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Properties of Concrete Mix with Crushed Pavement Blocks as Coarse Aggregate

Wadhah M. Tawfeeq, Othman AlShareedah, Taimoor Hossain

Abstract— With continuing rise in urbanization, the problem of accumulation and management of construction and demolition waste becomes a significant problem. Construction and demolition waste can be recycled and used as raw material for new applications. The main aim of this study is to investigate the possible use of crushed pavement blocks as coarse aggregate for the production of new concrete. In this study, concrete specimens are prepared by 100% natural coarse aggregate; which will then be replaced by crushed pavement blocks at various percentages (50 and 100%). The mechanical and physical properties of crushed pavement block aggregates such as specific gravity, clay percent, grading, water content and water absorption were tested. Experimental results indicated that absorption of coarse crushed pavement blocks aggregate were about 221% higher than that of natural aggregate. The compressive strength of 28 days by using crushed pavement blocks aggregate showed an increment of nearly 8% when it fully replaced the natural aggregate in concrete mixes.

Index Terms— Recycled aggregate, replacement, crushed pavement blocks, physical properties, concrete mix, compressive strength, workability.

1 Introduction

THE concept of recycling is simply to convert waste materials into new useful products. In order to achieve a sustainable development in the concrete industry, the concept of recycling should be implemented. The natural resources of natural aggregates are running out in different countries in the world. Furthermore, the cost of using natural aggregates in concrete production is increasing as the demand increases.

Million tons of concrete demolition and wastes around the world are produced every day and goes to the landfill. This concrete demolition and wastes can be recycled and reused as a coarse aggregate in concrete production (ECCO, 1999). Many tests on using recycled aggregates as part of concrete have been conducted since early 1980s. Despite serious differences in the original formulations, the general conclusions are that recycled aggregate should be considered as a valuable material in concrete industry. Such conclusions are also valid for high-strength, high-performance recycled aggregate (El-Reedy M. A., 2009).

Using recycled aggregate in concrete industry is still not widely practiced. This is simply because it is not a well-known method and it is difficult to predict the influence of the combination of properties on the overall behaviour of reinforced concrete members made from recycled aggregate concrete (El-Reedy M. A., 2009). Many researches have been published on the use of recycled concrete aggregate in new concrete. However, the main physical properties of recycled concrete aggregates which have a significant effect on the resulting concrete properties have not fully been categorized and investigated yet (Butler, et. al, 2011).

Recycled aggregate concrete composed of aggregates originating from demolition process possess high water demand due to the harsh texture from the increased adhered mortar of the aggregate (CCANZ, 2011). Based on one investigation presented by (Shicong, 2006), recycled aggregate present continued water absorption after mixing in a batch plant which could cause loss of slump and workability. Hence, pre-wetting of recycled aggregates before casting is required to offset this effect. In addition, it has been observed that the free water content needs to be about 10 L/m3 higher than that of natural aggregate concrete mix to attain the similar slump results. The study also concluded that the use of recycled aggregate would amplify the bleeding rate and bleeding capacity of the produced concrete, however, applying a lower w/c ratio would successfully be able resolve this issue.

Incorporating aggregates into concrete mix reduces its shrinkage and creep thereby giving enhanced volume stability, aggregates also add to a greater durability to concrete (Newman & Seng Choo, 2003). A two stage mixing approach for recycled aggregate concrete has been described to result in a strengthened interfacial zone, which leads to an improved performance in the recycled aggregate concrete (Tam, et. al., 2006). Employing recycled aggregate into concrete has been indicated to have various effects on hardened concrete. They result in lower compressive and tensile strengths and lower modulus of elasticity as well as significant increase in shrinkage value. This reduction in concrete strength can be attributed to the recycled aggregates features, which are dependent on the parent crushed concrete, such as its source (whether demolished or leftover), strength, or the use of multiple sources instead of one. Other factors that define this low strength of recycled concrete are the use of fine recycled aggregates, the percentage of replacement adopted or even the adjustments made to water cement ratio to maintain its workability (CCANZ, 2011). Furthermore, the compressive strength of recycled aggregate concrete is also strongly de-

- Wadhah M .Tawfeeq is currently an [1]Assistant Professor, Faculty of Engineering, Sohar University, Sohar, PC 311, Oman; email: WTawfeeq@soharuni.edu.om or wadhah78@yahoo.com
- Othman AlShareedah is currently Undergraduate Student of Engineering, Sohar University, Sohar, PC 311, Oman; email: othman155sh@gmail.com
- Taimoor Hossain is currently Undergraduate Student of Engineering, Sohar University, Sohar, PC 311, Oman; email: taimoorhossain@gmail.com

pendent on the combination of w/c ratio of the original concrete (Abed, 2009).

Thorough review of literatures on this topic, it has been concluded that using recycled aggregates in concrete production will reduce the depletion of the natural aggregates resources as well as avoid the environmental issues related to the natural aggregates production. In addition, the use of recycled aggregates will provide an effective solution to the landfills and disposal issues of waste concrete. The suitability of aggregates to be used on concrete production mainly depends on its principle qualities such as its strength, durability and inertness. It has been revealed that the high absorption capacity of recycled aggregate enables it to prolong the time needed to reach a Saturated Surface Dry (SSD) condition in contrast to natural aggregates (Butler, et. al., 2011). Although fine recycled aggregate are not often implemented in production of concrete, it has been reported that the use of fine recycled aggregate to a 10 to 30% extent results in higher strength gain beyond 28 days owing to its ongoing cementation action (CCANZ, 2011).

In Oman, natural aggregates are produced mainly from the Hajar Mountains in the northern part of the country. The rapid growing of concrete production will affect the environment in this region as well as lead to the depletion of natural aggregates resources. Consequently, recycled aggregate can be used in concrete industry since it leads to a sustainable development in concrete industry. This study involves investigating the effect of using the concrete pavement wastes as a coarse aggregate in producing new concrete. There are a lot of wastes of concrete pavement in Oman that has reached their end of life or the rejected quantities in the construction sites that can be crushed and converted into coarse aggregates with various sizes to be used in concrete production. This will be an economical solution for the ready mix plants in Oman since the raw materials are almost free..

2 Experimental Study

2.1 Materials

2.1.1 Natural Fine Aggregates

Natural fine aggregates used for this experimental study was obtained from local crushers in Oman. The grading of the fine aggregate and the limits of aggregate were performed as per the British Standard (BS 882: 1992). Three samples taken from fine Natural Aggregates (NA) were tested and passed the sieve test. The upper and lower limit is specified in (BS 882: 1992). The sample results are shown in Fig.1. The specific gravity, water content, water absorption (BS 1097-6:2000) and clay percent values were 2.59, 7.77%, 1.68% and 2.63% respectively.

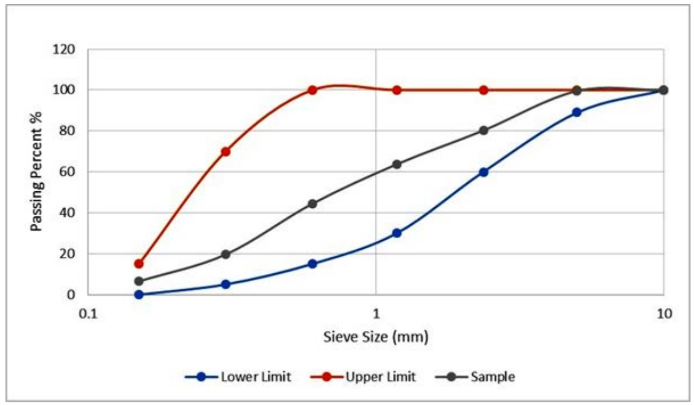

Fig. 1 Sieve Analysis for Natural Fine Aggregates.

2.1.2 Coarse Aggregates

The NA used in this study was brought from local crushers in Oman. The specific gravity, water content and absorption for coarse natural aggregate were 2.63, 1.2 and 1.67% respectively. The Crushed Pavement Aggregates (CPA) shown in Fig. 2 were collected from various sources such as waste of concrete pavement, factories, expired concrete pavement from pavements and sidewalks and surplus material from construction sites. The SSD specific gravity for the CPA was found out to be 2.54. The water content test for CPA revealed a value of 2.73 %. The water absorption value for coarse CPA was 5.36%. The sieve analysis results for both NA and CPA are as illustrated in Fig.3.

Fig. 2 Crushed Paving Blocks (CPA).

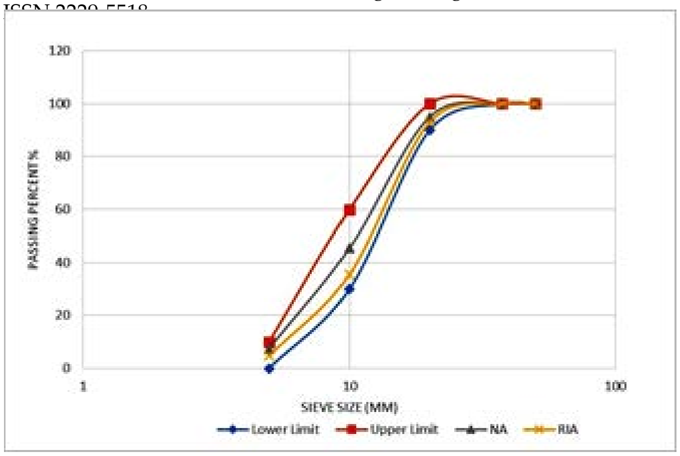

Fig. 3 Sieve Analysis for Coarse NA and CPA.

2.1.3 Cement and Water

The cement used in this study is Ordinary Portland Cement type (I) according to British Standard Specification (BS EN 197-1:2000) which is manufactured in local plant in Oman. Distilled water was used in all concrete mixes and curing. The Sulphate content, hardness and PH of water were 250 mg/l, 120-150 ppm, 6.5-8, respectively.

2.2 Testing of Specimens

The study involved experiments on CPA as well as NA to investigate and compare the properties of each type. Specific gravity, water absorption, water content, sieve analysis and clay percent tests were performed on each type. The control trial mix with NA was designed (BS 5328-2:1997) for target strength of 35-40 MPa and slump of 60-180 mm. Furthermore, the coarse NA was replaced by CPA in different percentages (e.g. 0%, 50% and 100%). Other parameters such as w/c ratio and G/S ratio were also changed.

3 Results & Discussion

Compressive strength can be defined as the resistance of a material to breaking under compression. The replacement percent of recycled aggregates implemented were 0%, 50% and 100% in separate concrete mixes. The bench marking trial mix was 400:835.2:904.8/0.6.

3.1 Slump Test Results

The Slump cone test was performed for all concrete mixtures immediately after mixing to measure workability of concrete. The compressive strength of the concrete mixtures was measured at 7 and 28 days using ADR-Auto 2000 Standard (2000 kN capacity compression machine) from ELE.

The slump test was conducted for each trial mix in this study to measure the workability of the concrete. High value of slump expresses high water content in the concrete mix. The relationship between slump and w/c ratio at G/S = 1.1 is illustrated in Fig. 4.

It can be observed that when the CPA percentage is 50%, the slump is the highest. However, the trial mix with 0% CPA replacement (the control trial mix) has the lowest slump values. Slump values at all percentages of replacement (0%, 50% and 100%) were the lowest when w/c ratio is 0.55 and the highest when w/c ratio is 0.65. Fig. 5 shows that when G/S ratio is 1.0 with 50% CPA replacement, the slump is 24.3% higher than the control trial mix. Replacement by 100% CPA resulted in a slump value higher than the control trial mix by 13.5%. Moreover, changing G/S ratio to 1.2 gave a slump value higher than the control trial mix by 22.2 % for 50% CPA replacement and 14.3% for 100% CPA replacement.

The parametric study shows that for all trial mixes with different characteristic, the highest slump recorded with 50% CPA replacement and the lowest slump was with 0% CPA replacement (i.e. the control trial mix). However, due to the high absorption capacity of the CPA, water content in the concrete mix had to be increased so that there is enough water for hydration process. Therefore, trial mixes with 50% and 100% CPA replacement recorded higher slump value than the control trial mix. Trial mixes with 50% CPA replacement have inconsistency in the shape of coarse aggregate since it has 50% natural crushed aggregate and 50% crushed pavement block aggregate unlike the trial mixes with 100% and 0% CPA replacement. Consequently, the interaction between the aggregates will decrease and the result is high value of slump. Furthermore, it is recommended to use such concrete with high workability for sections with congested reinforcement and vibration is not suitable (Neville & Brooks, 2010).

Increasing fine aggregate in the concrete mix will obviously increase its workability. Consequently, trial mixes with G/S ratio of 1.0 recorded the highest slump values. On the other hand, a balance should be maintained in the ratio of coarse to fine aggregate. This is because, if the fine aggregate quantity is reduced, the overall interaction between the aggregates will reduce which will result in high slump value. Therefore, trial mixes with G/S ratio of 1.2 had higher slump values than the trial mixes with 1.1 G/S ratio.

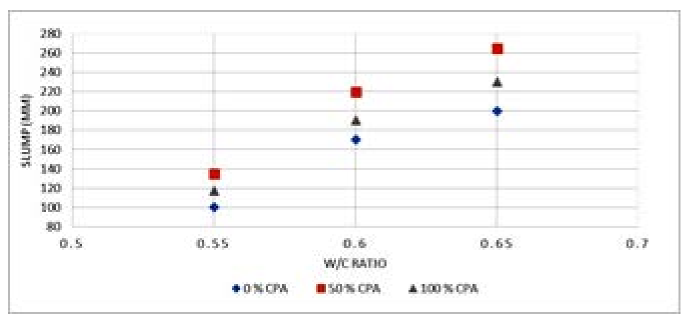

Fig. 4 Slump vs w/c Ratio (G/S ratio = 1.1)

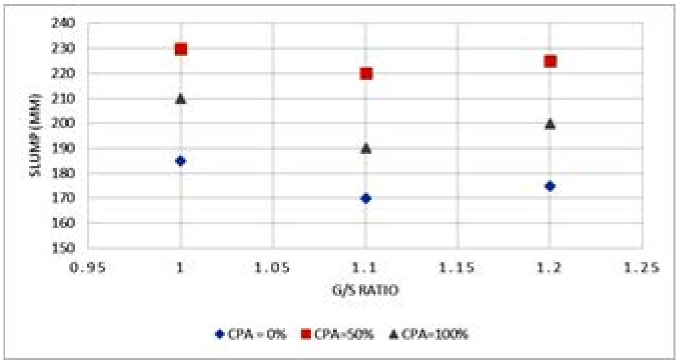

Fig. 5 Slump vs G/S ratio (w/c ratio = 0.6)

3.2 Compressive Strength Test Results

The concrete compressive strength was measured at 7 and 28 days. In Fig. 6 it can be seen that when reducing G/S ratio to 1.0, the compressive strength recorded the lowest values. Increasing G/S ratio to 1.2 gave better results of compressive strength although still it is lower than the designed G/S ratio. However, it is clear that the optimum G/S ratio is 1.1 where the compressive strength has recorded the highest values.

Fig. 7 clearly shows a decline in the general trend of 7 day compressive strengths with respect to their w/c ratios. Lower w/c ratio gave higher compressive strength and vice versa. The highest strength observed here is for the 100% CPA replacement trial mix with w/c ratio of 0.55. The difference between the strengths of 100 and 0 % CPA is noticed to be minor, whereas the 50 % CPA replacement low strength is seen to decline linearly. The 100% CPA replacement trial mix with w/c = 0.55 is higher than the same trial mix with w/c = 0.65 by 29.2%.

Fig. 8 shows that reducing G/S ratio to 1.0 reduces the compressive strength to its lowest values. Increasing G/S ratio to 1.2 decreases the compressive strength although it is still above the strength value associated with G/S ratio = 1.0. The optimum compressive strength was recorded at 1.1 G/S ratio.

The relationship between w/c ratio and compressive strength at 28 days shows that the highest compressive strength was at w/c ratio of 0.55 and the lowest was at 0.65 as shown in Fig. 9.

As noted from the trial mixes results, the 100% CPA replacement trial mixes have resulted in the highest concrete strength. This key strength can be directly linked to the original strength of the crushed pavement blocks used. The minimum original strength of concrete pavement is reported to be 50 MPa (ASTM C1319-11).

The 50% CPA replacement have yielded the lowest compressive strengths while producing high slump values. The shape of the CPA as well as NA plays major role in this case. The shape of NA's used in this study was irregularly crushed, but had possessed smoother surface compared to the CPA used. The CPA aggregates also had irregular surface but it's the rough adhered surface mortar that lead to the weak interaction with the NA, thus resulting in lower strength and higher workability mixes.

In general, low w/c ratio in concrete mixes produces high strength values, as this contain less water and more cement content. Hence, the trial mixes with w/c ratio higher than 0.55 possess lower compressive strength. Furthermore, the designed G/S ratio was set to be 1.1. Reducing this ratio to 1.0 resulted in increase in the amount of fine aggregates which in turn resulted in lowest concrete strengths. However, an increase in the G/S ratio to 1.2, which involved the reduction of fine and relatively increased amount of coarse aggregates resulted in strength higher than the G/S =1.0 trial mixes, although not exceeding the strength of trial mixes of G/S=1.1 , thereby making this is the optimum G/S ratio.

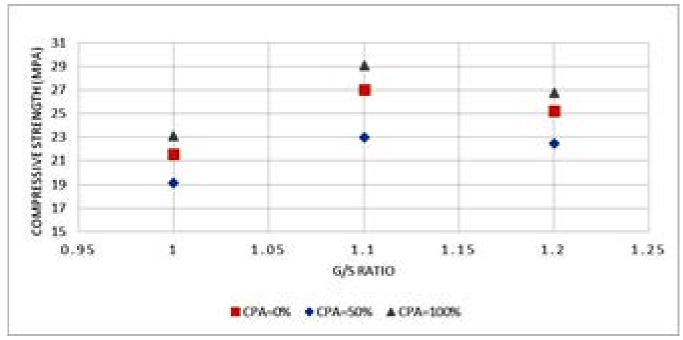

Fig. 6 Compressive Strength at 7 days vs G/S ratio (w/c ratio = 0.6)

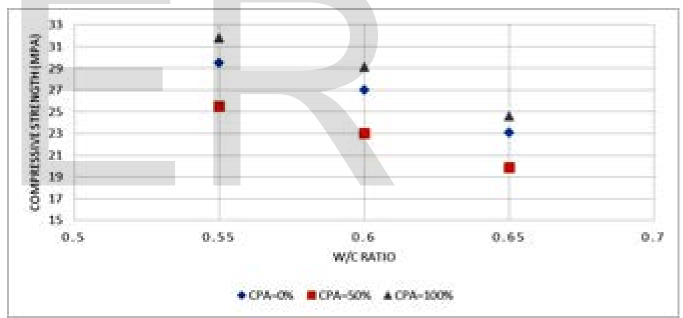

Fig. 7 Compressive Strength at 7 days vs w/c ratio (G/S ratio = 1.1)

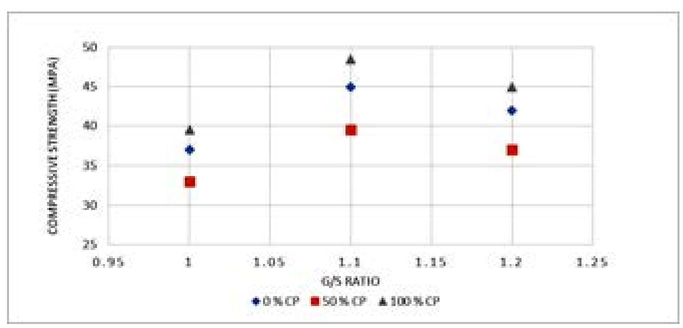

Fig. 8 Compressive Strength at 28 days vs G/S ratio (w/c ratio = 0.6)

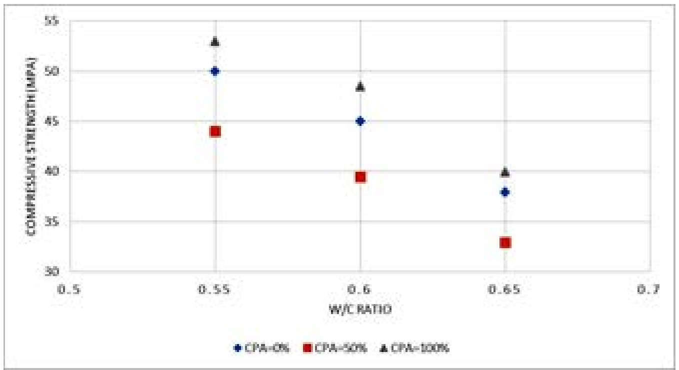

Fig. 9 Compressive Strength at 28 days vs w/c ratio (G/S ratio =1.1)

4 Conclusion

1. In this study, w/c ratio was varied from 0.55, 0.6 and 0.65 in order to investigate the effects of various w/c ratios in concrete. High w/c ratio means higher amount of water which leads to high slump and vice versa.
2. Replacement by 50% of CPA in trial mixes gave the highest slump values. Furthermore, the 50% CPA replacement trial mixes in all G/S ratios gave the highest slump values.
3. Trial mixes with G/S ratio of 1.1 had the lowest slump value compared to that of G/S of 1.0 and 1.2. The highest slumps noticed was with G/S = 1.0.
4. High w/c ratio has displayed lower concrete compressive strengths. The w/c ratio of 0.55 has resulted in the highest concrete compressive strengths. Lowest compressive strength was associated with G/S ratio = 1.0. Increasing the ratio of G/S to 1.2 resulted in higher compressive strength which did not exceed the strength results obtained from trial mixes with G/S = 1.1.

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