THE INFLUENCE OF FLY ASH AND GROUND GRANULATED BLAST-FURNACE SLAG ON THE ELASTIC MODULUS OF CONCRETE

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ABSTRACT

The typical South African cementitious material used in industry today differs from what was commonly used in the past. With the move toward reducing carbon emissions in the cement manufacturing industry, extenders have now become a staple part of nearly all binder type materials. Along with this shift in cement type manufacturing, it is imperative that the effect of these common modern cement types be assessed in terms of their influence on the Elastic Modulus (E) of concrete.

This study includes the assessment of 36 different concrete mixes where each mix differed in strength, aggregate type and cement type. A total of four cement types were utilized and chosen according to the type and proportion of extenders used. These cements were CEM I 52.5N, CEM II A-M 42.5N (15 % FA), CEM II A-M 42.5N additionally extended with 30 % FA, and CEM III A 32.5N (60 % GGBS). The E of concrete was determined for each mix and the results of specimens were grouped according to curing age and cement type for analytical purposes. Specimens were cast for 7, 28 and 56 day tests.

The presence of FA had a slight influence on concrete E at early ages whereas GGBS concrete showed no significant differences in E compared to the CEM I concrete, for all ages included in this study. In general, the effect of FA and GGBS can be regarded negligible, except in the case where the E at an early ages is of vital concern.

Keywords: Concrete, Elastic Modulus, Cement.

1. Introduction

With the global push to move away from the common use of plain Portland cement, a greater emphasis has been placed on diluting Portland binder with extenders such as Fly Ash (FA) and Ground Granulated Blast-furnace Slag (GGBS). Although one of the main goals in using extenders is to dilute Portland binder, the benefits of extenders in concrete have now been realized — even to the point where it is now imperative that concretes in certain regions contain certain extenders. Although extenders are known to improve durability and strength, it is important that their effect on the deformation properties of concrete are also understood, and for this study, the elastic modulus in particular.

Results by Giaccio et al. (1989) identified the effects of fly ash as insignificant, as the extender did not result in any major change in the concrete's E in comparison to concrete made solely with Portland cement. With regards to the effect of GGBS, Alexander and Milne (1995) found that the extender only really affected the elastic modulus of concrete at early ages. With concrete at early ages, they found that FA and GGBS delayed the early strength gain (delayed densification of the ITZ) and so influenced the E in yielding slightly lower values. A study by Alexander (1994) found that GGBS concrete resulted in relatively lower E values for early aged concrete and also for 28 day cured concrete.

This study specifically assessed the influence of FA and GGBS on the E of concrete. The cement types where selected according to their varying amounts of FA and GGBS. Included among the cement types was a CEM I (control mix) against which the extended cements could be compared. A total of 36 mixes were included in this study, where each concrete mix varied in strength, aggregate type and cement type. The mixes were designed to cover a whole range of typical South African concretes where concrete specimens were cast to represent 7, 28 and 56 day results for each mix. The specimen results for E were arranged according to their cement type and assessed. The objective of this study was to validate conclusions of previous authors on the effect of extended binders, using typical South African concretes, which vary widely in composition.

2. Experimental detail

2.1 Materials

A total of four different cement types were used namely a CEM I 52.5N, CEM II A-M 42.5N (15 % FA), a CEM II 42.5N which was further extended on site with 30 % siliceous fly ash and CEM III 32.5N. The coarse aggregates utilized were andesite, dolomite, quartzite and granite. The fine aggregate used were crusher sands of the same aggregate type as the coarse aggregate used for each mix.

2.2 Concrete mix design

There were a total 36 different concrete mixes where each mix differed in strength, aggregate type or cement type. The concrete design was carried out according to the Cement and Concrete Institute (Addis, 2001) method, a method derived from the ACI Standard 211.1-9 (1997).

2.3 Specimen Preparation

A total of 108 specimens were cast for elastic modulus testing. Each specimen differed in strength, aggregate type, cement type or curing age. All E specimens were cylindrical being 300 mm in length and 150 mm in diameter. The cube specimen is commonly used in South Africa for determining concrete compression strength and so it is due to this context that this study therefore describes all concrete strength in terms of the cube specimen. Three cube (100 mm) specimens were cast per mix in order to determine the compressive strength. Each of the E specimens were tightly sealed on both end faces to allow for the specimen to set lying on its side. This encouraged a more even distribution of coarse aggregate across the length of the cylinder. All specimen preparations were performed according to the British Standard (BS) 1881 (1983) and the BS EN 12390-1 (2012).

2.4 Specimen testing

All cube compression tests were performed according to the SANS 5863 (2006). The E test was performed according to the BS 1881 (1983).

2.5 Normalizing Data

Each specimen varied in strength, cement type, aggregate type and aggregate percentage content. The results were normalized according to the mean of the aggregate percentage content so as to assess the effect of the type of cement on the E of concrete while nullifying the effect of the aggregate percentage content.

3. Results and Discussion

The following sets of results were developed having isolated and observed the effect of the cement types on the E of concrete. The data for concretes containing the same cement type were grouped together for this analysis. Figs. 1–3 show scatter graphs of the 7, 28 and 56 day strength specimen results.

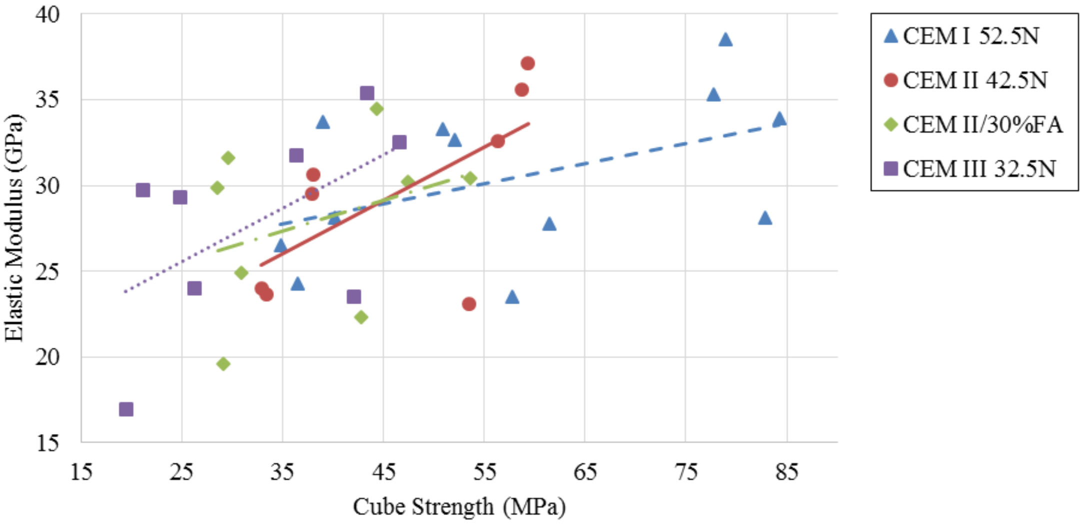

Fig. 1. Comparisons between the elastic modulus values of 7 day concrete

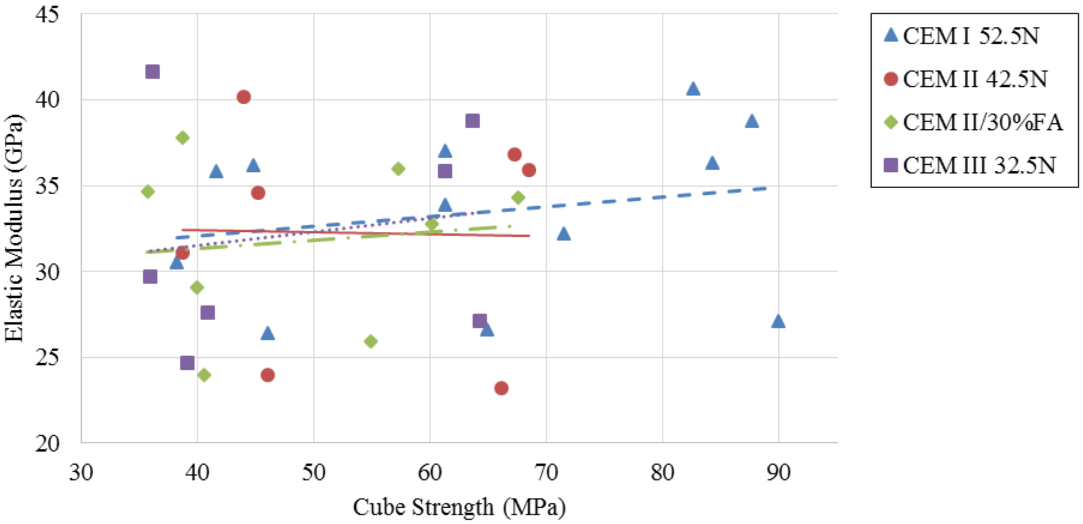

Fig. 2. Comparisons between the elastic modulus values of 28 day concrete

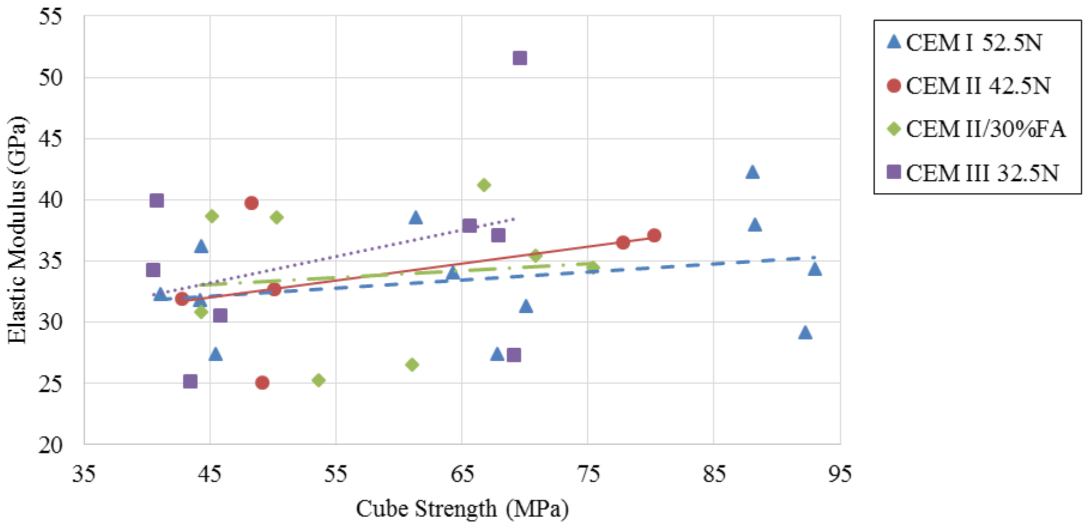

Fig. 3. Comparisons between the elastic modulus values of 56 day concrete

Figs. 1–3 shows relatively dispersed clusters of concrete E as specimens increased in strength. Obvious and distinctive trends are not readily visible enough to suggest that E is significantly influenced by the type of cement or, more specifically, with the inclusion FA or GGBS.

In order to nullify the effect of different percentage contents of aggregate, all the specimen E results were normalized according to the mean of the aggregate percentage content. In addition, all normalized data was separated according to the aggregate type to further isolate the effect of the different cements on concrete E. Figs. 4–15 display the normalized data according to aggregate type and curing ages.

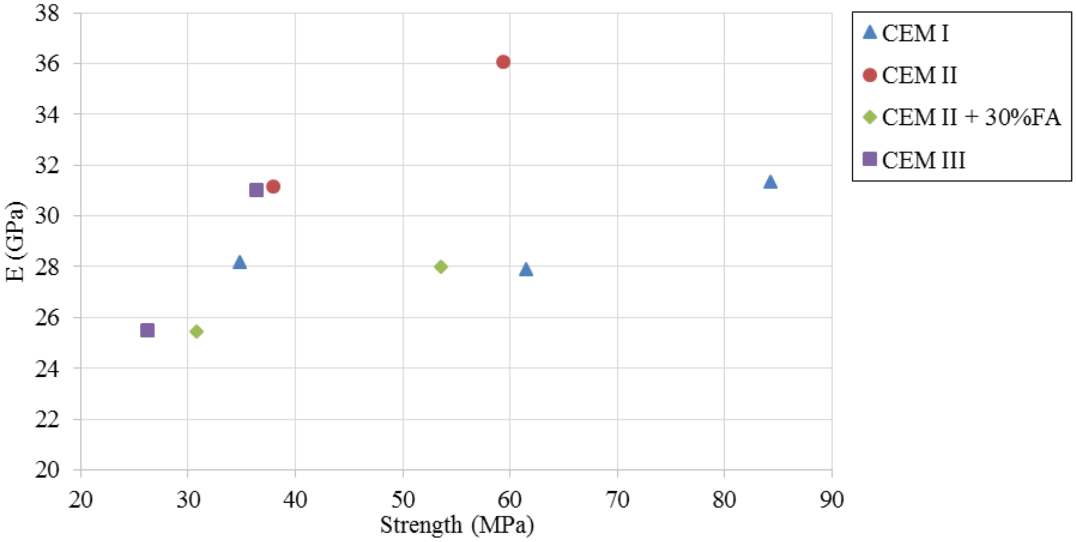

Fig. 4. Specimen results containing andesite cured for 7 days

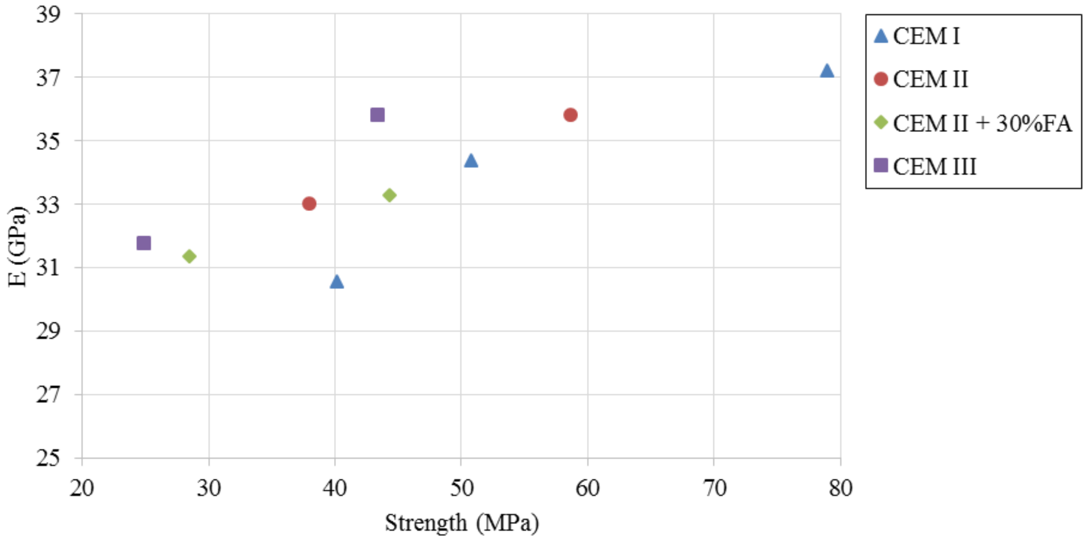

Fig. 5. Specimen results containing dolomite cured for 7 days

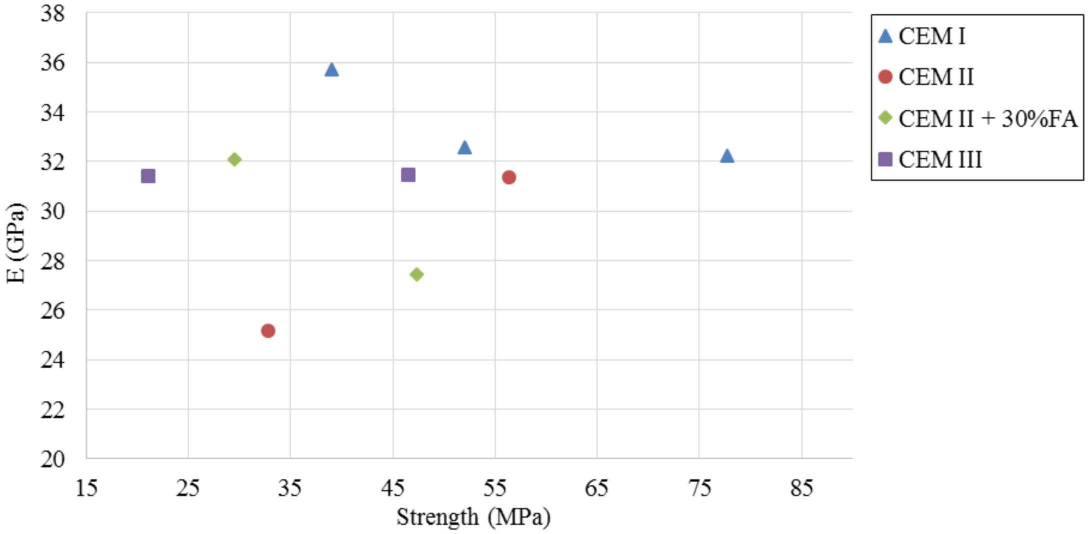

Fig. 6. Specimen results containing quartzite cured for 7 days

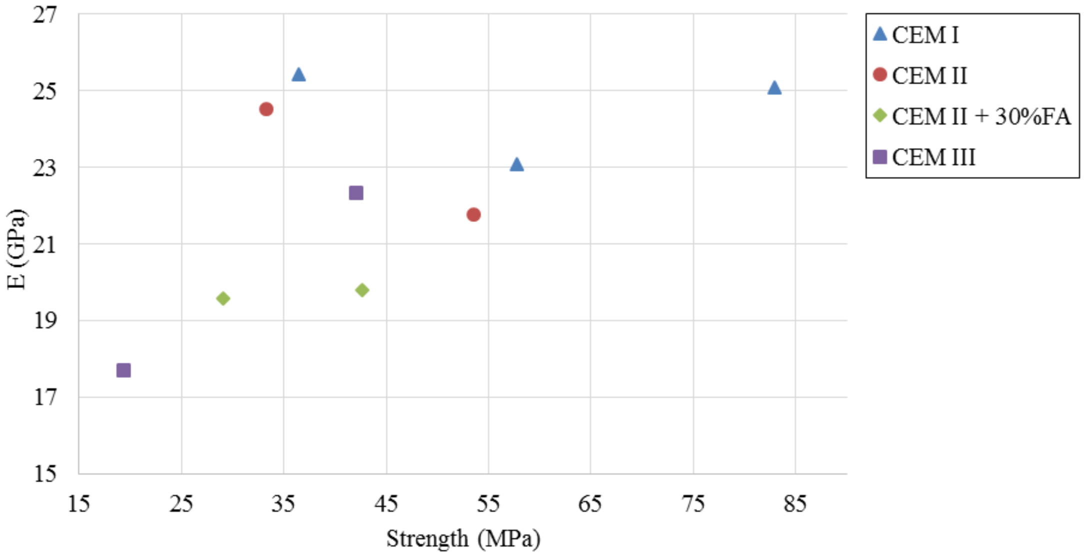

Fig. 7. Specimen results containing granite cured for 7 days

This study acknowledges that Figs. 4–7 do not contain sufficient data points to build a self-standing conclusion, but they supplement the results of Fig. 1 by further showing that concrete E is not largely influenced by the presence of extenders in concrete at 7 days. Although Alexander and Milne (1995) found both FA and GGBS to produce concrete with a lower E at early ages, Fig. 1 and Figs. 4–7 do not definitively confirm the same result. In addition, the CEM I concretes yielded higher E values only in the case of those containing quartzite or granite aggregates at early ages.

This study therefore does not deny the influence of FA and GGBS at early ages but rather suggests that since the data points of Fig. 1 represent concretes which also vary in aggregate type and strength, the nature of Fig. 1 can only identify trends of highly influential factors whereas minor factors such as cement type will not be evident. Figs. 1, 4 and 7 also suggests that the conclusions of Alexander and Milne (1995) may possibly be more evident for concrete younger than 7 days.

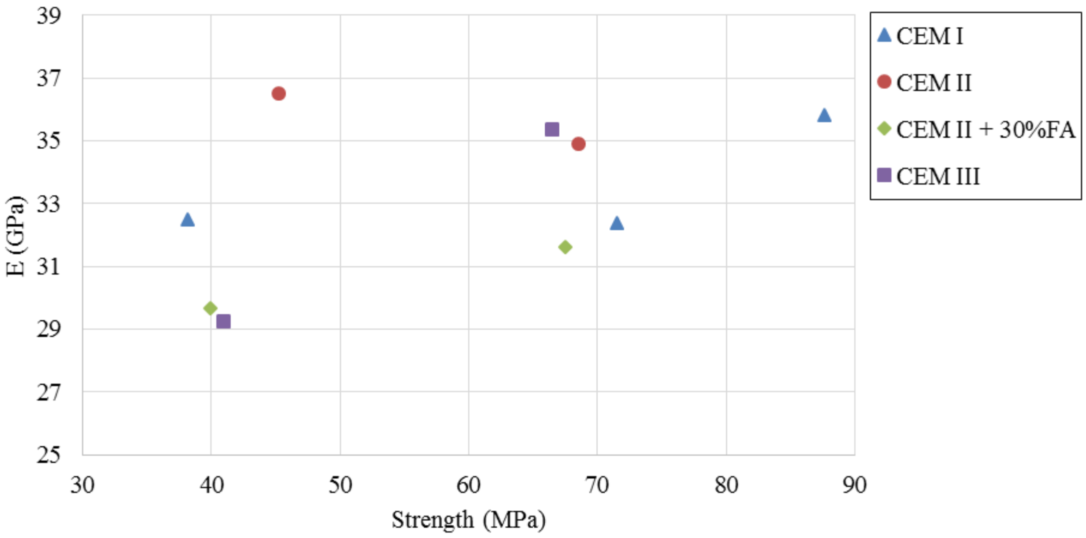

Fig. 8. Specimen results containing andesite cured for 28 days

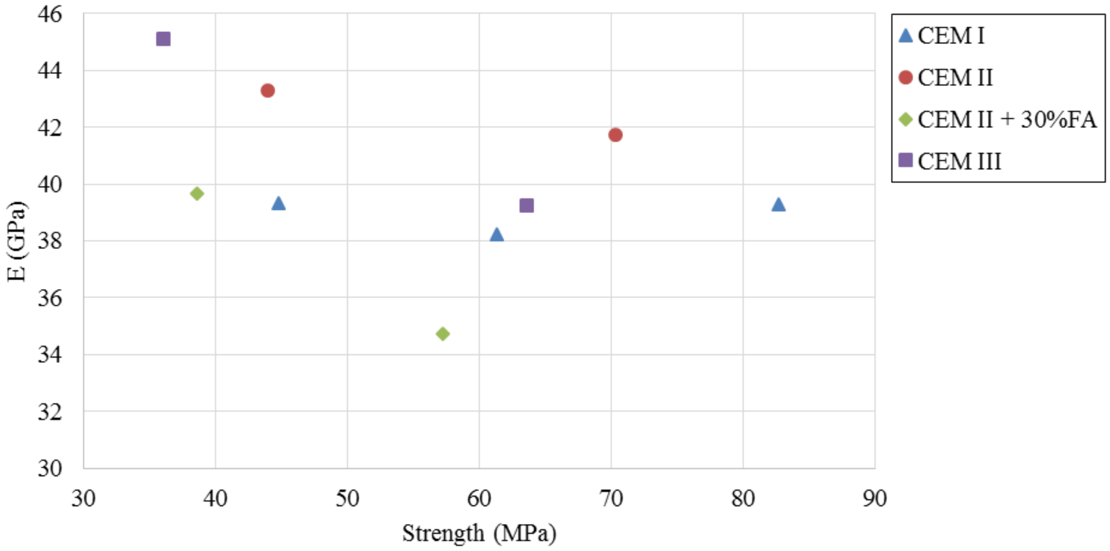

Fig. 9. Specimen results containing dolomite cured for 28 days

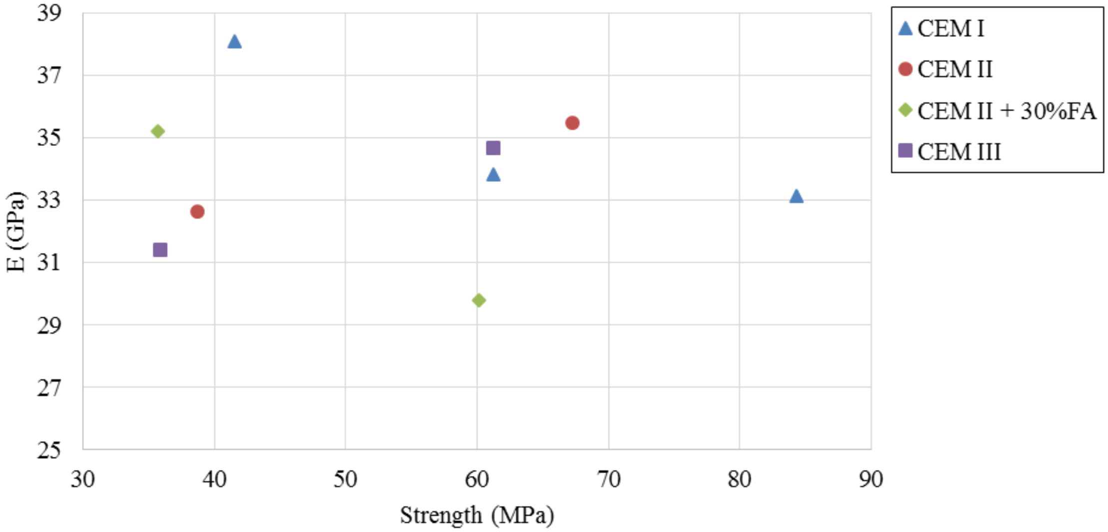

Fig. 10. Specimen results containing quartzite cured for 28 days

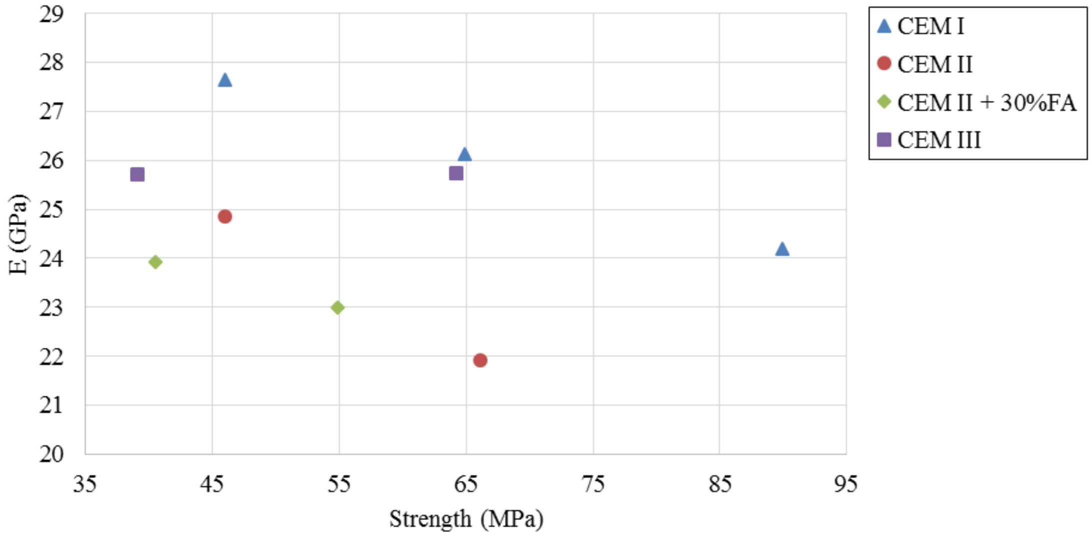

Fig. 11. Specimen results containing granite cured for 28 days

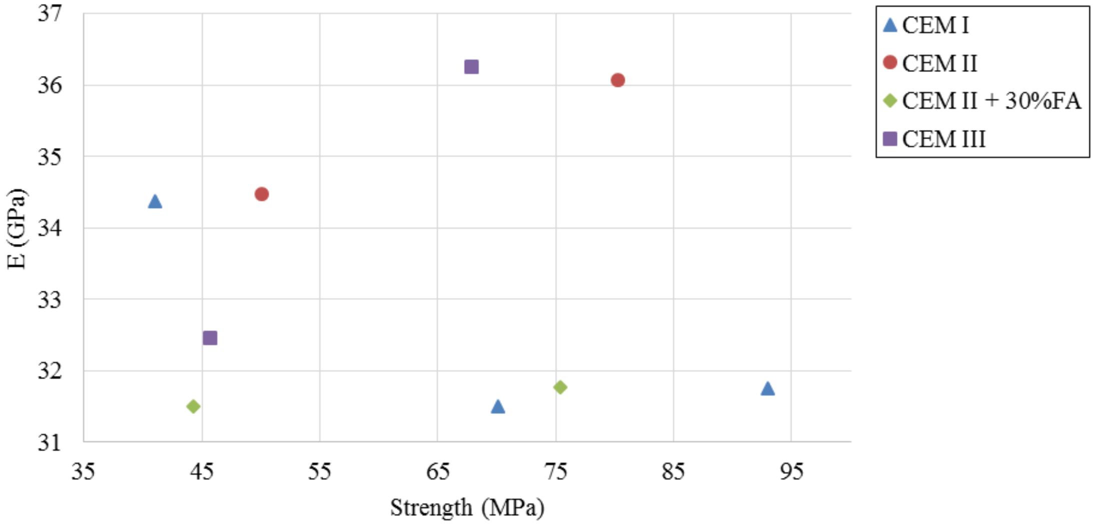

Fig. 12. Specimen results containing andesite cured for 56 days

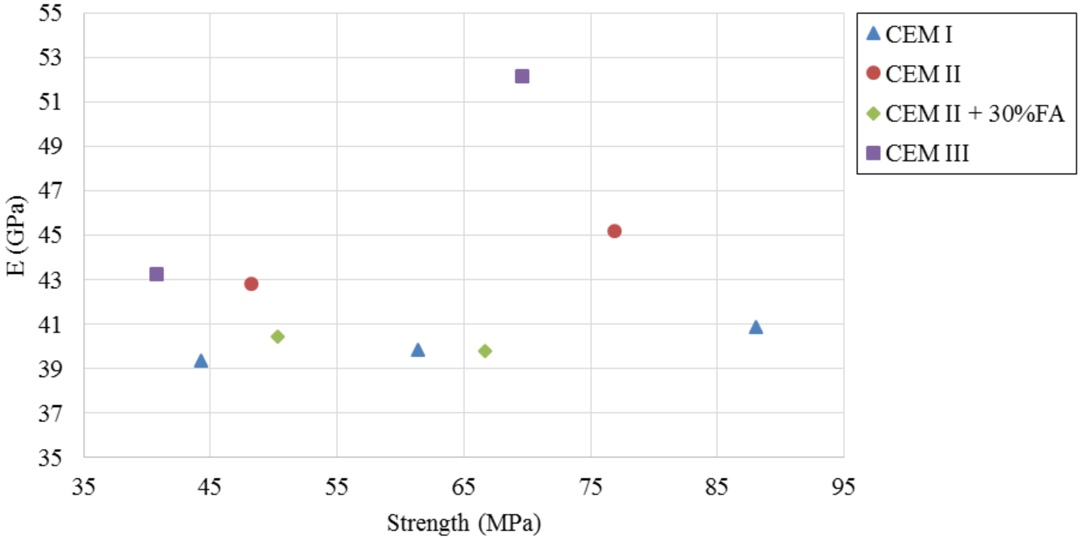

Fig. 13. Specimen results containing dolomite cured for 56 days

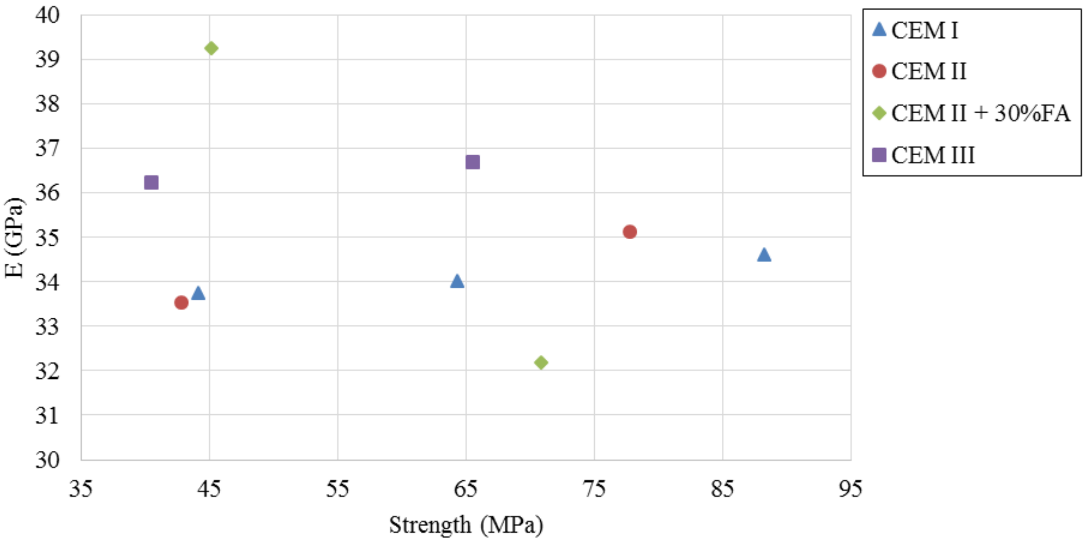

Fig. 14. Specimen results containing quartzite cured for 56 days

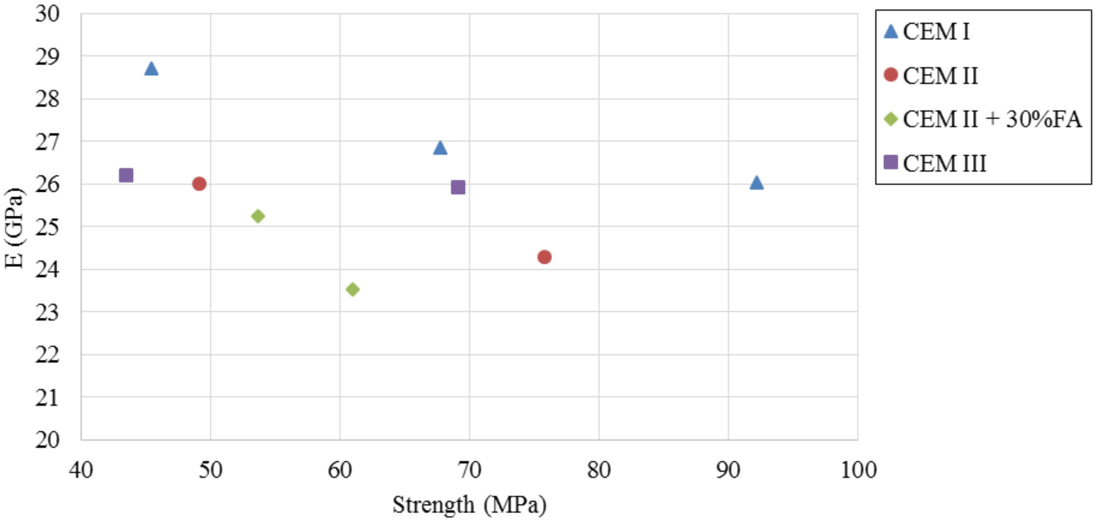

Fig. 15. Specimen results containing granite cured for 56 days

Table 1 displays information using Figs. 4–15 where the average E was calculated for each cement type and the percentage difference was determined in relation to the concrete mixes containing the control cement type (CEM I 52.5N).

Table 1. Percentage differences (Δ %) between the average E values of each cement type compared to CEM I 52.5N

Cement Type	Days	Andesite	Dolomite	Quartzite	Granite
CEM II	**7**	15.36	1.11	-15.61	-5.64
	28	6.38	9.19	-2.74	-10.04
	56	8.38	9.93	0.56	-7.56
CEM II + 30 % FA	**7**	-8.25	-5.07	-11.13	-19.74
	28	-8.68	-4.50	-7.19	-9.71
	56	-2.79	0.27	4.63	-10.36

CEM III	**7**	-3.07	-0.76	-6.19	-18.40
	28	-3.76	8.29	-5.64	-0.98
	56	5.56	19.21	6.81	-4.15

The andesite and dolomite concretes with the CEM II yielded higher E values than CEM I at all curing ages. Furthermore, in the case of the granite concretes, the mixes containing CEM I yielded the highest E values at all curing ages in comparison to the other cement types (included in this study) containing FA and GGBS.

This study did not find GGBS concrete to consistently comprise with lower E values at 28 days as was found by Alexander (1994). This study, however, does not deny the influence of GGBS on E but rather suggests that the concretes included in this study were not sensitive to the effects of the lesser factors of E such as extenders. However, the results do confirm that the influence of GGBS or FA are not as significant as major factors such as the aggregate type. In assessment of Figs. 1–3, this study arrived at similar conclusions to Giaccio et al. (1989) with regard to FA concrete, where its effect is not significant.

4. Conclusions

The following conclusions can be drawn from this study:

- The influence of FA on concrete E is more significant at early ages than at 28 and 56 days.
- The influence of GGBS on concrete E was found to be insignificant for all curing ages included in this study.
- In general, the effect of FA and GGBS can be regarded negligible for practical purposes except in the case of FA where concrete E at early ages is of vital concern.

5. Acknowledgements

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6. References

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