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SUSTAINABLE CONCRETE USING RECYCLED AGGREGATE AND SUPPLEMENTARY CEMENTITIOUS MATERIALS

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Abstract. Sustainability has become one of the key parameters in the construction industry in United Arab Emirates. Recently, Dubai municipality has introduced new regulations that enforced the use of green concrete in all construction projects in Dubai. The focus of these regulations is to reduce the Carbon foot print in the construction industry by greening of concrete. The current practice has been concentrating solely on the approach of replacing cement with supplementary cementitious materials (SCMs) such as grand granulated blast furnace slag (GGBS) and fly ash. However, the use of recycled aggregates also contribute to the greening of concrete and reducing the Carbon foot print of the construction industry in the UAE, where concrete is the main construction material. This research tends to expand the current practice by replacing aggregates with recycled aggregates in the concrete mix. Recycled aggregates are obtained from a local recycled aggregate plant in Abu Dhabi. These aggregates are recycled using concrete from demolished buildings in Abu Dhabi. The natural aggregates in self-consolidating concrete mixtures (SCC) were replaced by recycled aggregates with the following percentages: 30%, 50% and 100%. Various parameters affecting the behavior of fresh and hardened concrete are investigated including slump flow, rheology, and compressive strength. The results are analyzed to arrive to pertinent conclusions, in addition to recommendations regarding the utilization of concrete with recycled aggregates in some types of buildings and infrastructure projects in the UAE.

Key words: Supplementary Cementitious Materials, Grand Granulated Blastfurnace Slag, Flyash, Recycled Aggregate, Self-Consolidating Concrete, Green Buildings.

1 Introduction

Construction industry is one of the largest industries in the world, where raw natural materials are extracted and a lot of related waste is generated. Therefore, sustainable practices in this industry is always worldwide desired for the sake of environmental protection. Since concrete is the main skeleton material for majority of structures, and it is the most consumed material after water, incorporating sustainability practices, while maintaining the durability and service life of structure is always a challenge.

Partial replacement of cement content with supplementary cementitious materials (SCM) is widely adopted by concrete industry as sustainable practice. This approach dose not only improve concrete strength and durability, but it can be also considered a sustainable practice for concrete and construction industry. The SCM materials are waste by-products of other industries, which can improve the quality of concrete making it more durable with longer service life that can reduce the required repair and maintenance.

Coarse ad fine aggregates constitute around 75% by weight of an non-air entrained concrete, while cement occupy only 16% to 18% of concrete mix by weight. Therefore, replacing part of the aggregate content with available sustainable materials will be more effective and beneficial for environmental protection than just replacing cement with SCM. Moreover, it was documented that utilization of recycled aggregate fully or partially in concrete, reduces energy and cost of excavation of natural aggregate as well as it reduces the impact of waste material in the environment [1]. Recycled aggregate extracted from demolished structure is core replacement of the natural crushed aggregate used in concrete. Several studies have been conducted and reported in the literature to investigate the effects of recycled aggregates and the replacement percentages on concrete properties.

It has been found in various studies that the physical and mechanical properties of recycled aggregate are inferior to the natural crushed aggregate, which can affect the hardened properties of the concrete. Some studies reported decrease in compressive strength [2,3], when recycled aggregates replaced the natural aggregates between 50 to 100%. The reported decrease was between 7% and 19% compared to that for concrete with natural aggregates. Additionally, usage of recycled aggregate increased water absorption property of concrete [3]. The inforirity of recycled aggregate didn't only affect the hardened properties of concrete, but it also showed an effect on the fresh properties such as workability [2]. In terms of workability a drop of around 20 to 30 mm in slump was noticed when recycled aggregate was incorporated in the mixture.The drop in slump increased when the replacement percentages increased. This could be attributed to the dried mortar around the aggregate particles due to the high water absorption of recycled aggregates [1].

Some techniques were suggested to make the recycled aggregate suitable for structural concrete such as washing the recycled aggregate to remove the very fine materials [3]. High concrete porosity with recycled aggregate content can be related to possible contamination of recycled aggregates with other construction materials components, and the variability in aggregate gradation [4]. Some other studies suggested to use the recycled aggregate with certain ratio to produce a non-structural low strength (around 6.0 MPa) concrete material needed in construction industry [5].

This paper extends the commonly adopted sustainable practice in concrete industry (i.e., using SCM), and investigates the use of recycled aggregates as another sustainable parameter. The paper studies the effect of recycled aggregate replacement percentages on key fresh and hardened properties of concrete with more focus on the effects on main fresh properties including the rheological charectristics till one hour workability retention.

2 Experimental program

The concrete mixture used in this study was of a 40 MPa target cube mean compressive strength with 400 kg/m^3 total ordinary Portland cement content, and fixed water to cementitious ratio of 0.38. Maximum nominal aggregate size was 20 mm. A single type of a low range polycarboxylate base admixture conforming to ASTM C949 as type G superplasticizer was used for all mixes in the study. The natural aggregates in concrete mixture were replaced by recycled aggregates with the following percentages: 20%, 40%, 60% and 100%.

The natural aggregates used in this investigation (20 mm, 10 mm, and 5 mm) for the concrete mixtures were of limestone aggregate type -extracted from Ras Al Khaima, United Arab Emirates- that crushed and single graded as 20 mm, 10 mm, and 5 mm that conforms to BS 882 limits. The recycled aggregate used were from a local recycled aggregate plant in Abu Dhabi, United Arab Emirates. These aggregates are recycled using concrete from demolished buildings in Abu Dhabi.

Results of key significant physical parameters of recycled aggregate for concrete usage showed some remarkable variations compared to the same for crushed limestone aggregate and sand. These major variations were represented as an increase in water absorption value, and reduction in particle density of recycled aggregate compared to regular crushed limestone aggregate. The water absorption for the coarse fraction of recycled aggregate was 6.2 %, and 8.2 % for fine fraction. While the water absorption for the coarse fraction of limestone crushed coarse aggregate is 0.5 %, and 0.90 % for crushed sand. Thus, recycled aggregate absorbs around 10 times more water compared to the regular used aggregate. Furthermore, the saturated surface dry particle density of the recycled aggregate is 2.42, while for the regular used limestone aggregate is of around 2.70.

Five concrete mixtures were prepared and investigated in the course of the current research. Four mixtures were made with recycled aggregate and one mixture (reference) was made with 100% crushed natural aggregates. These mixtures were evaluated to study the effect of recycled aggregate and its replacement percentage on both fresh and hardened properties of concrete. The assessed parameters for fresh concrete mixtures covered the following properties: workability retention through slump or slump flow test up to an one-hour duration, superplasticizer dosage demand to achieve an initial slump value between 220 to 240 mm and corresponding flow of 600±25 mm, rheology for a duration of one hours, air content, and fresh density. The assessed hardened properties of concrete covered the cube compressive strength of the mix at different 1 day, and 7 days.

The workability retention was assessed using the consistency test by checking the slump of each of the mixtures as per BS EN 12350-2 at 30 minute-interval till one hour. All concrete mixtures had comparable initial slump of around 240 mm. Different Rheology parameters were assessed in this investigation using I-CAR rheometer. The rheology parameters highlighted herein are static yield stress, dynamic yield stress, and plastic viscosity. For Air content test, the pressure method was used using air meter as per BS EN 12350-7. Regular concrete cube compressive strength tests were performed to evaluate the compressive strength of the mixes as per BS 1881-166 using 150 mm x 150 mm 150 mm concrete cubes.

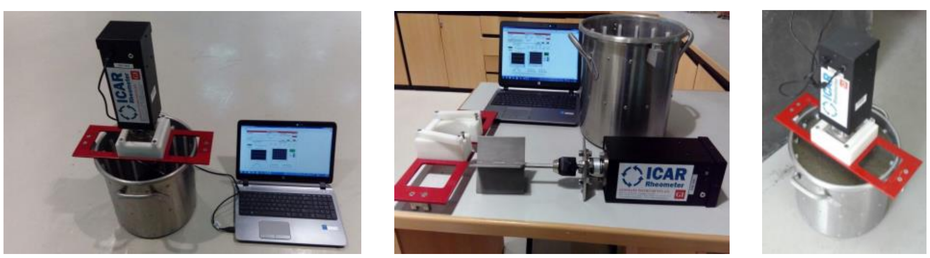


Figure 1. I-CAR Rheometer

3 Results and Discussion

3.1 Effect of Recycled Aggregate on Concrete Slump Retention

Figure 2 shows the effect of recycled aggregate with different replacement percentages on the slump retention of concrete for a duration of 1 hour. As mentioned above, initial slump value for the five mixtures was targeted to be of 240 mm with corresponding achieved flow of 610 mm for control mixture, 590 mm for 20% recycled aggregate mixture, 600 mm for 40% recycled aggregate mixture, 590 mm for 60% recycled aggregate mixture and 600 mm for 100% recycled aggregate mixture.

It can be observed in Fig. 2, that in general the slump drops with time. Moreover, concrete with more replacement percentage of recycled aggregates experienced more drop in slump than that with lower recycled aggregates content. For instance, a drop of around 16% in slump value occurred after 1 hour for concrete with 100% recycled aggregate compared to the control mixture.

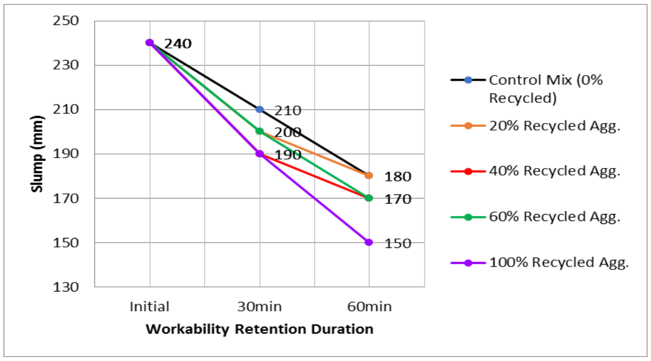


Figure 2. Effect of recycled aggregate on slump

3.2 Effect of Recycled Aggregate on Concrete Mixture's Superplasticizer Dosage Demand

Figure 3 shows a direct proportional relationship between the increase in replacement percentage of recycled aggregate in the mixture and superplasticizer dosage required to achieve the required initial slump value that is sufficient to retain the workability for two hours as discussed in the section 3.1. It can been seen that a mixture with more replacement of recycled aggregates required more dosage to achieve the required initial slump.

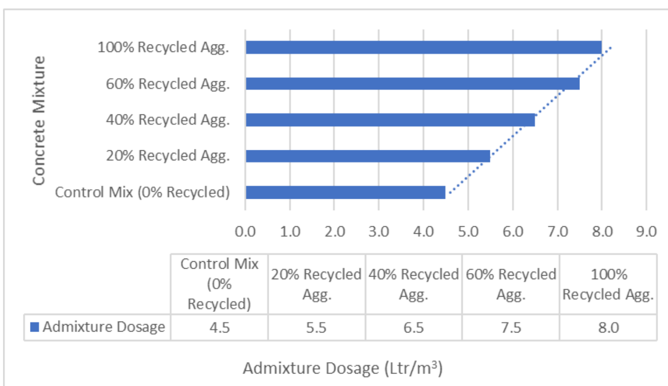


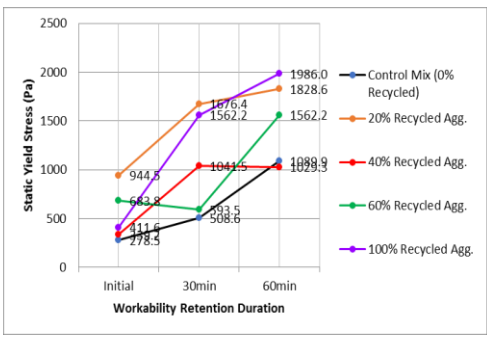
Figure 3. Polycarboxylate superplasticizer dosage demand to achieve initial slump of 240 mm

3.3 Effect of Recycled Aggregate on Concrete Mixture's Rheology

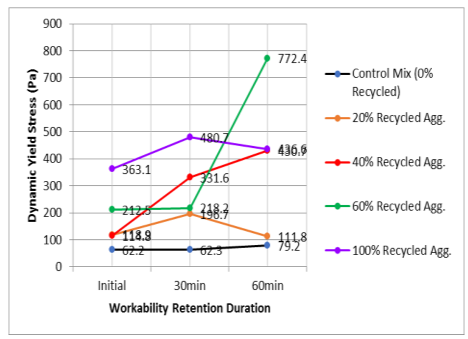
Figure 4 presents the effect of recycled aggregate percentage in the concrete mixture on the stress required to intiate the move of fresh concrete, dynamic stress and related plastic vicosity of concrete mixture. All three rheological parameters were examined for a duration of 1 hour at an interval of 30 minutes.

The static yield stress graph in Fig. 4a demonstrates relatively higher values of static yiled stress when the percentage of recycled aggregate increases. This can be noted from the static yield stress graph in which the data drawn for the 100% recycled aggregate mixture is the top most graph therein compared to others. However, the 20% recycled aggregate mixture shows higher yield stress at the initial time and after 30 minutes (944.5 Pa, and 1676.4 Pa respectively) compared to the other concrete mixtures after same time. Also, the 20% recycled aggregate mixture shows a static yield stress value at 60 min (1828.6 Pa) of more than the one of 40% and 60% recycled aggregate percentage after the same duration.

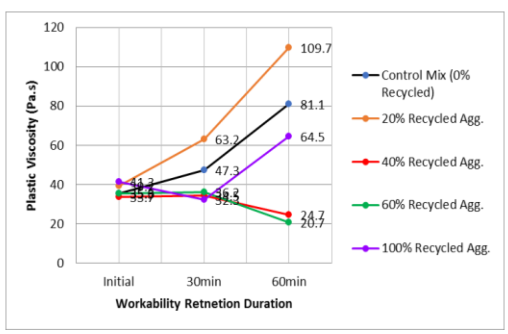
In case of dyamic yield stress, it can be noted that generally with increase in recycled aggregate percentage in the concrete mixtures, the the dynamic yield stress increases at all workability retention interval except for the mix with 60% recycled aggregate content which shows an maximum dynamic yield stress among the rest at 60 minutes (Fig. 4b). With regards to plastic vicosity achieved values, no clear pattern between the mixtures was noted as show in figure 4c.



(a)



(b)



(c)

Figure 4. Rheology parameters of concrete mixtures with recycled aggregate (static yield stress, dynamic yield stress, and plastic viscosity)

(a) Static yield stress at initial, 30-minute, and 60-minute workability retention
(b) Dynamic yield stress at initial, 30-minute, and 60-minute workability retention
(c) Plastic viscosity at initial, 30-minute, and 60-minute workability retention

3.4 Effect of Recycled Aggregate on Concrete Mixture's Air Content and Fresh Density

Figures 5 and 6 show measured air content and density of concrete mixtures, respectively measured with different recycled aggregate replacement. it can observed that as the recycled aggregate content in the mixture increases, entrapped air in the concrete increases and accordingly the density reduces. This is justifiable since increased air content reduces the strength, and this can be related to the property of aggregate as it is more absorbent as highlighted earlier in this paper.

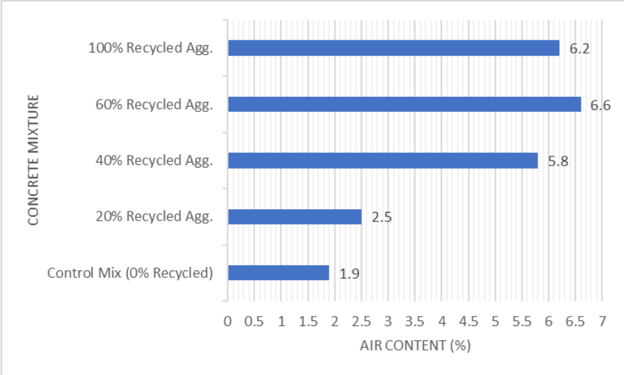


Figure 5. Air content of concrete mixtures

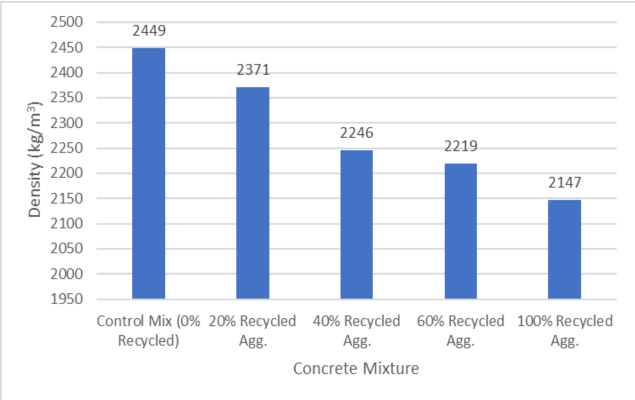


Figure 6. Measured actual density of concrete mixtures

3.5 Effect of Recycled Aggregate on Concrete Mixture's Compressive Strength

Results of compressive strength at early concrete age for the different replacement percentages show clear pattern that when the recycled aggregate content increases in the mixture, the compressive strength decreases as demonstrated in Fig. 7. It can be further observed that at a 7 day age, the compressive strength of the mixture with 100% recycled aggregate drops to around 50% of the same age for the control mixture.

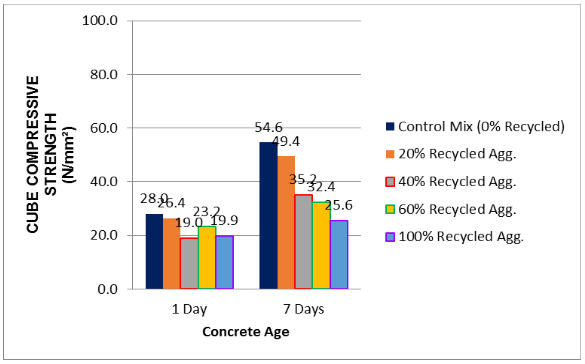


Figure 7. Compressive strength evaluation of the different mixtures

4 Summary and Conclusions

Recycled aggregate is a valuable sustainable ingredient that can be incorporated in concrete mixtures, yet several effects should be taken always into consideration as this study shows and concluded as follows. When the percentage of recycled aggregate exceeds 20%, slight drop in concrete slump value is noted, The drop is around 16% when the natural crushed aggregates are totally replaced by 100% of recycled aggregate. Furthermore, an increase in recycled aggregate replacement is a direct proportional relationship with superplasticizer dosage that is also needed to maintain a workable mixture for certain duration.

Regarding the related effect on rheology related findings, recycled aggregate conctent in the concrete mixture increases the static yield stress as well as the dynamic yield stress while there is no specific pattern of the recylced aggregate replacement effect on concrete mixture's plastic viscosity.

Additionally, the increase in percentage replacement on recycled aggregate increases, entrapped air in the concrete increases and accordingly the density reduces. Attention to the effect on strength should be always taken when the recycled aggregates are incorporated. This is due to the reduction in compressive strength when recycled aggregate content increases in the mixture.

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