fill concrete's pore thus increasing concrete's strength [5].CaO, a compound resulted from dehydration process of $Ca(OH)_3$ at 400$^{o}$C and CaCO-$_3$decarbonation at 700$^{o}$C, are released during heating process. This compound will be hydrated back into $Ca(OH)_2$ due to water absorbance during freezing process. This rehydration process will then cause 44% volume increase that weaken the cement paste and cause crack. On the other hand, the excessive CaO production will increase the concrete's burnability level up to 400$^{o}$C. At the exposure of 400$^{o}$C and above heat temperature, interestingly, the concrete's burnability level is reduced. The addition of pozzolan materials into Portland cement will eliminate the presence of $Ca(OH)_2$ compound thus elevating the concrete's endurance towards high temperature [6].

The reaction between pozzolan and CH is highly depends on the age and the treatment process of the concrete. By the age of 90 days, Portland cement made-concrete with 25% containment of pozzolan will have 22%, 37% and 43% pozzolanic reaction under treatment at 20$^{o}$C, 35$^{o}$C and 50$^{o}$C, respectively [7]. Portland cement made-concrete that have 20% pozzolan (silica flour) have a relatively high residual strength after being exposed to 400$^{o}$C for two hours. The concrete's cooling method by natural cooling is considered better than rapid cooling.

Damage such as spalling of the concrete's cover surface that being exposed to high temperature is the most common effect and can be classified into four: aggregate, surface, and explosive spalling, which are highly affected by the heating level, and concrete spalling which resulted from maximum temperature exposure [8].

The colour change on concrete's cover can be utilized as an indicator of the heating level, which red indicates temperature more than 300$^{o}$C up to 600$^{o}$C, and light grey that indicates temperature 700$^{o}$C and above. In addition of their function as an indicator of the heating level, the colour (hue) degradation also correlates with the residual pressure strength of the concrete, which decline as the hue level increase [9].

The damage on concrete's internal structure will get worse as the concrete is cooled down on room temperature due to both fast cooling process, causing thermal shock as a result of the temperature drastic change, and slow cooling process that result in long term heat exposure on the concrete. In other words, the concrete's strength value after heat exposure is divided into three categories: the strength before heating, strength during heating, and strength after heating. The strength level in each category is different, in which the strength level during heating is higher than after heating. The difference in determining the level of strength depends on the testing method applied on concrete.

**Reinforced Concrete Beam Deflection**

The structure compounds of reinforced concrete beam are likely to crack on stretched area, as following the nature of concrete materials that less strong in holding the stretch tension and also the temperature changes and high temperature exposure. On the other hand, the deflection behavior of the beam is correlated with the crack behavior and becomes a damage indicator that can be visually evaluated on concrete's surface as part of reinforce concrete beam's strength and ability control. As the guideline and standard of maximum deflection of reinforced concrete beam structure in normal condition has been established, in this study we will further evaluate this deflection behavior specifically in post-burn condition.

**The temperature Effect on Deflection**

Studying the comparison of the maximum load for every different heat exposure time duration and level of structure's deflexion, were able to describe that fire damage can increase structure's weakness to hold maximum load [10].The curve diagram of correlation between deflection and heat exposure duration showed that different heat exposure duration result in different structure ability in holding the load resulted from concrete's cover scalding that leads to direct fire exposure on reinforce steel.

**The Stiffness of Reinforced Concrete Beam**

Reinforced concrete beam structure that was planned to be deflected need to be stiff enough to limit the deflection that will reduce the strength and ability in holding the loading weight. Stiffness can be defined as the needed force to obtain one unit displacement. In-plane bending stiffness is a product from two variables: in-plane inertia moment ($I_x$) that reflect the cross section strength, and modulus elasticity ($E$) which represent the concrete's ability, both during loading process. In terms of reinforced concrete beam, the loading process will change both of these two variables. The inelastic strain-stretch behavior of concrete that surpass the elastic limit during excessive loading will cause variation on modulus elasticity, while concrete's crack that occur as the pulling force exceeding the stretch that cause crack will then cause variation in beam's inertia moment.

Modulus elasticity is a measure of hardness of some specific material that reflects the material's ability in holding weight. Modulus elasticity can also be defined as the comparison between the strain force level and the stretch force level working on some materials. Based on the elasticity theory, the slope shown in stretch-strain curve during the early phase or in proportional elastic reach represents the modulus elasticity of the material. Strain-stretch curve of concrete has an arch shape thus showing that concrete is not entirely elastic. Therefore, the modulus elasticity will changed based on its strength and cannot be determined solely by looking at the slope of the concrete's strain-stretch curve.

In fact, the modulus elasticity value itself has been brought into the available planning standard, in which the smaller concrete's compression strength, the smaller its modulus elasticity. The concrete's strength reduction that occur due to the internal structure damage by C-S-H compound decomposition and increasing crack on transition zone between aggregate and cement paste will result in reduction of the concretes ability in receiving load. Therefore, decrease of concrete's compression strength may further reduce the modulus elasticity value.

The high temperature exposure on concrete will reduce its modulus elasticity. The reduction of modulus elasticity mostly resulted from broken bonds in concrete's microstructure. The modulus elasticity of high temperature exposed-concrete is higher than the cold one[10] . Fast cooling method by watering can reduce more modulus elasticity than slow cooling method by leaving the concrete in room temperature [4]

The inertia moment of reinforced concrete beam reflects the ability of concrete's cross-section surface on receiving load. Crack on concrete's cross section surface affect the inertia moment value and stated that effective inertia moment is need in the calculation of actual deflection on reinforced concrete beam [11]

## III. METHODOLOGY

**Research Plan**

**Table 3.2 Reinforced Concrete Beam Test Plan**

| Cooling Method | Temperature | Sample |
|---|---|---|
| - | Room Temperature (unburned) | 3 x 3 |
| Sprayed | 400$^o$C | 3 x 3 |
| | 600$^o$C | 3 x 3 |
| | 800$^o$C | 3 x 3 |
| Total Sample | | 36 |

The sample will be burned in high temperature (400$^o$C, 600$^o$C, 800$^o$C) using a burner with thermocouple. These samples will be then compared to the unburned control. The concrete beam were tested for deflection and the measurement was done using LVDT with 50 mm capacity and 0.01 mm capacity.

**Concrete Beam Test**

The deflection test was done based on ASTM C

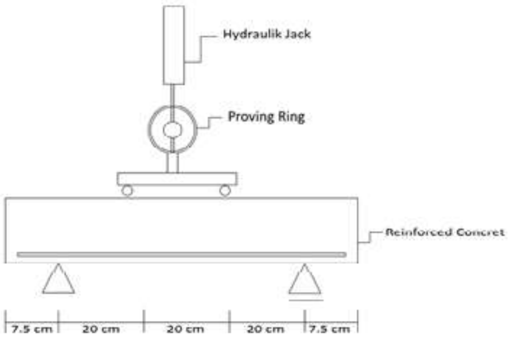
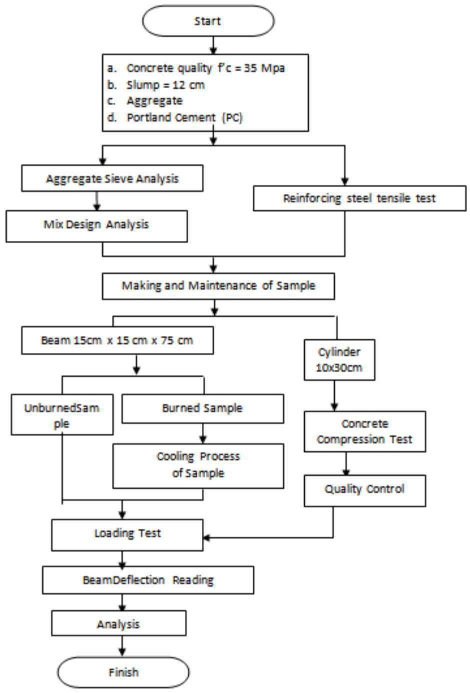



**Figure 1. Deflection Test on Reinforced Concrete Beam**

This study used concrete's material with compression strength reaching 35 MPa,was being made based on the mix design with water cement ratio 0.48, soft aggregate-nature sands, rough aggregate (stone) with maximum diameter 20 mm, slum value: 10-30 mm, by using type I Portland cement and mixing plan using SNI T.15-1990-03 standard, the weight ratio of cement:sands:agregate= 1 : 1,97 : 2,9

**Study Flowchart**




**Reinforced Concrete Beam Deflection**

The deflection observation on tested reinforced concrete beam was divided into two groups:

a. observation of deflection on unburned concrete
b. observation of deflection on burned concrete under temperature : 400$^o$C; 600$^o$C; 800$^o$C

and the observation result for every treatment (unburned, burned under temperature 400$^o$C; 600$^o$C; 800$^o$C) are represented in Figure .2 - 5
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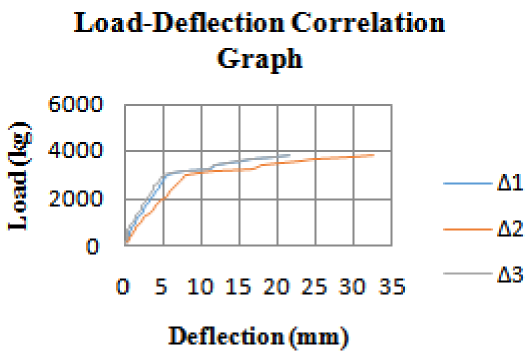



**Figure.2.** The correlation between load and deflection on unburned concrete

**Figure 3** The correlation between load and deflection on concrete burned at 400$^o$C

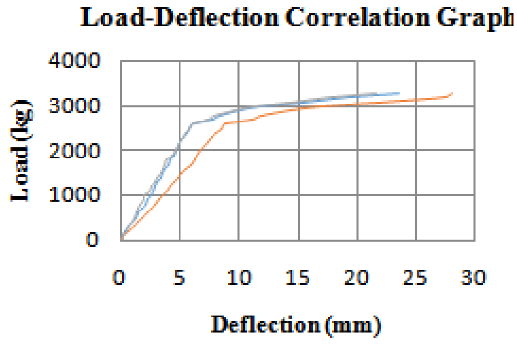



**Figure.4.**The correlation between load and deflection on concrete burned at 600°C

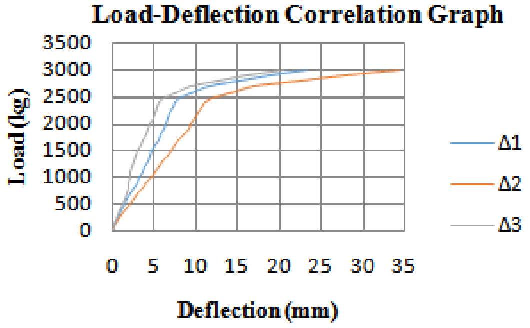



**Figure.5** The correlation between load deflection on concrete burned at 800

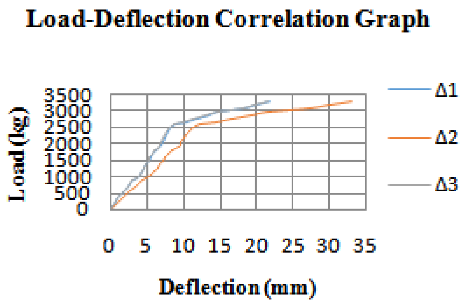
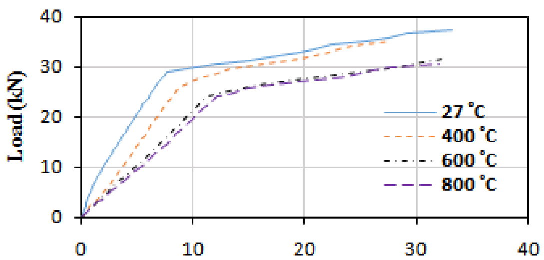



**Figure 6**. The correlation between deflection and temperature




The mean deflection level was calculated in each observation of concrete beam behavior, as shown in Figure 6. Deflection was measured in three different places according to the mid location of the stretch, as can be seen in Figure.7

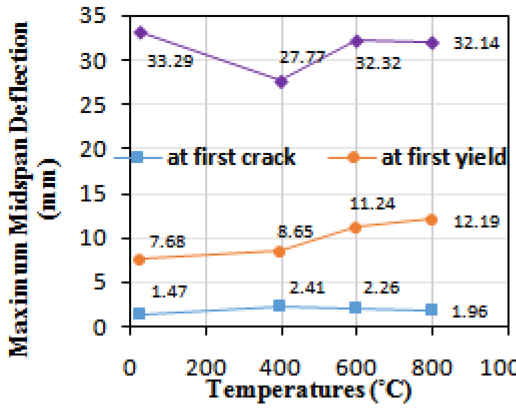



**figure.7.** The colleration between temperature and maximum deflection

Based on the observation of testing materials , we can see that the likelihood for increasing deflection as the load increase is a natural condition up to the maximum loading point. Similarly, the maximum deflection level is also increase as the temperature increase.

However, we can see that for testing materials exposed to 400°C, most of the samples have reduced deflection. This condition occur as the micro structure of the concrete is changed after ther 400°C exposure. The heat exposure cause an increase of silica unsure thus making more massive concrete [1]. this condition leads to reduced crack width and consequently affect the deflection curvature and deflection reduction [1].

## IV. CONCLUSION

Based on our study about high temperature exposed-reinforced concrete beam and the comparison between the testing materials and control, we can conclude that:

1. The compression strength of concrete materials is reduced when exposed to high temperature, or in the other hand, temperature is reversely correlated with compression strength.
2. The loading capacity of the concrete is reduced when exposed to high temperature. as the temperature increase, the reduction of loading capacity is getting bigger, except on 400°C when the reduction is not significant.
3. After high temperature exposure, the microstructure of the concrete is changed. On 400°C, there is some anomaly on the microstructure, in which the Silica (Si) unsure is increasing more than under 600°C exposure and above. The concrete's surface on 400°C is

more solid than under 600oC and higher temperature exposure.

4. Under high temperature exposure, the microstructure of the concrete, especially the chemical bond is changed. The reduction of portlandite phase shows that the cement characteristic is eliminated under 800$^{o}$C exposure which will then lead to drastic reduction of the concrete's strength.
5. Under 600$^{o}$C and above, the concrete beam deflection is increased. On contrary, under 400$^{o}$C the concrete beam deflection is reduced due to the positive changes of the concrete's microstructure.

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