THE NEED TO ASSESS EFFECT OF AGGREGATES ON PERFORMANCE OF CONCRETE IN BOTSWANA

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Concrete is the most widely used construction material worldwide. Therefore, for structural safety as well as to provide economic designs, it is essential to understand well, its performance. Whilst in most developed countries extensive research has been done to characterise concrete, little is known about the performance of concrete in Botswana. This paper reviews previous work carried out in other countries to assess performance of their concrete. Focus is on influence of aggregate type. It is shown from the review that there is great need to study influence of aggregate on performance of concrete in Botswana, particularly compressive strength. A brief description of the needed research is outlined.

Keywords; strength of concrete; aggregate type; cement.

1 INTRODUCTION

Concrete is a mixture of water, cement and aggregates. Its properties, especially compressive strength, are controlled by the quality of cement paste, paste-aggregate interface and aggregates. Ordinary Portland Cement (OPC) is widely recognised as the basic cement and is therefore often used as a control for assessment of quality of other cements. In addition, other cements are normally a blend of OPC with other cementatious materials such as limestone as well as with waste products from other manufacturing industries. Mostly used waste products are fine granulated blast furnace slag from the metal industry and fly ash from burning coal. Cement blends are used mainly to reduce the cost of cement with anticipation that the quality of a binder is not excessively harmed. Interestingly, it has been shown that some cement blends such as an integral of OPC and condensed silica fume are superior to OPC [1,2]. Qualities of cement blends are well researched and well controlled by cement producers such as PPC-Botswana. Similarly, the general effect of water content presented as a ratio of the amount of water to the amount of cement in a mix (w/c) on performance of concrete is reasonably understood. For example, it is known that lowering w/c ratio raises the performance of concrete but at the expense of workability of fresh concrete mix. Actual values of different properties of concrete such as compressive strength at various w/c ratios however, differ between concretes. It should be mentioned that for conventional concrete, w/c ratio normally ranges from 0.4 to 0.8. Ratios below 0.4 are used in high strength concrete.

Previously, researchers and structural engineers viewed aggregates as inert and effectively defined performance of concrete on the basis of quality of paste (cement and water). Surprisingly, aggregates are purposely added to a concrete mix to give it its well-appreciated engineering properties. Without them, cement paste or mortar is unsuitable for use as an engineering material. Note that aggregates are significantly cheaper than cement. It is therefore economically viable for concrete producers such as building contractors and concrete ready-mixers to add large proportions of aggregates to a concrete mix. In conventional concrete, more than two thirds of a concrete mix is often occupied by aggregates. It is therefore unsurprising that recent research has found aggregates to have a profound influence on properties of concrete. Whilst some aggregates such as slag are artificial, the majority of aggregates for concrete are obtained from crushing natural rocks and from natural gravel on river beds. Properties of natural aggregates, like any other natural material, vary appreciably even between nominally similar aggregates. It is therefore difficult to characterise them accurately and yet critical that their influence on properties of concrete be known.

Many countries such as South Africa, various European countries and USA have carried out extensive research on qualities of aggregates and provided guidelines (mostly as annexes in design codes) for their use in each region. This type of research is yet to be carried out in Botswana. However, similar to those countries, Botswana exhibits a wide range of aggregates. For example; quarries around Francistown primarily produce granite; there is granite and quartz in and around Gaborone; feldspar, quartz, basalt and dolomite are produced by quarries in and around Kasane; and in Moshana, there is dolomite and dolerite. Another factor that supports the need to understand quality of aggregates for concrete in Botswana is that quarries for aggregates here are opened and closed primarily on the basis of civil engineering projects around the area. This implies that aggregates suppliers may stop mining high quality aggregates because they are remote or worse, some construction projects may use poor quality aggregates because of proximity.

1.1 Objectives of the paper

This paper discusses the need to conduct an extensive research to study performance of concrete in Botswana. In order to show this need, it presents a review on the general effect of aggregate type on performance of concrete. With little work available on the subject in Botswana, the review focuses on studies carried out elsewhere. This review is intended not only to confirm the need for research but also to provide a valuable insight on parameters that need to be studied to meet research objectives.

2 PREVIOUS WORK ON INFLUENCE OF AGGREGATE TYPE ON PERFORMANCE OF CONCRETE

Compressive strength is the most important property of structural concrete from an engineering view point. Expectedly, it is the most common property of concrete studied by various researchers. The majority of them have shown that in conventional concrete (< 40 MPa), the type of aggregate used does not have a profound influence on compressive strength of concrete [3,4]. As previously indicated, these concretes often have large w/c ratios (>0.4). Failure in conventional concrete was shown to be within the cement paste or the transition zone between cement paste and aggregates. However, some researchers contend that certain aggregates such as laterite have much lower unconfined compressive strength than the cement paste [2]. Failure in such concrete is therefore within aggregates. According to Neville [2], laterile rarely produces concrete stronger than 10 MPa. Note that this mode of failure is very rare for conventional concrete where the strength of aggregates is often larger than the strength of paste. Contrary to conventional concrete, researchers have shown compressive strength of high strength concrete (>40 MPa), particularly very high strength concrete (>80 MPa), to be controlled by the type of aggregate but not the hardened cement paste or the transition zone. The following summarises results from various researchers.

Aitcin and Mehta [5] on concrete with w/c ratio of 0.275 found crushed aggregates from diabase and limestone to produce concrete with higher (up to 1.2 times) compressive strength than concrete from crushed granite aggregates. Similarly, concrete from diabase and limestone aggregates yielded larger elastic moduli. Interestingly, the highest compressive strength values and the highest moduli did not necessarily belong with the same aggregate. For example, limestone aggregates produced concrete with the highest moduli whilst diabase aggregates produced concrete with highest compressive strength. This was attributed to chemical interaction between calcite in limestone and calcium hydroxide in hydrated cement paste increasing the strength of the transition zone in limestone concrete.

Beshr et al. [6] found 28-day compressive strengths of concretes with w/c ratio of 0.35 to be 54 MPa, 47 MPa, 45 MPa and 43 MPa when made with steel slag, quartzitic-limestone, dolomitic-limestone and calcareous-limestone aggregates, respectively. In discussing their results, they presumed failure of concrete with calcareous and dolomitic-limestone aggregates to be within the weak aggregates since the interface in those concretes was strong due to a good bond between the aggregates and the cement paste. The highest split tensile strength was observed in concrete made from steel slag aggregates and the lowest in concrete with calcareous-limestone aggregates. Despite a defined difference in compressive strength, after 28 days of curing, quartzitic and dolomitic concretes had about the same tensile strength. Modulus of elasticity was found to be highest for concrete made from steel slag aggregates with the least still belonging with concrete made from calcareous-limestone aggregates. Note that concretes with high elastic moduli are not always desired because they often exhibit a brittle failure. In confirmation, Beshr et al. [6] found concrete from calcareous-limestone aggregates to give a more desirable ductile failure.

Wu et al. [3] found that at w/c ratio of 0.26, compressive strength of granite > quartzite > limestone > marble concretes. However, at w/c ratio of 0.55, compressive strength of limestone > marble > quartzite > granite concretes. Note that on the contrary, Aitcin and Mehta [5] found concrete from limestone aggregates to have a larger compressive strength than concrete from granite aggregates. This clearly speaks of the need to evaluate strength of concrete made from each aggregate. In consent with findings by Beshr et al. [6], Wu et al. [3] found splitting tensile strength of concrete not to be greatly influenced by type of aggregates.

Ezeldin and Aitcin [7] assessed effects of type of aggregate on compressive strength and flexural strength of normal-strength concrete (w/c = 0.45) as well as high strength concrete (w/c = 0.3). In consent with findings by other researchers, they found aggregate strength to have little influence on compressive strength of normal-strength concrete (w/c = 0.45). At a w/c ratio of 0.3, crushed limestone produced concrete with significantly larger compressive strength than smooth siliceous gravel. The superiority of concrete from limestone aggregates that was observed in compressive strength was however, not observed in flexural strength. In fact, crushed granite aggregates gave concrete with larger flexural strength.

Özturan and Cecen [4] studied various strength of concrete made from gravel, crushed limestone and crushed basalt aggregates. For each aggregate, they tested concrete with w/c ratios of 0.3, 0.4 and 0.58. For low w/c ratios such as 0.4, particularly 0.3, they found concrete from basalt aggregates to have a significantly larger compressive strength than concrete made from other aggregates. Despite with less variation, similar results were observed on flexural as well as on tensile strength of concretes. However, in concretes with w/c ratio of 0.58, limestone aggregates produced concretes with highest strength. Basalt and gravel aggregates produced concretes with nominally-similar strengths.

Kilic et al. [8] tested concrete made from gabbro, basalt, quartzite, limestone and sandstone aggregates at w/c ratio of 0.35 for compressive strength, tensile strength, flexural strength and abrasion. At 3 days, concrete from basalt had the largest compressive strength (76.2 MPa) with sandstone having the least strength (43.4 MPa). After 90 days, compressive strength of concrete from sandstone, limestone and basalt aggregates (53, 108, 135 MPa, respectively) was very close to the unconfined compressive strength of the various aggregates (52, 110 and 132 MPa, respectively). It should be mentioned that compressive strength of concrete made from gabbro aggregates was 136 MPa compared to 247 MPa unconfined compressive strength of the aggregates. The researchers concluded that for aggregates with a low strength, such as sandstone and limestone, failure was controlled by the strength of the aggregates as opposed to the strength of the paste. However, for much stronger aggregates such as gabbro, failure was controlled by the paste. Except for sandstone aggregates, flexural strength of concrete was not overly dependent on aggregate type.

Another important work on the influence of aggregate type on compressive strength of concrete was carried out by Alexander and Davis [9] and later comprehensively discussed by Alexander and Mindess [1]. Even for conventional concrete, they found aggregate types in common use in South Africa to produce concrete with significantly different compressive strength. Interestingly, various types of aggregates displayed similar behaviour. They therefore put aggregates that they assessed into three main groups with group 1 providing concrete with highest compressive strength and group 3 having the least strength. At w/c ratio of 0.8, group 1 aggregates produced concrete with a compressive strength of 30 MPa compared to about 20 MPa from groups 2 and 3 aggregates. The primary difference between concrete from groups 2 and 3 aggregates was that at high w/c ratios (>0.5), group 3 aggregates yielded stronger concrete whilst at ratios below 0.5, stronger concrete was from group 2 aggregates. It is important to mention that aggregates that produced the strongest concrete did not necessarily have the largest unconfined compressive strength. For example, group 1 aggregates had unconfined compressive strength that ranged from 100 to 540 MPa. The mineralogy of an aggregate did not necessarily put it into a certain group. This was confirmed by quartzite aggregates appearing in group 1 as well as in group 3. Similar results were found by Mackechnie [10] on concrete made from New Zealand aggregates. Interestingly, Mackechnie [10] only used conventional concrete with w/c ratios of 0.5, 0.6 and 0.7. Discussion by Alexander and Mindess [1] and a report by Mackechnie [10] clearly indicate the need to characterise concretes in Botswana.

3 OUTLINE OF NEEDED RESEARCH IN BOTSWANA

As already mentioned, mechanical properties of concrete, particularly compressive strength, are probably the most important properties needed by structural engineers for the obvious reason that they are closely related to structural safety. This is evident from the above review. It is therefore logical for research on the influence of aggregates on quality of concrete in Botswana to also firstly look into mechanical properties of concrete. Fortunately, equipment to fully characterise it such as compression and flexural testing machines are available at the University of Botswana.

It should be pointed out that most design of concrete in Botswana is based on conventional concrete. The need to understand the influence of aggregates on performance of concrete is therefore not as pressing as in other countries such as USA where there is extensive use of high strength concrete. However, it was discussed in the above review that according to Alexander and Mindess [1], Neville [2] and Mackechnie [10], different aggregates can yield conventional concrete with significantly varying compressive strength. In addition, with increased construction of multi-storey buildings in Botswana, it is foreseeable that before long, high strength concrete will also be used here.

According to PPC-Botswana and many building material retailers, the most used cement in Botswana is a blend between 65 to 79% OPC and 21 to 35% calcareous fly ash. The manufacturers (PPC-Botswana) report that this cement is manufactured according to SANS 50197-1 [11] and gives performance in the 32.5 N strength class [12]. Surely, structural engineers and contractors in Botswana will benefit the most from results of concrete made with this cement. However, from a research viewpoint, this will make it difficult for researchers to fully characterise various concretes in Botswana. This is because some of the compounds in the cement blend (particularly fly ash) may react negatively with certain aggregates. In corroboration, Alexander and Mindess [1] when discussing results from Alexander and Milne [13] showed that a blend of 30% fly ash and 70% OPC yielded conventional concrete that was at times 20 MPa less than concrete made from OPC. Therefore, if researchers were to use a blend of OPC and fly ash in their study, they may incorrectly conclude that aggregates are poor performing whilst it is the synergic interaction between some aggregates and the blended cement that gives poor performance. To overcome this potential setback, research on the influence of aggregate on performance of concrete in Botswana will use both OPC and the blended cement.

4 CONCLUSION

While concrete is the most widely used construction material in Botswana, little is known about its performance. This paper provided a review of work carried out in other countries to assess influence of aggregate type on performance of their concrete. Most researchers contended that aggregate type has little influence on strength of conventional concrete. It however, greatly influences compressive strength of high strength concrete. This is somewhat convenient in that most concrete in Botswana is conventional. Unfortunately, some researchers showed that even in conventional concrete, aggregate type has a great influence on performance of concrete. It was concluded that there is need to study influence of aggregate type on performance of concrete in Botswana. This study is in progress at the University of Botswana and its findings will be provided in subsequent publications.

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