COMPARATIVE EVALUATION OF THE FLEXURAL STRENGTH OF CONCRETE AND COLCRETE

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ABSTRACT

Colcrete is a construction material resulting from grouting of prep laced coarse aggregates with colgrout. Colcrete is more economical to use than concrete. If the performance of colcrete in service is favourably comparable to that of concrete, some construction costs could be saved in the use of colcrete in place of concrete. This paper reports the findings of a study carried out to compare the flexural strength of colcrete to that of concrete. Concrete beams of 750 mm × 150 mm × 150 mm were cast in accordance to BS 1881: Part 118: 1983 using 1:2:4 and 1:3:6 nominal mix ratios, with water-cement ratios of 0.56 and 0.58, respectively. Similar colcrete beams were cast using 1:2 and 1:3 colgrout with 0.56 and 0.58 water cement ratios, respectively. Three different sizes - 47 mm, 50 mm, and 55 mm - of coarse aggregates were used. The beams were tested for flexural strength after 28 days of casting and curing in water. Flexural strength results for the concrete and colcrete were compared. Results show that for the two mix ratios investigated, and the three types of coarse aggregates used, the flexural strength of colcrete is higher than that of concrete. On the basis of this study, it is concluded that colcrete performs better in flexure than concrete. The use of colcrete is, therefore, recommended in structures, especially members predominantly loaded in flexure, so as to reap the benefits of better performance and cost savings in construction projects.

Keywords: Colcrete, Colgrout, Comparative, Concrete, Construction projects, Economy, Flexural strength, Performance.

Introduction

Concrete is a fundamental construction material used in civil engineering and building structures. Concrete is primarily composed of the mixture of cement, fine and coarse aggregates, and water. Colcrete has the same primary compositional materials as concrete. The main difference between concrete and colcrete lies in the mode of preparation and the sizes of aggregates. Concrete is made by mixing together all the component materials before placing; while in the case of colcrete, the coarse aggregates are first placed in the mould before a specially formulated mortar known as colgrout is added to grout the aggregates. The mortar is agitated to fill the spaces between the aggregates. It can, therefore, be understood that while concrete is a one-stage operation, colcrete is a two-stage operation. In casting of colcrete, the first stage involves placing the coarse aggregates in the forms; the second stage entails grouting the prep laced coarse aggregates with colgrout.

Colcrete emerged, among many other types of concretes such as prestressed concrete and polymer concrete, from continuous researches being carried out on concrete to improve upon its quality and economy. Rolt (1967) and Tomlison (1995) described colcrete as a grouted concrete made by introducing a specially formulated substance known as colgrout into the voids of coarse aggregates placed in the moulds of structural elements such as foundations, beams, and columns. In some literatures, colcrete is referred to as prepakt concrete (Troxell and Davis, 1956), or grouted concrete (Lea, 1970), or preplaced coarse aggregate concrete (Neville, 2003). Troxell and Davis (1956) described prepakt concrete as a system of construction that involves filling of the forms with aggregates coarser that "1 in" (i.e., 25 mm) and then filling the voids in the aggregates by pumping in a grout of 1 part cement, Y:z part finely divided silicious materials, and Y:z part fine sand. The flowability of the grout, as further stated by Troxell and Davis (1956), is enhanced by a small amount of special lubricant added to the mix. The resulting concrete is strong and exhibits practically no shrinkage, as the coarse aggregate particles are in direct contact with each other (Troxell and Davies, 1956).

According to Lea (1970), earlier concrete production involved the use of large stones as aggregates. In the present day, the sizes of aggregates in common use for concrete range between 12 mm and 25 mm. The components of colcrete, as generally documented in literature, comprise of coarse aggregates of not less than 38 mm, and mortar. In a contrary opinion to the generally recommended 38 mm minimum size of coarse aggregate in colcrete, Neville (2003) has provided for the use of coarse aggregates sizes smaller than 38 mm. What can, however, be deduced from Neville (2003) is that when the aggregates sizes are less than 38 mm, they should be of multiple sizes and they should be gap-graded. In what seems to be the most convenient guide for the choice of the size of coarse aggregate in colcrete, Rolt (1967) recorded that the most appropriate maximum size of coarse aggregate in colcrete depends on the type of work. Following Rolt (1967) guide, therefore, the most appropriate size of coarse aggregate to be used in colcrete should be based on the type of work.

In colcrete, the coarse aggregate component is about 600.10, while the remaining 40% or so is the grout (Lea, 1970). According to Neville (2003), the volume of coarse aggregate represent about 65-70 per cent of the overall volume to be concreted; the remaining voids, about 30-35 per cent, are filled with mortar. A typical mortar, according to Neville (2003), consists of a blend of Portland cement and pozzolana in the ratio of between 2.5:1 and 3.5:1 by mass. This cementitious material is mixed with sand in the ratio of between 1: 1 and 1: 1.5. It should, however, be noted that the common practice is to produce the mortar or the colgrout by mixing Portland cement and sand in the ratio corresponding to the nominal mix ratio specified for the equivalent normal concrete. The mortar or colgrout is poured and vibrated into successive layers of prep laced aggregates of appropriate sizes until the whole structural element is completely cast. It has been advised (Neville, 2003), that care should be taken to ensure that the coarse aggregates in colcrete are free of dirt and dust because, since these are not removed in mixing, they would impair bond. The advantage of being able to use larger sizes of coarse aggregates in colcrete is the major reason for the reduction of the cost of producing colcrete compared to concrete.

In addition to the economy achieved in producing colcrete when compared to concrete, colcrete has been found to perform better in drying shrinkage than concrete (Troxell and Davis, 1956). Neville (2003) made it clear that the drying shrinkage of preplaced aggregate concrete (colcrete) is lower than that of ordinary concrete. In preplaced coarse aggregate concrete, otherwise known as colcrete, the reduced shrinkage is due to point-to-point contact of the coarse aggregate particles, without the clearance for cement past which is required for plasticity in ordinary concrete. This contact reduces the amount of shrinkage that can actually be realised, so that the overall shrinkage of the colcrete is less than that of the ordinary concrete of the cement content, the tendency to crack is correspondingly reduced. Hence colcrete has a lower tendency to crack than concrete. Troxell and Davis (1956) reported that the bond strength of prepakt concrete, otherwise referred to as colcrete, to regular concrete is considerably greater than that of regular concrete to regular concrete.

Because of the greater bond strength, reduced shrinkage, low tendency to crack, and low permeability, colcrete has found applications in tunnel linings, dams, bridges and underwater constructions, water retaining structures, large monolitihic structures, and structures subjected to freezing and thawing conditions. Colcrete has also been found useful in the provision of exposed aggregate finish. Colcrete has been extensively used for patch works in hardened concrete. Thus colcrete has many useful features. According to Troxell and Davis (1956), although pneumatically placed mortars have been used quite extensively for repair works in the past, their relatively high shrinkage has restricted their use. To overcome this disadvantage, continued Troxell and Davis (1956), a method of grouted concrete known as prepakt concrete (i.e. colcrete) has come into use for many types of repair jobs. Troxell and Davis (1956) observed that colcrete is ideal for patch work in hardened concrete because it is strong and exhibits practically no shrinkage, as the coarse aggregate particles are in direct contact with each other.

Ironically, with all these numerous benefits derivable from the use of colcrete in construction, little attention has been paid by researchers to colcrete. The result is that no recent information are available on colcrete. Information on colcrete is, therefore, available largely in literatures that existed during the period of its discovery. It will be of immense benefit to the construction industry to enhance the knowledge of this important type of concrete by expanded researches into its properties.

Flexural strength is one of the important properties of concrete. By extension, flexural strength is an important property of colcrete. Flexural strength according to Murdock and Brook (1979) is described as the tensile strength in bending. Murdock and Brook (1979) further described flexural strength as the modulus of rupture. Flexural strength is expressed in terms of "modulus of rupture" which is the maximum tensile stress at rupture (Troxell and Davis, 1956).

The flexural strength property of concrete vis-à-vis colcrete becomes very important when steel reinforcement are not provided in a concrete structure. In unreinforced concrete roads and runways, reliance is placed on the flexural strength of the concrete to distribute concentrated loads over a wide area. In roads and aerodrome runway slabs, the flexural strength of concrete is equally as important as the compressive strength; and for this reason, Wright (1954) suggested that the mix for them should be designed on the basis of flexural strength. Wright (1954) pointed out that leanest mix is obtained with rounded aggregates for mixes based on compressive strength; while in design mixes on the basis of flexural strength, leanest mix is obtained with crushed rock. Wright (1954) stated further that in order to meet the flexural strength requirement, the cement content could be less with crushed rock aggregate than with rounded gravel aggregate which is the reverse to the normally accepted requirement for compressive strength.

Some other researches have been undertaken to check the effects on the flexural strength of concrete. Orchard (1973) reported that air entrainment in concrete, which is accompanied by a reduction in water-cement ratio, increases the flexural strength in lean concrete mixes, and decrease the flexural strength in rich concrete mixes. Similarly, Graf (1949) cited in Orchard (1958) concluded that for aerated concrete, the flexural strength is from 0.3 to 0.5 times the compressive strength. Shaver (1953) cited in Orchard (1958) reported that the flexural strength of concrete made with bloated lightweight aggregate is equal to that of the normal weight aggregate. From a similar research, Orchard (1973) reported that the flexural strength of lightweight concrete is far greater in proportion to its compressive strength than for normal weight concrete; the flexural strength increases with the weight of concrete but becomes progressively less in comparison with the compressive strength as the compressive strength increases. Gunashekaran (1975), Rahimi and Kelser (1979), Ravindrarajah and Tam (1984), and Padmarajaiah and Ramaswamy (2002) in different studies focused on economic enhancement of flexural strength, reported that the inclusion of fibres over a partial depth of a normal strength concrete (NSC) beam without tensile reinforcement will economically enhance the flexural strength of concrete. Letsch (2001) in a study conducted to assess the mechanical behaviour of a polyester polymer concrete at different temperatures, concluded that the presence of higher temperatures resulted in a small decrease in compressive strength, but relatively large decrease in flexural strength and a very large decrease in creep deformation. In a closely related investigation, Ribeiro *et al* (2004) discovered that the flexural strength of unsaturated polyester and epoxy mortars formulations decreases drastically as temperature increases. Ashour *et al*., (2004) found that the use of carbon fibre reinforced polymer (CFRP) strengthens the flexural strength of reinforced concrete continuous beams. Padmarajaiah and Ramaswamy (2004) reported that the placement of reinforcement steel fibers over a partial depth in the tensile side of pre-stressed structural members is an economical route to the enhancement of the flexural strength of high-strength concrete (HSC).

The effects of flexural strength on concrete will be similar to its effects on colcrete. This study will not only identify a more economical material in colcrete for achieving a good flexural strength if colcrete is found to compare favourably with concrete in flexure, but will also go a long way in improving on the scanty and non-current information on the properties of colcrete.

EXPERIMENTAL PROCEDURE

Mix design was not carried out for concrete, since the technology of colcrete production does not require mix design. Therefore, to ensure that the materials are compared on the same basis of materials mixes, nominal mix ratios of 1:2:4 and 1:3:6 were used. The water-cement ratios of 0.56 and 0.58 used in the study for 1:2:4 and 1:3:6 mixes, respectively, were determined through trial mixes. The materials were batched by weight, mixed thoroughly, and cast into 750 mm × 150 mm × 150 mm steel moulds. Fine aggregate of zone 1, and three different sizes of coarse aggregates (47 mm, 50 mm, and 55 mm) were used in the investigation. In the case of concrete, casting was done with all the materials mixed together. As for the colcrete, the cement, fine aggregate, and water were mixed together to form the colgrout; the coarse aggregates were placed in the steel moulds before adding the colgrout, and the moulds were vibrated to ensure that the spaces between the coarse aggregates were filled by the grout. For both concrete and colcrete, the moulds were vibrated to achieve compaction to the required density. The top of the concrete and colcrete were leveled off and smoothened, using hand trowel. Demoulding was effected after 24 hours of casting. The concrete and colcrete specimens were weighed before immersion in water in a curing tank for 27 days. At the end of 27 days of curing, the concrete and colcrete specimens were air-dried in the laboratory for 24 hours and weighed before testing for flexural strength in accordance to BS 1881: Part 118: 1983.

RESULTS AND DISCUSSION

Results

Flexural strength test results for 1:2:4 concrete and colcrete with 1:2 colgrout are presented in Table 1. As for 1:3:6 concrete and colcrete of 1:3 colgrout, the results for the flexural strength test are given in Table 2. Figures 1 and 2 show the graphical comparison of the flexural strength results of concrete and colcrete for 1:2:4 and 1:3:6 nominal mix ratios, respectively.

Discussion

From Tables 1 and 2, and Figures 1 and 2, it is clearly shown that the flexural strength of colcrete is higher than that of concrete for the two nominal mixes studied, and with all the three sizes of coarse aggregates employed. It is indicated in Table 1 that for 1:2:4 nominal mix ratio, the flexural strength of colcrete is higher than that of concrete by 43.75%, 39.17%, and 21.43%, with 47 mm, 50 mm, and 55 mm aggregates sizes, respectively. In the case of 1:3:6 nominal mix ratio featured in Table 2, the flexural strength of colcrete is higher than that of concrete by 38.59%, 18.96%, and 3.97%, with aggregates sizes of 47 mm, 50 mm, and 55 mm, respectively. Generally, there are no large discrepancies between the increases in he flexural strength of concrete obtained from 1:2:4 and 1:3:6 nominal mix ratios as the coarse aggregate size increases. Comparatively, there exist a big difference between the flexural strength values of colcrete made from 1:2:4 and 1:3:6 nominal mix ratios as the size of coarse aggregate increases, because the colcrete increases in flexural strength in the former, while the colcrete flexural strength decreases in the latter.

In addition to the results that are clearly shown in Tables 1 and 2, some other interesting results can also be observed from the individual tables. In Tables 1, for 1:2:4 nominal mix ratio, as the size of coarse aggregate increases, the flexural strengths of both concrete and colcrete increase. However, the specific increase in the flexural strength at a smaller size of coarse aggregate to a higher value at a larger size of coarse aggregate is higher n concrete than in colcrete. Illustratively, between 47 mm and 50 mm sizes of aggregates, the flexural strength increased by 7.14% in concrete and 3.73% in colcrete. Between 50 mm an d 55 mm sizes of aggregates, the flexural strength was increased in concrete and in colcrete by 16.67% and 1.80%, respectively. From 47 mm to 55 mm aggregates sizes, the increase in the flexural strength of concrete is 25%, while the corresponding increase in the flexural strength of colcrete is 5.59%. It is also clear from these results that while the percentage difference in flexural strength between a smaller aggregate size and a larger aggregate size increases in the case of concrete, the difference in flexural strength between a smaller size aggregate and a larger size aggregate decreases in the case of colcrete.

The flexural strength results for nominal mix ratio of 1:3:6 presented in Table 2 indicate that while the flexural strength of concrete increases as the size of coarse aggregate increases, the flexural strength of colcrete decreases as the size of coarse aggregate increases.Demonstratively, between 47 mm and 50 mm aggregate sizes, the flexural strength of concrete increased by 11.61%, while the flexural strength of concrete was increased by 12.64%, but the flexural strength of colcrete decreased by 1.56%. From 47 mm to 55 mm aggregates sizes, the flexural strength of concrete increased by 25.73%, with a corresponding decrease of 5.69% in the flexural strength of colcrete. The decrease in the flexural strength of colcrete as the size of aggregate increased could be attributed to the leanness of the colgrout mix. With 1:3 colgrout, it seems that the colgrout mix is not rich enough to provide sufficient bond between the spaces in the preplaced aggregates of larger sizes. It should, however, be noted that the decreases in the flexural strength of colcrete for the 1:3:6 nominal mix ratio, and between a smaller size of aggregate and a larger size of aggregate are generally small.

The study has clearly established that the flexural strength of colcrete is better than that of concrete. Colcrete has a stronger flexural strength than concrete because in colcrete the coarse aggregate are packed closely together in the form with the result that the aggregate are in contact with each other. The colgrout which is vibrated into the spaces between the preplaced aggregae provides the bond that is required for the preplaced aggregate to acquire the strength for the material to behave like one-solid stone. Troxell and Davis (1956) observed that prepakt concrete, also referred as colcrete, is strong and exhibits practically no shrinkage as coarse aggregates are in direct contact. Furthermore, Troxell and Davis (1956) concluded that the bond strength of prepakt concrete, in other words colcrete, cast to regular concrete is considerably greater than that for regular concrete cast to regular concrete. If this is the case, it can reasonably be inferred that the greater bond strength obtained between colcrete against concrete than concrete against concrete is made possible by greater bond strength developed in colcrete compared to concrete. It follows, therefore, that for the same mortar content, the bond strength of colcrete is greater than that of concrete. The combined effect of direct aggregate-to-aggregate contact and a stronger bond strength provided by the mortar or colgrout provides higher flexural strength in colcrete compared to concrete. Consequently, colcrete resists flexural stresses better than concrete; and therefore, performs better than concrete in flexure.

Conclusions

On the basis of the results from this study the following conclusions are drawn.

1. The flexural strength of colcrete is higher than that of concrete. Hence colcrete performs better in flexure than concrete.

Table 1: Flexural strength results for concrete (1:2:4) and colcrete (1:2: colgrout)

Types of specimen	Aggregate size	Water-cement ratio	Average flexural strength (N/mm^2)		Extent of flexural strength of colcrete higher than that of concrete (%)
			1:2:4 concrete	1:2 colgrout	
Beams	47		2.24	3.22	43.75
	50	0.56	2.40	3.34	39.17
	55		2.50	3.40	21.43

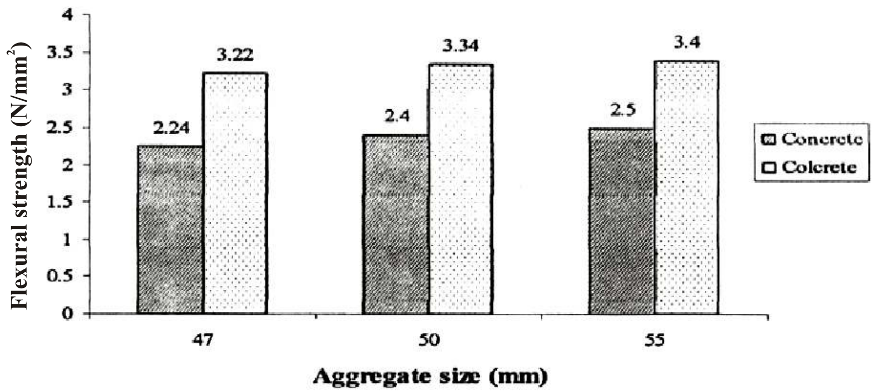

Figure 1: Flexural strengths of concrete and colcrete for 1:2:4 nominal mix ratio.

Table 2: Flexural strength results for concrete (1:3:6) and colcrete (1:3: colgrout)

Types of specimen	Aggregate size	Water-cement ratio	Average flexural strength (N/mm^2)		Extent of flexural strength of colcrete higher than that of concrete (%)
			1:3:6 concrete	1:3 colgrout	
Beams	47	0.58	2.41	3.34	38.59
	50		2.69	3.20	18.96
	55		3.03	3.15	3.97

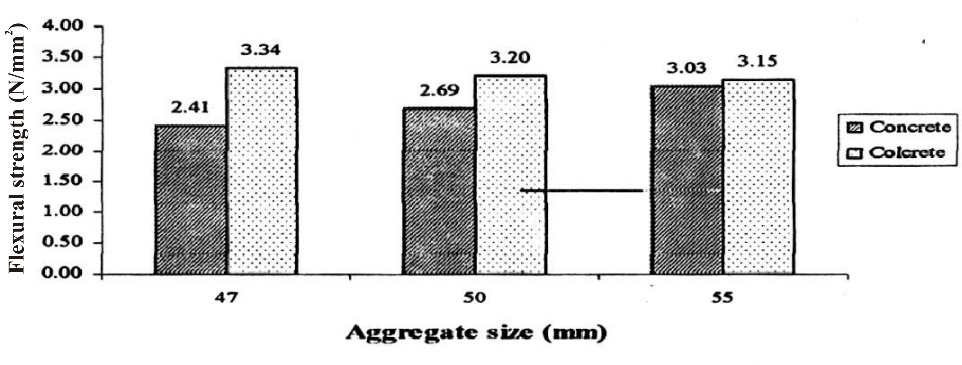

Figure 2: Flexural strengths of concrete and colcrete for 1:3:6 nominal mix ratio.

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