THE INFLUENCE OF AGGREGATE ON THE ELASTIC MODULUS OF CONCRETE

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ABSTRACT

Concrete is a heterogeneous material and as a result, there are numerous factors that contribute to its resulting modulus of elasticity (E). One of the major factors is said to be the type of aggregate.

This study assesses the influence of aggregate type on concrete E, through the use of 36 mixes each containing one of four commonly used South African aggregates namely, granite, quartzite, andesite and dolomite. The E for each concrete mix was determined for 7, 28 and 56 day concrete and their results were analyzed according to the E of the aggregate type contained.

The E values of the concretes were found to decrease with a decrease in the E of the included aggregate, in the order dolomite, quartzite, andesite and granite.

The aggregate type significantly influences the E of concrete. In fact, the specific influence of an aggregate on concrete E can be mainly attributed to the E of the included aggregate.

Keywords: Concrete, Elastic Modulus, Aggregate.

1. Introduction

The Modulus of Elasticity (E) of concrete is an important design consideration for reinforced concrete, as it is responsible for excessive deflections, secondary cracking, column shortening etc. Since concrete is a multi-phase material, there are numerous factors that influence its E to varying degrees. The common factors are concrete age, strength, density, aggregate type, the volume fraction of aggregate, the interfacial transition zone and cement type.

However, the aggregate type is known to be one of the more influential factors that affect the E of typical concrete, according to Kaplan (1959). Supporting results from Counto (1964) showed that the E of concrete increased with an increase in the E of the included aggregate. Research has also shown that it is not only the E of the aggregate that affects the E of concrete, but it is also the physical properties of the aggregate that have an effect. Physical properties such as surface roughness can promote good bonding between the aggregate and cement paste which has bearing on concrete's E. Additionally, Baalbaki et al. (1991) briefly showed how concrete's E also varied in accordance with the porosity of the aggregate, where aggregates of higher porosity resulted in concretes with a lower E.

This investigation specifically assess the effect that an aggregate's E has on the E of concrete. A total of four typical South African aggregates were selected for this research in order to cover a wide range of possible E values.

2. Experimental Details

2.1 Materials

A total of four different cement types were used namely a CEM I 52.5N, CEM II 42.5N, CEM III 32.5N and the fourth cement type was a CEM II 42.5N which was further extended on site with 30 % siliceous fly ash. The coarse aggregates utilized were andesite, dolomite, quartzite and granite whose E value ranges (taken from Davis and Alexander, 1994) were 96–105 GPa, 109–118 GPa, 42–98 GPa and 76–84 GPa, respectively. 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 an aggregate's E on the E of concrete while nullifying the effect of aggregate percentage content.

3. Results and Discussion

Figs. 1–3 show the influences of aggregate at curing ages 7, 28 and 56 days, respectively and are a plot of concrete E against concrete cube strength without normalizing of the data. The E results of all the concrete specimens were grouped and displayed in Figs. 1–3 according to the type of aggregate contained within each specimen.

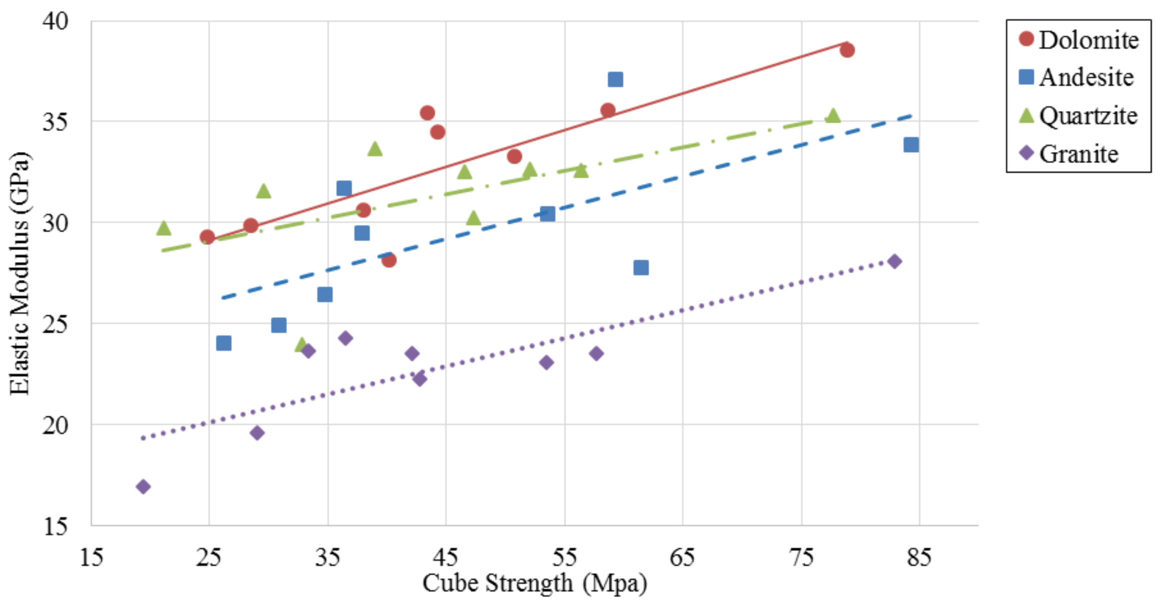

Fig. 1. Effect of aggregate type on 7 day cured concrete

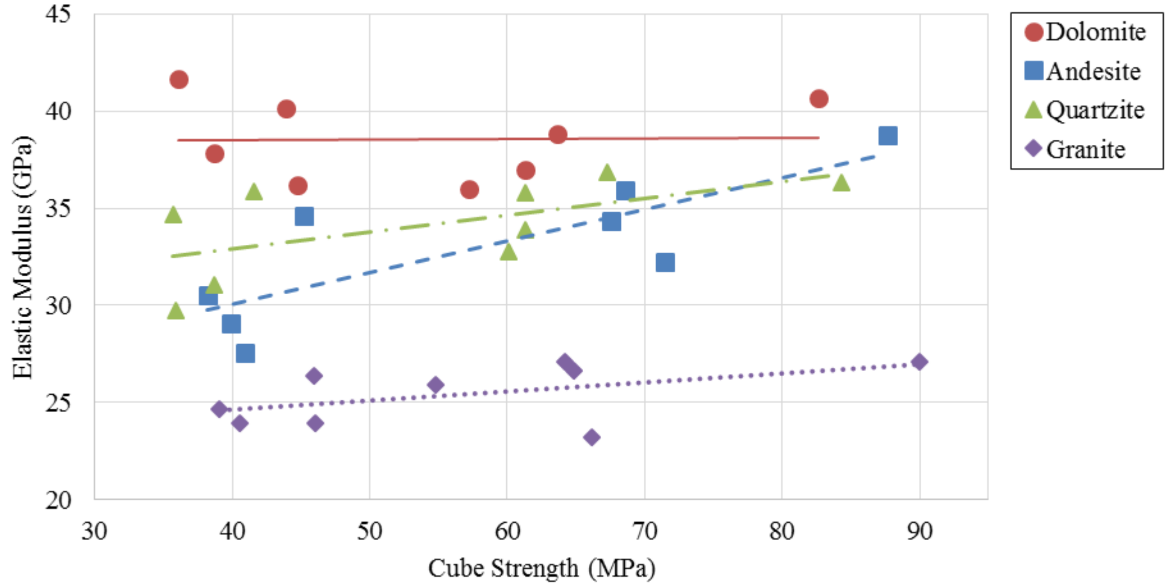

Fig. 2. Effect of aggregate type on 28 day cured concrete

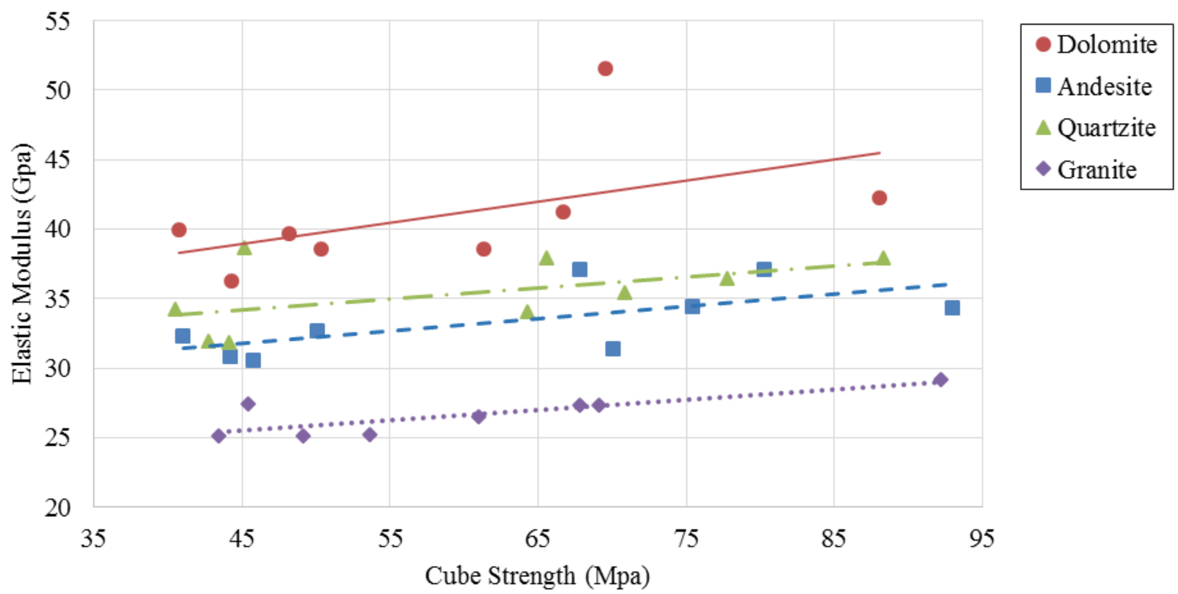

Fig. 3. Effect of aggregate type on 56 day cured concrete

When viewing Figs. 1–3, in light of the E ranges of the aggregate types included in this research, it was evident that dolomite (the aggregate having the relatively highest aggregate E range) produced a concrete with a relatively higher E compared to other specimens of similar strength but of a different aggregate type. In addition, concretes with quartzite aggregate generally yielded higher E values than the concrete with andesite. This trend consistently occurred through all curing ages included in this study namely 7, 28 and 56 days. When assessing the effect of granite (the aggregate type with the relatively lowest E range), concrete specimens consistently resulted with lower E values in comparison to other concrete specimens of similar strength. The trend of concrete E varying according to the E of aggregate affirms the conclusion of Counto (1964) who found that the E of aggregate was particularly influential.

Table 1 shows the average differences of E between concretes with dolomite to concretes with granite at each of the curing ages. It was interesting to find that the E average difference increased with an increase in curing age. The reason for this occurrence may be attributed to the densifying of the ITZ over time. As the

ITZ densifies, the bond between paste and aggregate improves and the specific deformation properties of the aggregate are better transferred to the concrete as a whole.

Table 1. Comparison between dolomite and granite concrete

Days	**E Average Difference (GPa)**
7	10.03
28	13.31
56	14.35

In order to nullify the influence of the varying percentage content of aggregate in each specimen, the data in Figs. 1–3 were normalized according to the mean of the proportions of aggregate content, as mentioned in section 2. The results are shown in Figs. 4–5.

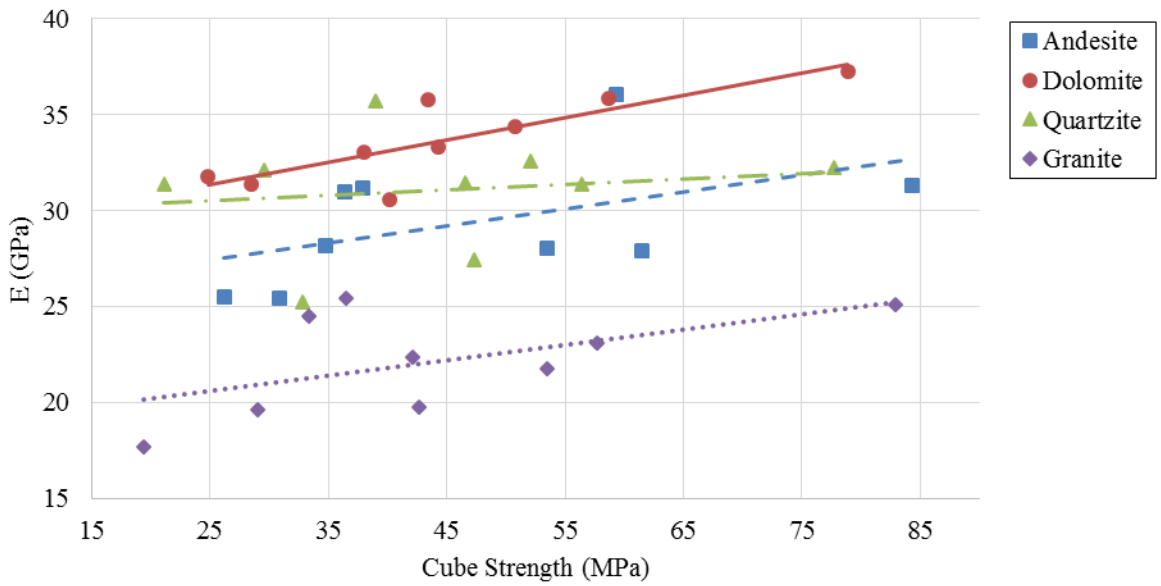

Fig. 4. Effect of aggregate type on 7 day cured concrete normalized according to the mean percentage content of aggregate

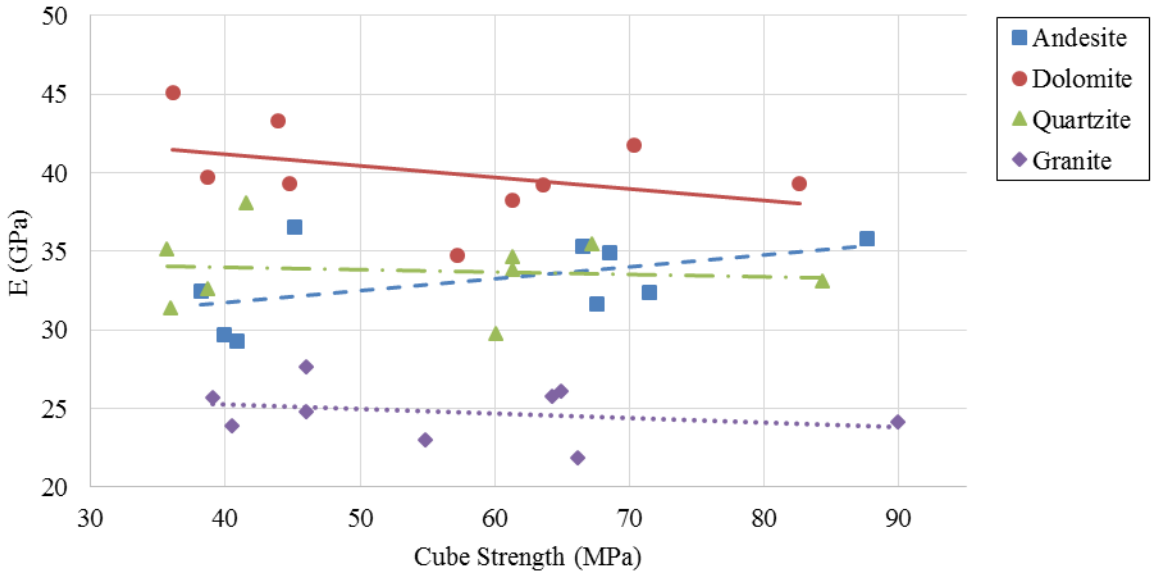

Fig. 5. Effect of aggregate type on 28 day cured concrete normalized according to the mean percentage content of aggregate

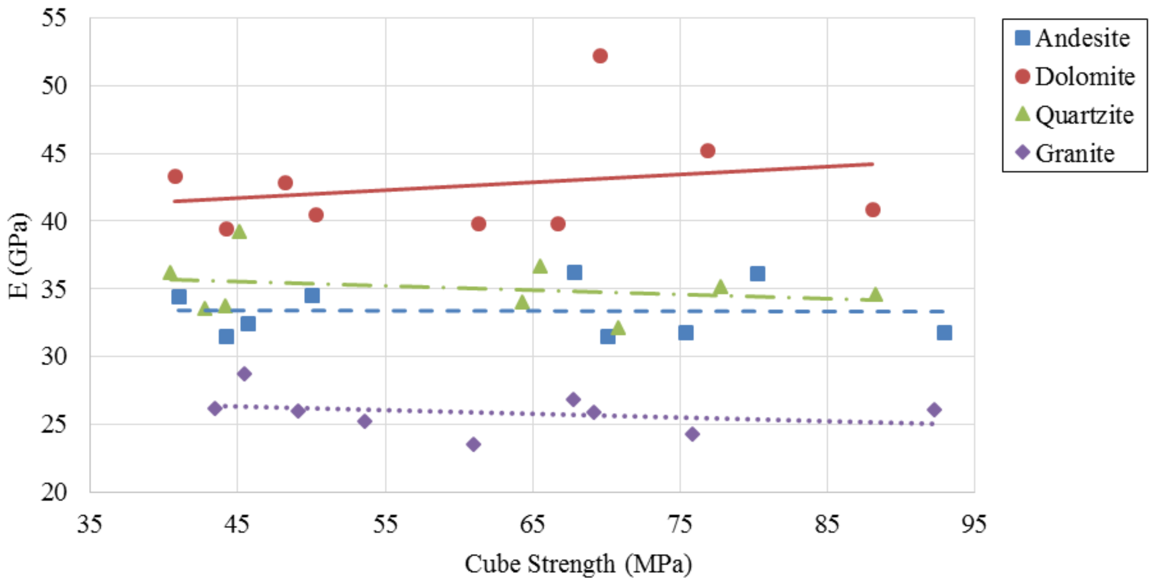

Fig. 6. Effect of aggregate type on 56 day cured concrete normalized according to the mean percentage content of aggregate

With the nullification of the percentage content of aggregate, Figs. 4–5 still affirm that aggregate with higher aggregate E values produce concrete with higher E values. It also remained the case in Figs. 4–5 that granite produced concrete with relatively lower E values and that the concretes with quartzite aggregate generally yielded higher E values than the concretes with andesite aggregate.

4. Conclusions

The following conclusions can be drawn from this study:

- The E of concrete is influenced by the type of aggregate contained in the concrete
- The E of concrete is particularly sensitive to the E of the aggregate type used in the concrete
- It is important that engineers consider the type of aggregate utilized in concrete in order to account for possible values of concrete E for design purposes

- The influence of the aggregate type on concrete E becomes more apparent with an increase in curing age.

5. Acknowledgements

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6. References

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