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Stress Strain Characteristics of Flyash Based Geopolymer Concrete

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ABSTRACT

Geopolymer concrete prepared from class F fly ash and mixed alkali activator of sodium hydroxide and sodium silicate solution were investigated. Sand and M-Sand were used as Fine aggregates. The aim of this project is to study the behaviour of stress and strain characteristic of geopolymer concrete by using ambient and heat curing. Also the suitability of using an existing constitutive model originally proposed by Popovics for ordinary Portland cement concrete was studied. It was found that the equation of Popovics can be used for geopolymer concrete with minor modification to the curve fitting factor.

Keyword: Geopolymer, Popovics equation, heat curing.

1. INTRODUCTION

1.1. General

Concrete is the most widely used construction material; its usage by the communities across the globe is second only to the water. Customarily, concrete is produced by using the Ordinary Portland Cement (OPC) as the binder. The usage of OPC is on the increase to meet infrastructure development.

The world wide demand of OPC would increase further in future. It is well known that cement production depletes significant amount of natural resources and releases large volume of carbon –di-oxide. Cement production is also highly energy intensive, after steel and aluminium.

On the other hand, coal-burning power generating plants produce huge quantities of fly ash. The volume of fly ash would increase as the demand for power increases. Most of the fly ash is considered as waste and dumped in landfills.

In order to address the issues mentioned above, it is inessential that other forms of binders must be developed to make concrete. The geopolymer technology developed by Davidovits in the 1980s offers an attractive solution. [1, 2]

Aggregates occupy 65-80% of the total volume of the concrete and affect the fresh and hardened properties of concrete. Out of the total composition of aggregate, the fine aggregate consumes around 20-30% of the volume. The shortage of resource of natural sand has opened the possibilities for the use of M-Sand. M-Sand is contrast with the natural sand, come from the mechanical crushing of virsin rock, which many times is also used for aggregate of larger size and whose mineralogical composition well known.

1.2. Definition of Geopolymer

Geopolymer are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolite materials, but the microstructure is amorphous instead of crystalline. The polymerisation process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds.

1.3. Reaction Mechanism

The chemical reaction may comprise the following steps:

- Dissolution of Si and Al atoms from the source material through the action of hydroxide ions.
- Transportation or orientation or condensation of precursor ions into monomers.
- Setting or poly condensation / polymerisation of monomers into polymeric structures.

However, these three steps can overlap with each other and occur almost simultaneously, thus making it difficult to isolate and examine each of them separately.

The water required in the first stage of reaction is released again at the second stage i.e., it does not take part in the reaction as compared to that in the case of ordinary cement concrete.

2. OBJECTIVE

- To find out the effectiveness of fly-ash based geopolymer concrete using sand and manufactured sand by heat and ambient curing.
- To find the correlation between the experimental results and mathematical modelling of stress strain curves for sand and M Sand.
- To compare the Stress Strain results of heat and ambient curing.

3. MATERIALS

The materials used for making fly-ash based geopolymer concrete specimens are

1) Low calcium fly ash
2) Fine aggregates (Sand, Msand)
3) Coarse aggregate
4) Activators (Sodium Silicate and Sodium Hydroxide Solutions)
5) Water (as a Workability agent)

Figure 1 Coarse aggregates, fine aggregates, fly ash, NaOH pellets and Na_2SiO_3 solution

4. MIX DESIGN

The mix design in the case of geopolymer concrete is inverse to that of conventional concrete. In the case of conventional concrete the material proportion can be found out for the required strength using the code, but in case of the Geopolymer concrete there is no design method or codal provisions. Hence by means of trial mixes the concrete is being produced. By testing that concrete produced by trial mixes we will get some strength. Now this trial proportion is the required mix design for the particular strength attained.

Table 1 Mix design for geopolymer concrete in kg

Materials	Fly ash	Sand	C.A	Water	Sodium Silicate	NaOH solution
M20	2.28	3.34	5.46	0.21	0.94	0.167
M25	2.54	2.97	5.46	0.28	1.108	0.196
M30	3.02	2.48	4.82	0.30	1.34	0.23
M35	3.39	2.19	4.19	0.34	1.53	0.271

Materials	Fly ash	M-sand	C.A	Water	Sodium silicate	NaOH solution
MS20	2.23	4.42	5.82	0.198	0.89	0.16
MS25	2.54	3.39	5.34	0.246	1.11	0.196
MS30	3.02	2.84	4.71	0.29	1.34	0.237
MS35	3.39	2.21	4.16	0.34	1.53	0.271

5. EXPERIMENTAL INVESTIGATION

5.1. Casting of Specimens

Figure 2 Preparation of concrete mix

The cylinders of size 150mm dia x 300 mm high were casted to obtain the stress-strain curves. 8 cylinders were casted for sand similarly 8 cylinders were casted for manufacturing sand for ambient curing and heat curing. Different mix ratios in both sand and manufacturing sand (M20, M25, M30, and M35) and (MS20, MS25, MS30, MS35) were adopted.

5.2. Curing

The curing of specimens was done by ambient curing and heat curing. The specimens were cured in open air for 28 days. For heat curing specimens were kept at the temperature of 60˚C for 24 hours. Then the cylinders were tested by using LVDT to obtain the lateral strain and longitudinal strain.

Figure 3 Specimens kept for heat curing

5.3 Test Set-Up and Instrument

The cylinder is placed in the universal testing machine to obtain the strains by using the strain indicator. The strains were obtained by fixing 3 numbers of Linear Variable Differential Transducer (LVDTs). These (LVDTs) were used to measure the deflections at selected at locations along the centre line of the cylinder. The LVDT is fixed to the strain indicator and the strain values are noted. 2 no of LVDT are placed in the sides of the cylinder to measure the lateral strain and 1 LVDT is placed in the centre of the cylinder to measure the longitudinal strain.

Figure 4 Test setup with LVDT and strain indicator

6. ANALYSIS AND TEST RESULTS

6.1. Equation Formation

The stress-strain curve of geopolymer concrete is plotted for the experimental values and calculated strain values by the expression proposed by Popovics was subsequently modified by introducing a factor k in the equation to ensure a steeper descending part of the curve for high-strength concrete. This expression of Popovics was selected to investigate the suitability of its use for geopolymer concrete.

The stress-strain relationship by Popovics, modified is given under the following expression:

$$\frac{f_c}{f'_c} = \frac{\varepsilon_c}{\varepsilon'_c} \text{ x } \frac{n}{n-1+(\frac{\varepsilon_c}{\varepsilon'_c})^{nk}} \qquad \text{-(1)}$$

Where f_c=concrete compression stress, =strain in concrete, f_c'=maximum compressive stress in concrete, =stain when f_c reaches f_c' and n=curve fitting factor. The factor k equals 1 when is less than 1. Collins and Mitchell suggested that k is given by equation (2) for is greater than 1 and the curve fitting factor n is estimated by equation (3).

$$k = 0.67 + \frac{f'c}{62} \quad when \ \frac{\varepsilon c}{\varepsilon' c} > 1 \qquad -(2)$$

$$n = 0.8 + \frac{f'c}{17} \qquad -(3)$$

Collins et.al recommended that the strain at peak stress can be found from Eq. (4) by knowing the value of the modulus of elasticity (E_c).

$$\varepsilon' c = \frac{f'c}{Ec}\frac{n}{n-1} \qquad -(4)$$

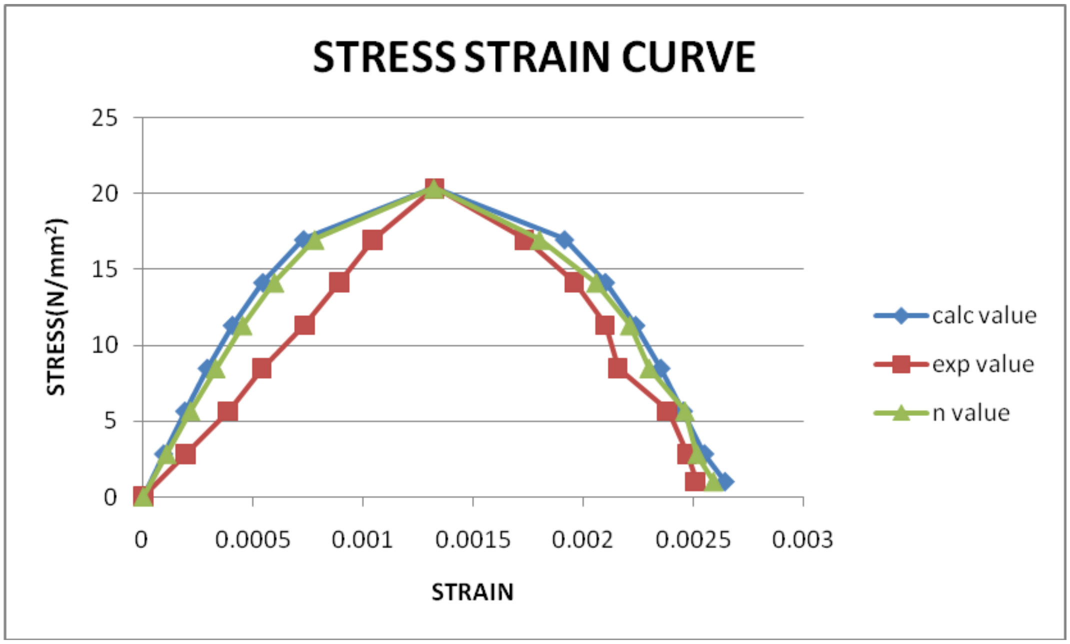

Figure 5 Stress-Strain curve for M20 Grade- Ambient Curing

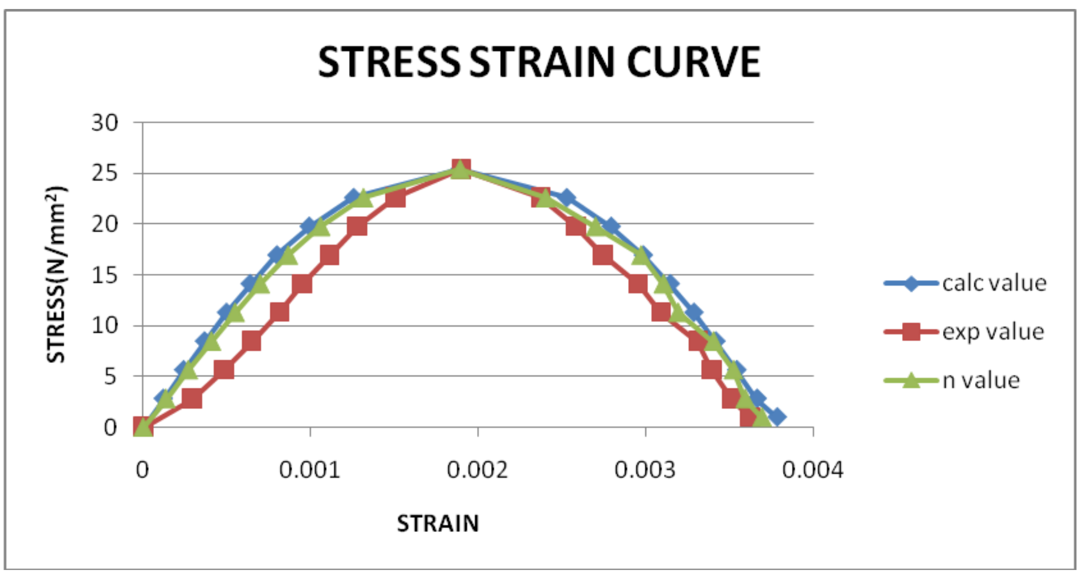

Figure 6 Stress-Strain curves for M25 Grade - Ambient Curing

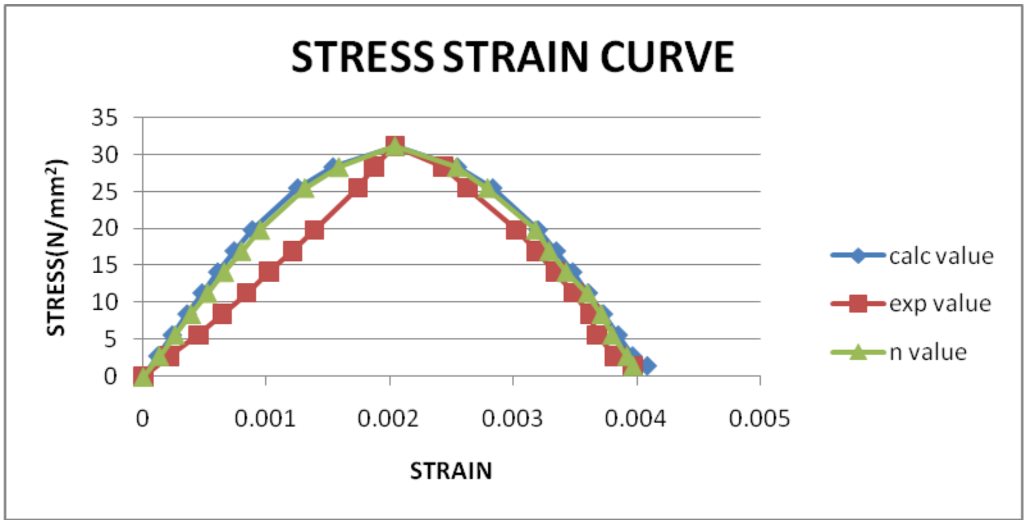

Figure 7 Stress-Strain curve for M30 Grade-Ambient Curing

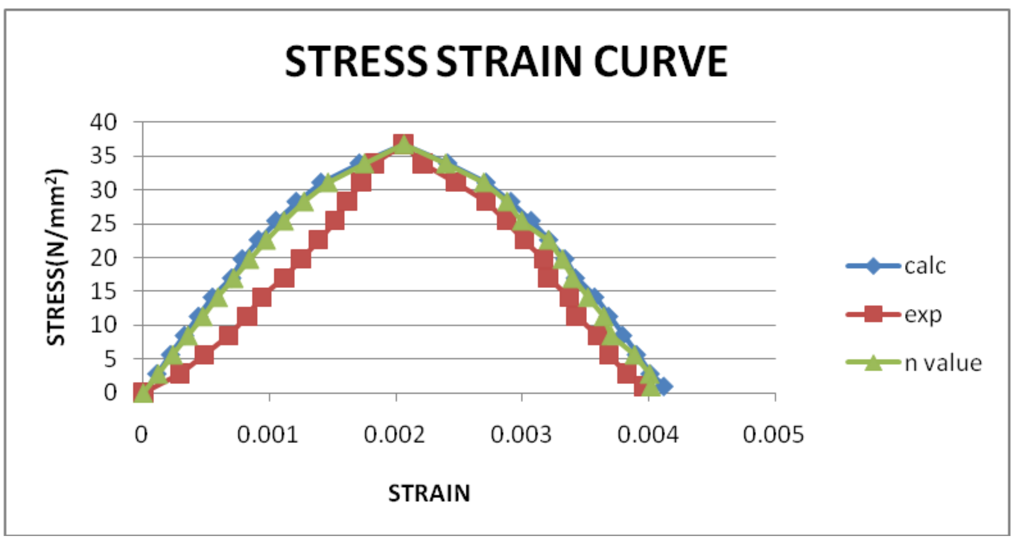

Figure 8 Stress-Strain curve for M35 Grade - Ambient Curing

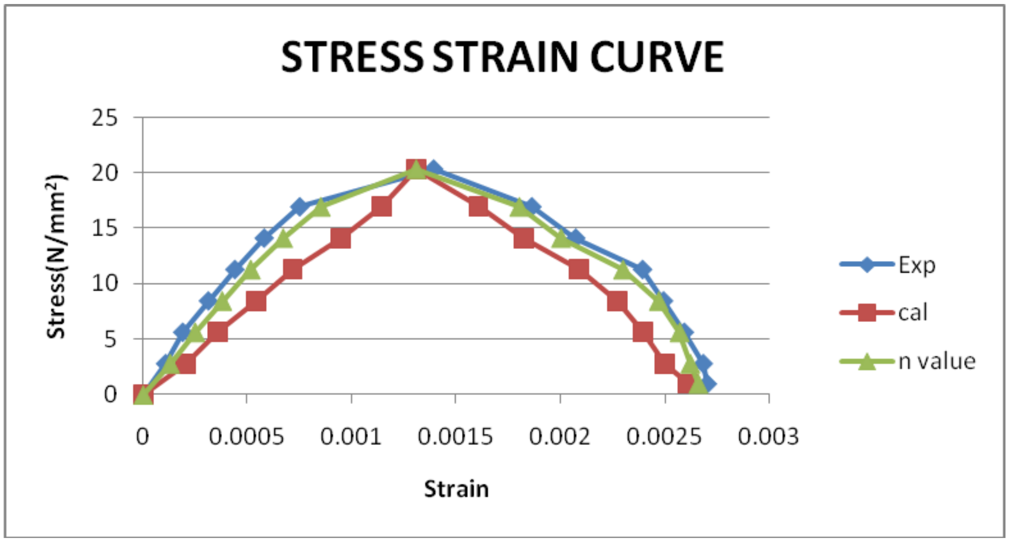

Figure 9 Stress-Strain curve for MS20 Grade- Ambient Curing

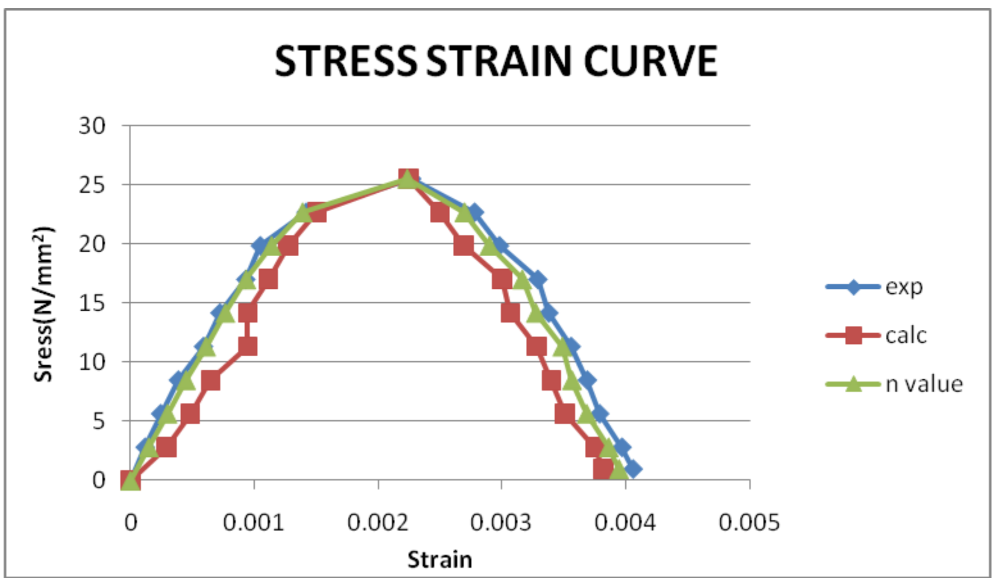

Figure 10 Stress-Strain curve for MS25 Grade-Ambient Curing

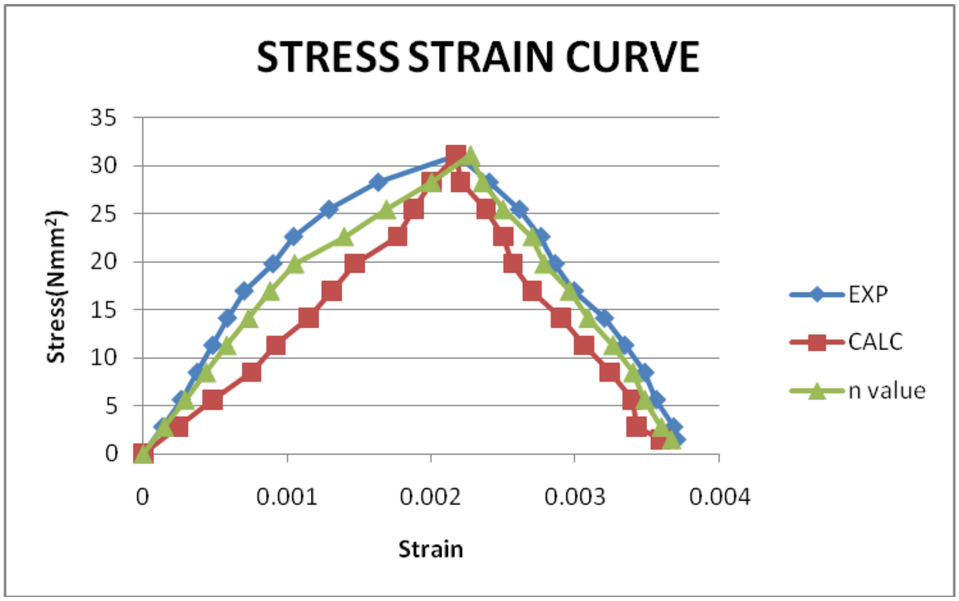

Figure 11 Stress-Strain curve for MS30 Grade- Ambient Curing

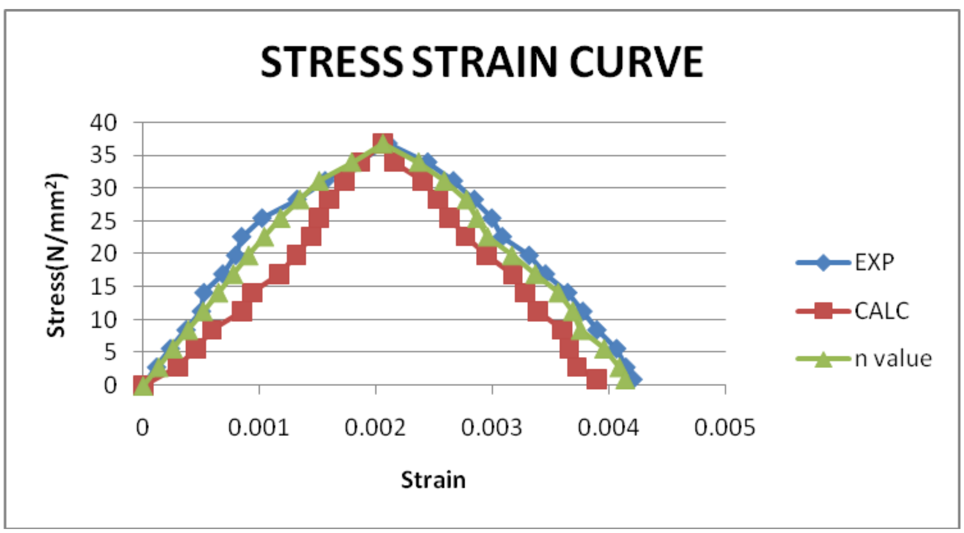

Figure 12 Stress-Strain curves for MS35 Grade- Ambient Curing

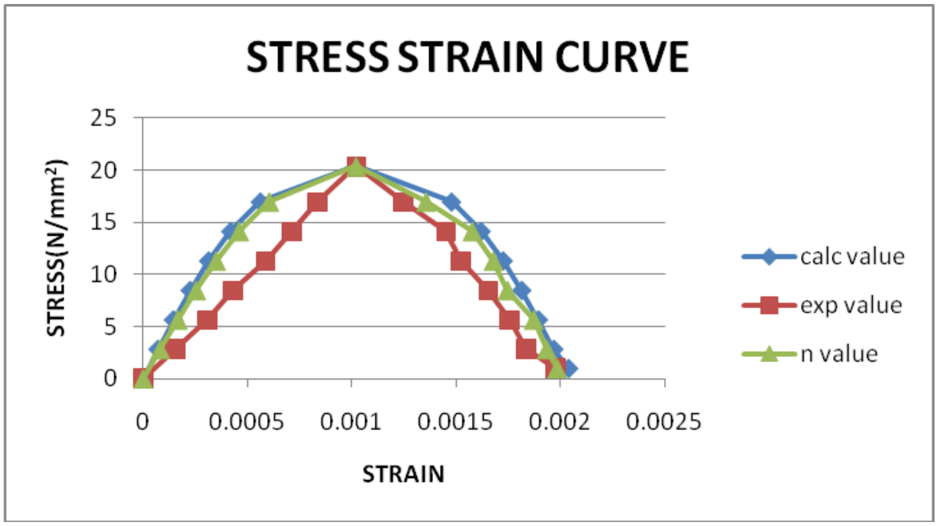

Figure 13 Stress-Strain curve for M20 Grade-Heat Curing

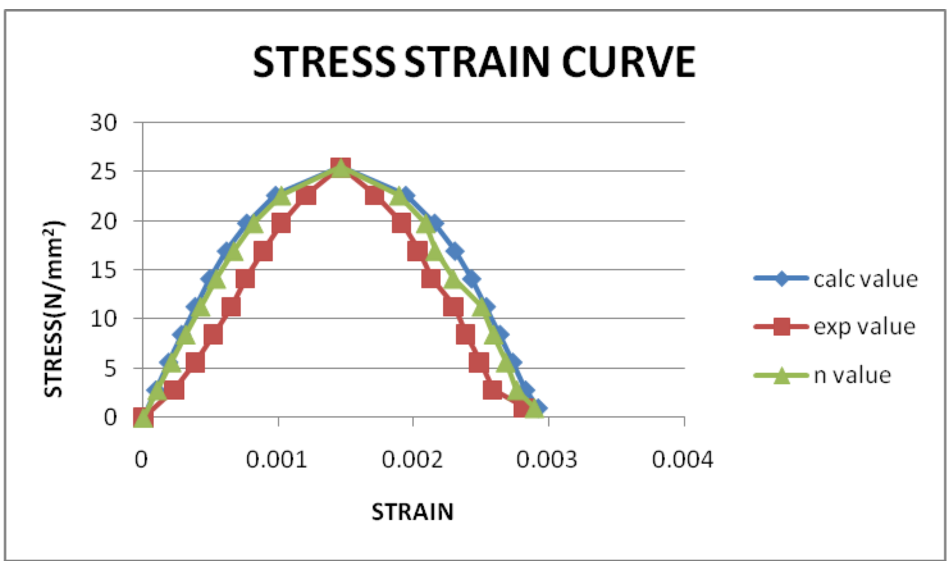

Figure 14 Stress-Strain curve for M25 Grade- Heat Curing

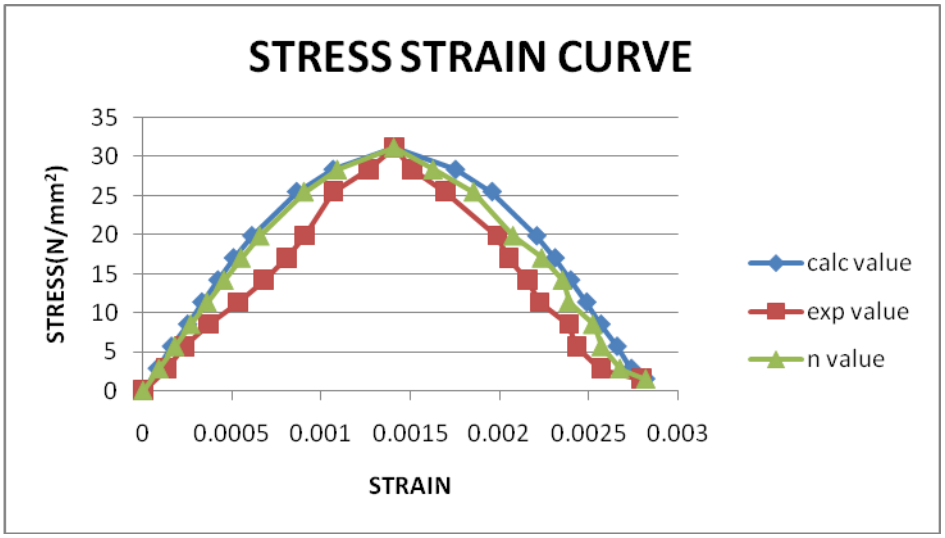

Figure 15 Stress-Strain curve for M30 Grade- Heat Curing

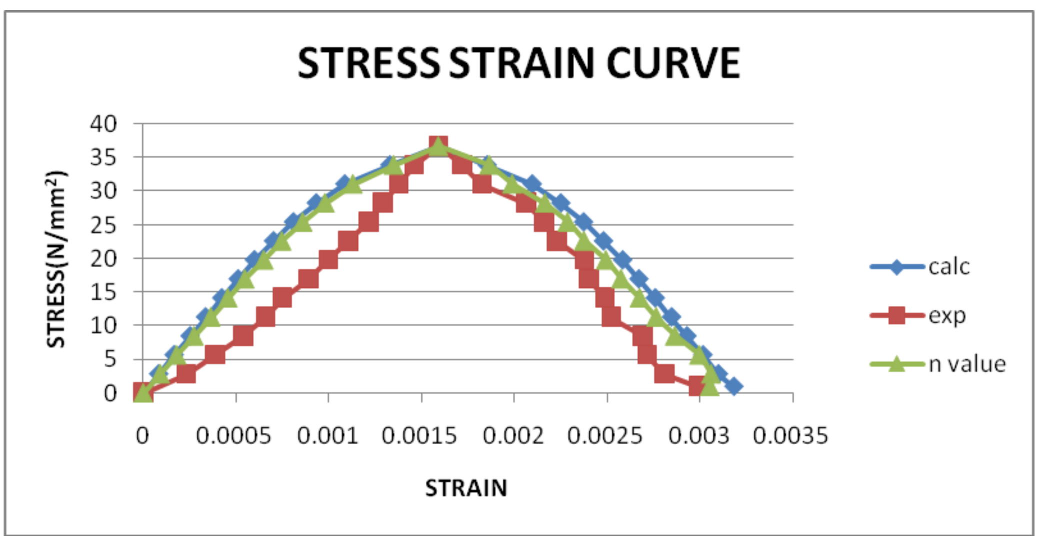

Figure 16 Stress-Strain curve for M35 Grade- Heat Curing

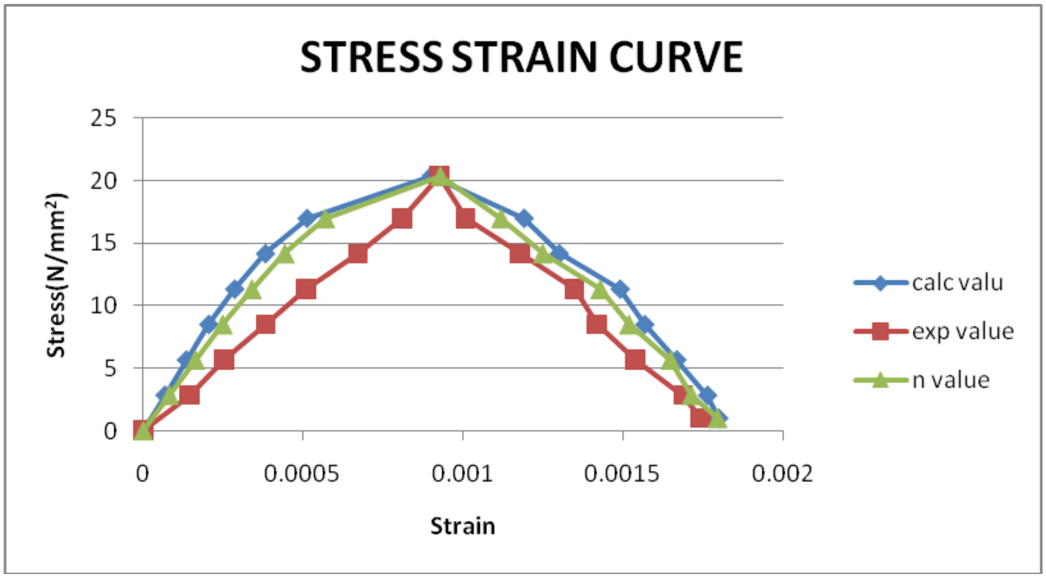

Figure 17 Stress-Strain curve for MS20 Grade- Heat Curing

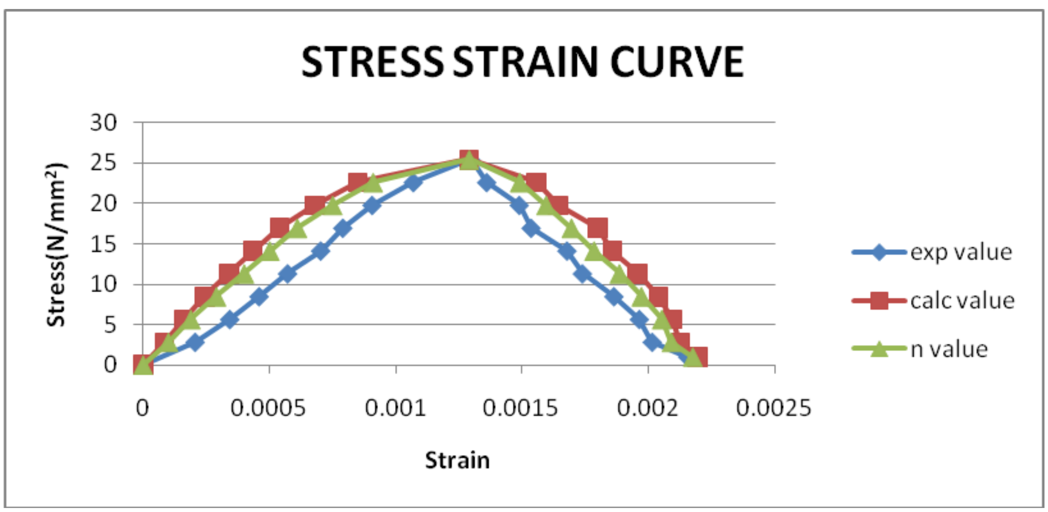

Figure 18 Stress-Strain curve for MS25 Grade- Heat Curing

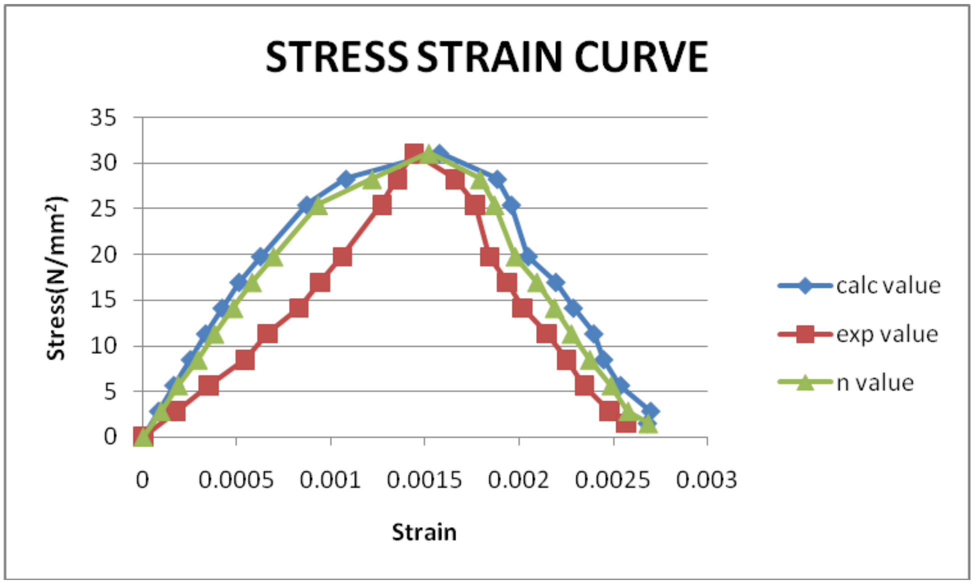

Figure 19 Stress-Strain curve for MS30 Grade- Heat Curing

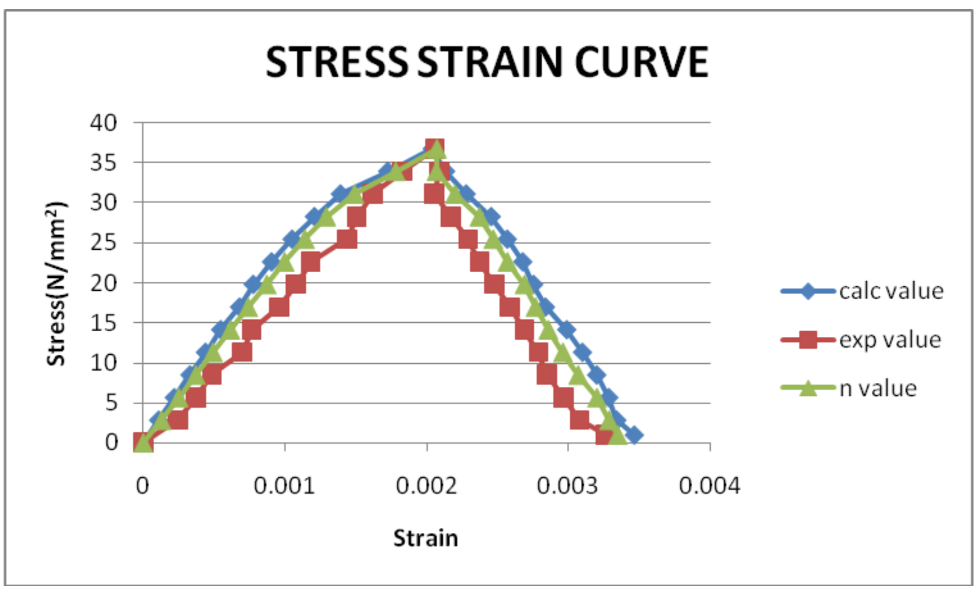

Figure 20 Stress-Strain curves for MS35 Grade- Heat Curing

6.2. Discussion

The calculated stress-strain curves are shown in fig 6.1 to 6.16. It can be seen from the figures that when the curve fitting factor n is calculated by equation.3, the strains corresponding to peak stress calculated with the use of equation.4 are slightly higher than the measured values and the post peak parts of the calculated stress-strain curves are pushed to the right from the measured curves for all three cases. It was therefore attempted to obtain a similar modified equation for the curve fitting factor in obtain s better fit between the calculated and the measured stress-strain curves. Equation 5 was obtained from trials.

$$n=0.7+f_c'/14 \text{ in MPa unit} \qquad -(5)$$

The stress-strain curves calculated by using the curve fitting factor given by equation.5 are also shown in fig.6.1 to 6.16. From the comparison between the calculated and measured stress-strain curves, it can be seen that equation.5 provides better correlation between the experimental and calculated values. Similar mixtures were also used to large beams. Therefore equation.1, together with equation 2 and equation 5 were used to calculate the complete stress-strain curve of fly ash-based geopolymer concrete.

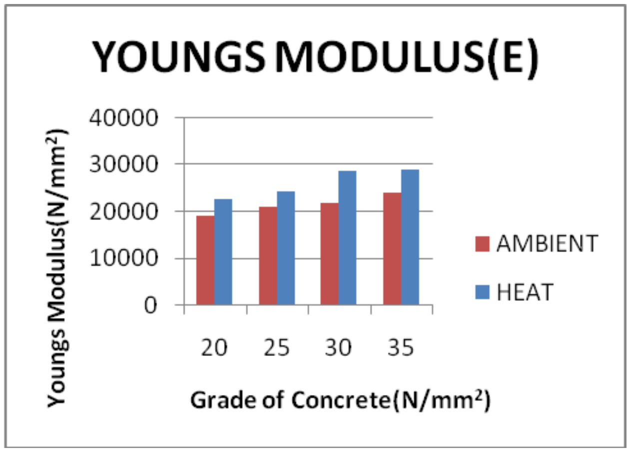

Figure 21 Comparison of Sand

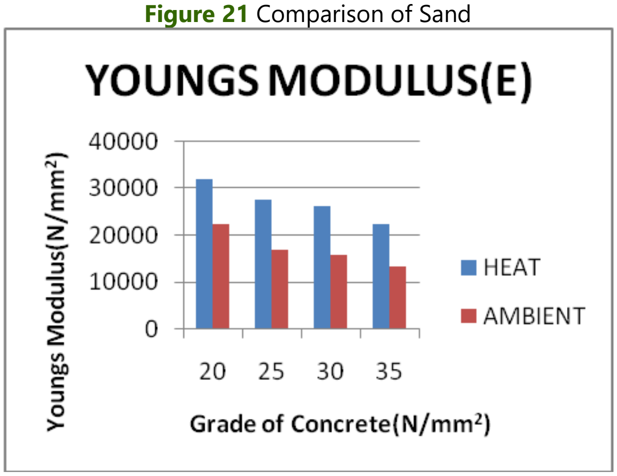

Figure 22 Comparison of MSand

From the graph, we know that the Young's Modulus of sand and MSand is greater for heat curing than that of ambient curing.

7. CONCLUSION

In the geopolymer concrete, Low-calcium fly ash is used as the source material, instead of the Portland cement, to make concrete. The stress-strain curves calculated by using equation-1 together with the proposed modification to the curve fitting factor (equation-5) correlated well with the test stress-strain curves of fly ash based geopolymer concrete. This shows that the constitutive model used for ordinary Portland cement (equation 1) can be used for geopolymer concrete with minor modification to the curve fitting factor.

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