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STRESS-STRAIN RELATIONSHIP OF FIBRE REINFORCED CONCRETE EXPOSED UNDER ELEVATED TEMPERATURES

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Abstract: A research had been done to study the stress-strain relationship of fibre reinforced concrete (FRC) exposed under elevated temperature. The FRC used were single fibre concrete and hybrid fibre concrete which is combination of two different properties of fibres i.e. steel (SF) and polypropylene (PPF) by applying fibres volume fraction at 1.5%. At the same time, the fibres proportion of steel-to-polypropylene ranged in the following percentages: (100-0), (75-25), (50-50), (25-75) and (0-100). Cylinder samples of 150 mm diameter × 300 mm high were used and subjected to a compressive load to determine the relationship. All samples were casted and then water cured for 28 days before exposing them to the desired temperature i.e. 200°C, 400°C, 600°C and 800°C for 1 hour. For the control specimens, the cylinders were left at room temperature (27°C) until the test day. Before placing the cylinders into the compression testing machine, they were left to cool naturally. All test results were tabulated and the stress-strain relationships were compared between the variations of the elevated exposure temperature. The findings show that the addition of fibres only improve the Elastic Modulus of concrete at room temperatures (27°C), but when exposed under elevated temperatures, the Elastic Modulus decreased especially above 400°. High temperatures caused spalling effect on the specimens especially when exposed above than 400°C.

Keywords: *Fibre reinforced concrete, elevated temperature, stress-strain relationship, elastic modulus.*

1.0 Introduction

Concrete in the recent years had been enhanced by adding materials to cope with the problems and damage that occurred for its brittle properties. One of the questions which normally arise is when plain concrete is exposed under elevated temperature i.e. reduction of the strength. This also includes concrete deterioration after exposure and its failure mode. Previous researches show that adding other materials in plain concrete, such as fibres and geopolymer can resist the deterioration effect under exposure temperature(Kong & Sanjayan 2010; Lau & Anson 2006; Rao et al. 2013). This is because fibres characteristic itself is able to hold the material constituents in concrete from breaking apart when loading is applied. Geopolymer which is an inorganic polymer based on alumino silicates has ceramic like properties possess good fire resistance.

Stress-strain relationship is one of the important parameter for concrete properties. The stress-strain curves are normally taken when either cubes or cylinder specimens are subjected to compression load. The relationship is important in order to study the strain hardening behaviour at elastic and plastic properties. There are many researches that had been done relating fibre reinforced concrete (FRC) and temperature. However, most of the them only used single type of fibre in concrete (Chang et al. 2006; Cheng et al. 2004). In this research, the study focused on the effect of the compressive stress-strain relationship of FRC after exposure to elevated temperature. From the relationship, Elastic Modulus of FRC is also determined. Addition to this, the FRC not only used single type of fibre, but also combined two fibres with different properties steel (ST) and polypropylene (PP). The findings from this study will answer the questions regarding the elasticity of FRC when exposed under elevated temperatures. Not only that, the findings can help engineers in designing in better and safer structures in the future.

2.0 Experimental Programme

This study involved experimental work to determine the stress-strain relationships under compressive load. In order to achieve the objective of the study, cylinder specimens as shown in Figure 1 are used having dimension of 150 mm diameter × 300 mm high. All specimens are subjected to compression load after they are exposed to elevated temperature.

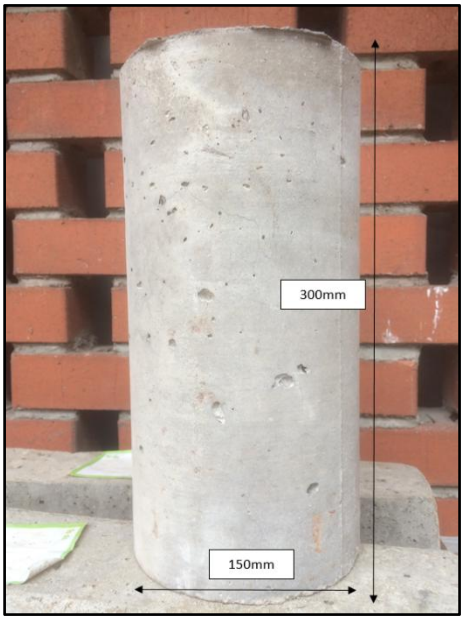

Figure 1: Cylinder specimens used in this study

Ordinary Portland Cement (OPC) is used in this study and the water-to-cement ratio is also fixed at 0.47. This ratio is used in order to achieve grade C40 concrete at 28 days and at the same time to ensure that the mixture is not too dry when fibres are added. Fine aggregates of less than 5 mm are used, while coarse aggregates ranged between 10 mm and 20mm.

The total fibre volume fraction, V_f is fixed at 1.5% from the total percentage of the concrete for all batches. This fraction (i.e. V_f = 1.5%) was chosen based on the findings from previous researcher whereby for V_f ranged between 0.5% and 1.5%, the optimum V_f was found for 1.5% which resulted in improvement of concrete strengths(Ibrahim et al. 2013).For each total fibre volume fraction at V_f = 1.5%, they are divided into five main fibre proportions for either the single or combined fibres: (i)100% ST with 0% PP (100-0), (ii) 75% ST with 25% PP (75-25), (iii) 50% ST with 50% PP (50-50), (iv) 25% ST with 75% PP (25-75), and (v) 0% ST with 100% PP (0-100). Example of the ST and PP fibres used in this study are shown in Figure 2.

(a) (b)

Figure 2: Types of fibres used in this study: (a) Steel (ST), and (b) Polypropylene (PP)

The volume of ST fibres, V_{ST} to be added in the concrete mixture is calculated using the following expression:

$$V_{ST} = \frac{x_{ST}}{100} \cdot \frac{1.5}{100} \cdot (Steel\ Density) \times \ (Concrete\ Volume) \tag{1}$$

Where x_{ST} is the percentage of ST, while the steel density is taken as 7850 kg/m^3. Meanwhile, the volume of PP fibres, V_{PP} is calculated using the following expression:

$$V_{PP} = \frac{x_{PP}}{100} \cdot \frac{1.5}{100} \cdot (Polypropylene\ Density) \times \ (Concrete\ Volume) \tag{2}$$

Where x_{PP} is the percentage of PP, while the polypropylene density is taken as 869.14 kg/m^3. Both ST and PP densities are given by the manufacturer.

The cylinder specimens of FRC are exposed to different temperature variations of 200°C, 400°C, 600°C and 800°C. At each desired temperature, the specimens are left to expose for 1 hour. Meanwhile, for control specimens, each concrete batches were left at room temperature (27°C) until the test day. Altogether, there are a total of 25 batches for the five different fibre proportions at V_f = 1.5%. At 28 days, the cylinder specimens are removed from the curing tank and left to dry for 1 day before they are placed in the firing furnace as shown in Figure 3. This process is carried out to ensure that the specimens are completely dry and also to control the shrinkage strain that may occur due to the sudden increase in temperature. Before the beginning of the 1 hour exposure, the firing furnace is firstly heated gradually at a rate of 8°C per minute until it reached its desired temperature. This process may takes about 1 – 3 hours depending on each targeted temperature (200°C – 800°C).

Figure 3: Firing furnace for the elevated temperature exposure

After the cylinder specimens had been exposed at each desired temperature, they are then removed from the firing furnace and left to cool under room temperature for at least 24 hours. In order to ensure that the cylinders are completely flat under the compression testing machine, the top surface are capped using high alumina cement as shown in Figure 4.From the compression test done onto cube samples of size 50 x 50 x 50 mm of high alumina cement material, the average result was 70kN, which was higher than the designated concrete strength which was C40.Strain gauges are attached on the side of the cylinder as shown in Figure 4 to determine the compressive strain during the compression test.

Figure 4: Cylinder specimen completed with the capping material and strain gauges

The compression load test is carried out in accordance with BS EN 12930-13 (British Standard 2012). In order to determine the Elastic Modulus, compression load is applied in three cycles until it reached one third of the maximum load. After reaching the desired load, it is then returned to 0 kN gradually. After completing the three load cycles, the test continued for the final loading increment until failure of the cylinder specimens are observed. The Elastic Modulus together with the compression load test setup is shown in Figure 5.

Figure 5: Test setup for the Elastic Modulus and compression load

3.0 Experimental Results and Discussions

The Elastic Modulus value for the plain concrete for this study was 31.63GPa. The Elastic Modulus is determined from the best fit line of the three load cycle from the stress-strain relationship. A sample of the stress-strain relationship is shown in Figure 6. The tangent from the best fit line is then calculated in order to determine the Elastic Modulus. The relationship between the Elastic Modulus and the elevated temperature exposure is discussed in this section.

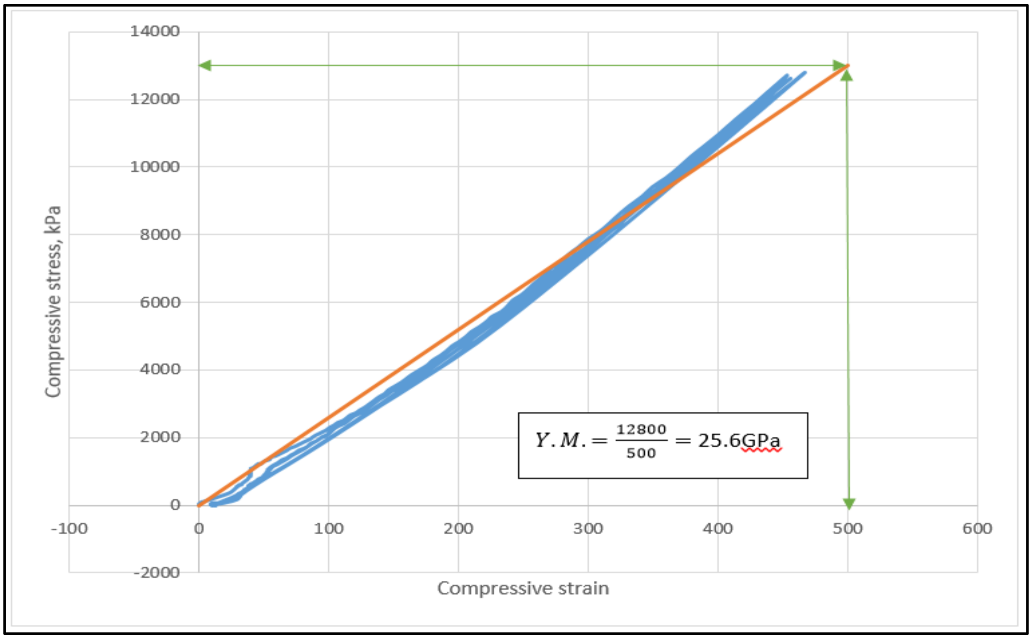

Figure 6: Sample of determining the Elastic Modulus from the stress-strain relationship. This relationship is taken for percentage proportion of (50-50) exposed at 400°C

The relationship between the Elastic Modulus and the elevated temperature exposure is shown in Figure 7.The relationship shows that the Elastic Modulus decreases as the temperature increases from 200°C to 800°C. The study shows that the effect of adding fibres in concrete does not improved the compressive strength of the concrete. Furthermore, adding two different fibres with different properties also does not have any significant effect on the improvement of the Elastic Modulus and even the compressive strength. The same findings were also observed by other researcher where the FRC strength decreased slightly at below 400°C, but when it was exposed to more than 400°C, the decreasing pattern was significant (Sukontasukkul et al. 2010).

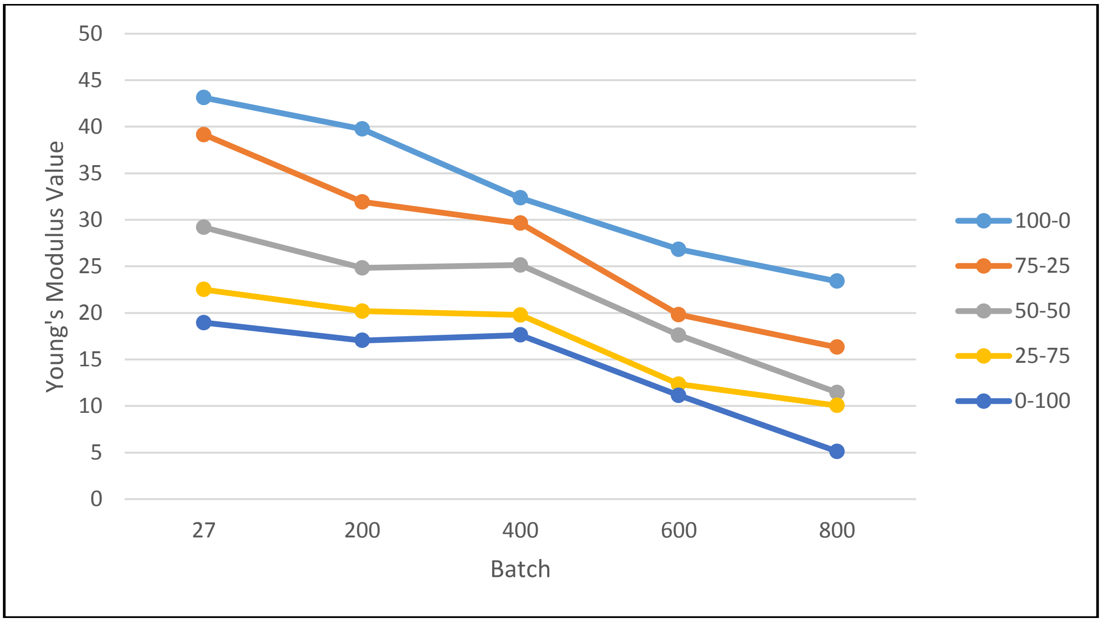

Figure 7: Relationship between Elastic Modulus and exposure to elevated temperature

The relationship also shows that for FRC containing 100% ST fibres has the highest Elastic Modulus as compared with the others including the one combined with ST and PP fibres. In contrast, FRC containing 100% PP fibres resulted in the lowest Elastic Modulus. This is because ST has higher elasticity properties and can also withstand higher temperature under exposure condition. In contrast to PP fibre, the properties itself can only withstand up to 170°C as given by the manufacturer. Therefore, exposing them above the required temperature will either melt the PP fibre itself or changing the properties to become more brittle. However, combining both ST and PP fibres improved slightly the Elastic Modulus, but it is still lower than the FRC mixture with ST fibres alone. The reason for the slight improvement of the Elastic Modulus is because of the available ST fibres that still able to resist the loading even though the PP fibres might have been melted during the temperature exposure. This shows that combining two of more fibres with different properties help improved the weakness of the other fibres i.e. the low elasticity. Furthermore, PP fibres are able to reduce the porosity of the concrete matrix (Kalifa et al. 2001).

4.0 Conclusion

The study concluded that the Elastic Modulus of FRC decreases when exposed at high temperature especially above400°C. When compared with the Elastic Modulus value of plain concrete that is 31.63GPa, only batch of (100-0) and (75-25) at temperatures below 400°C were larger than the plain concrete's Elastic Modulus. The effect of the FRC when exposed under elevated temperatures reduced the elasticity of the FRC. This gave the answer of the elasticity of FRC when exposed under elevated temperatures. Not only that, the addition of fibres into concrete does not improve the elasticity of FRC when exposed under elevated temperatures, but still minimise the deterioration effect caused by the temperatures at below 400°C. The findings can help Engineers and relevant authorities to take precaution action when designing structure that is exposed to high temperature.

5.0 Acknowledgement

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