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Strength and Workability Evaluation of Recycled Aggregate Concrete using Black Sand

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Abstract
Recycling concrete (RC) has emerged as an increasingly prominent subject of research on a global scale in recent years. The main objective of this investigation was to assess recycled concrete aggregates RCAs that were formerly produced using North Sinai materials. Establishing Tennessee Department of Transportation TDOT in suitable gradations of recycle aggregates that meet the requirements of Egyptian code and specifications for the selection of RCAs. Utilizing RCA , Natural Sand (NS) and Black Sand (BS) in concrete mixtures is one of the most effective means of addressing this issue and achieving the sustainability objective. This investigation focused on the utilization of North Sinai fine aggregates in natural state and aggregates derived from demolished structures as a recycled concrete. The RCAs was modified to be more suitable for fresh and hardened concrete. Six concrete mixtures were examined. Initial testing of the use of 100% original Gradation RCAs in concrete mix was conducted using the Coarseness Curve. The original gradation was adjusted as follows: 15% #1" was improved to gradation S1, and 15% #1" plus 15% #4 was reduced to 3/8" gradation S2. Coarse aggregate demonstrated superior and more remarkable results in terms of fresh and hardened properties with black sand compared to natural sand. The results showed that the compressive strength was evaluated; at 7 and 28 days curing ages, and the flexural behavior were assessed. At 28 and 56 curing days, the mix RCA3, consisting of 15% # 1" + 15% #4 + Reduction 15% # 3/8" S2, achieved the highest compressive strength of 42.3 MPa. At that point, the results of all other mixes were lower. The influence of different gradation effect of RCAs with natural and black sand on strength and workability, also was investigated by microstructural investigations employing scanning electron microscopy (SEM).The discussion centered around the correlation between these effects and the chemical compositions of the specimens.

Key words:*Recycled Concrete Aggregate, gradation, compressive strength, flexure strength, workability, slump.*

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I. Introduction

The building sector in Egypt is seeing growth, especially in the Sinai Peninsula. Following the demolition of the old buildings, new ones were constructed, and numerous structures were dismantled and reconstructed. This study aimed to show the effective methods for disposing of the substantial quantities of recycle concrete generated during this search. Advantages of utilizing recycled concrete aggregates RCAs is a beneficial ecological alteration. It conserves the earth's resources and protects the environment by minimizing the necessity to initiate new mining operations. Various distinct RCA modification processes were employed to strengthen and modify recycled aggregate [1,2]. The altered RCA exhibited comparable performance to that of natural aggregate. Optimized aggregate combinations can improve the efficiency of concrete and be utilized for concrete design [3]. An ideal aggregate gradation can be achieved by employing both theoretical and empirical methods [4,5]. The majority of theoretical models employ uniform or randomly shaped spherical particles to determine the packing of aggregates [6], on the other hand the RCA is a fabric contains of cement mortar range between 30-35%, which covered with natural aggregates (67-70%) and can be created by crushing specimens of concrete [7]. Generally, RCA exhibits more porosity, unevenness, and permeability compared to natural aggregates. RCA exhibits several key features, including enhanced water absorption, reduced volume and specific gravity, and little abrasion. However, the process of crushing RCA might potentially impair the bond between the original natural aggregates and the mortar, leading to an increase in the number of microcracks in the RCA [8]. Extensive study has been conducted to enhance the substandard physical and mechanical characteristics of RCA through the exploration of various treatment methods and procedures [9]. These actions involve the removal of loose mortar particles from the surface of the aggregate and the enhancement of the quality of the mortar that adheres to the aggregate. The water-to-cement ratio (w/cm) and the strength of recycled concrete aggregate RCA exhibit a similar and robust correlation as conventional mixtures. However, when Recycled Concrete Aggregate RCA is utilized in the production of concrete, the resulting concrete generally lacks the same level of strength compared to concrete manufactured with newly sourced aggregates. The weakness of the RCA stems from potential microcracks caused by the crushing process and the inferior strength or porosity of the mortar in the RCA [10]. When compared to the use of nature sand in concrete, the use of fine sand results in higher compressive and tensile strength and effect on [11] decreasing in curing ages and an increase in compressive strength. The inclusion of small sand particles in concrete can affect many properties of the material, including its workability, strength, and long-term durability [12]. The main chemical components of sand are silica oxide (SiO_2), iron oxide (Fe_2O_3), calcium oxide (CaO), and alumina oxide (Al_2O_3) [13]. However, it is crucial to remember that natural sand has a smooth and rounded surface texture, which considerably reduces the interlocking qualities of concrete and so affects its strength [14-17]. Black sand One of the few financial radioactive mineral-rich deposits on Earth, BS is ordinary sand combined with high economic radioactive minerals, including rare earth metals, thorium, and titanium [18].Placer deposits have thick, lustrous, partly magnetic black sand. Basalt particles are also dark sand on volcano beaches. High iron generates dark hue and heavy metals[19]. Most minerals are black because iron absorbs light and is dense. Sun-heated sands are heavier than light-colored ones. Some beaches are predominantly black sand because lava cools quickly and shatters into sand and debris when it strikes water [20,21,22]. The substance is mostly sand [23]. Like Egypt, a massive lava flow entering an ocean or sea can create enough basalt to make a black sand beach overnight. Egyptian black sands are seen in Figure 1. Black sands occur north of the Nile Delta and along the Mediterranean. To get the desired slump, it is more effective to raise the paste content of the mixture while keeping the water-to-cement ratio constant, rather than just adding additional water [24,25]. The mortar component of recycled concrete aggregate RCA not only enhances water absorption but also results in a decreased unit weight, which needs to be considered when determining the proportions of mixes[26]. Interconnecting hydration compounds By examining the microstructure of completely recycled coarse aggregate concrete with different proportions of cementitious components, we significantly decreased the interfacial transition zone of porosity and compression [27]. When using sixty percent recycled aggregates as a replacement, it was observed that the strength of recycled concrete did not decrease as typically anticipated. These methods entail significant economic costs and intricate procedures, which do not facilitate technical progress. As a result, academics are evaluating the advantages of doing research on reinforced concrete [28]. An investigation was conducted to examine the influence of recycled concrete aggregate RCA on the strength of high-strength concrete. Concrete samples were produced using RCA for this purpose. Statistics suggest that approximately thirty percent of recycled concrete aggregate RCA could be utilized in the production of concrete that possesses similar levels of strength and durability [29]. Previous research has shown that using a well-graded aggregate gradation with a maximum size of 20 mm has resulted in concrete with the appropriate characteristics when using both natural aggregate (NA) and recycled aggregate (RA) [30]. Slump is a method used to assess the consistency of fresh concrete, and it is a component of workability, along with cohesion. The water content has a direct impact on the slump. Water-reducing admixtures can enhance the workability of concrete by increasing its slump without the need for additional water. The addition of water-reduction admixtures to concrete can enhance its consistency while also decreasing the water content by five percent [31]. In order to mitigate the impact of water and additives, the inclusion of intermediate-sized aggregates can enhance the workability of concrete by occupying empty spaces and diminishing friction. Mixtures that do not contain aggregates measuring between 2.36 and 9.5 millimeters will require additional mortar [32].

II. Materials and methods

Materials

Cement: The Portland cement from the Sinai cement factory, known as CEM I N52.5, conforms to the Egyptian standard specification (ESS. 4657-1/2009). It has a specific gravity of 3.15 and an initial setting time of 60 minutes and a final setting time of 360 minutes. Its strength exceeds 18 MPa at 3 days and 25 MPa at 7 days [33]. Coarse Aggregate: the coarse aggregates utilized for enhancement were sourced from quarries in the El-Arish North Sinai Region., The properties of RAC were characterized by an angular shape and a texture that was reasonably smooth; Which appropriate the properties of the materials used in the search. This was mostly because most of the RAC particles were either completely or partially covered by residual mortar, which made the Original aggregate particles less sharp. Each of these particles was categorized and graded, the gradation satisfy ASTM C33 [34]. A few RCAs surpassed the grading restrictions by a little margin. Sand: The natural sand sourced from the El-Arish quarry in North Sinai has a particle size ranging from 0.3 to 0.6 mm. This sand possesses the necessary qualities that meet the requirements of both the Egyptian Code and ASTM C33. Black Sand (BS): it was used as a main component in the production of concrete. black sand XRD analysis are shown in Fig.1,the term "coarse" encompasses not only ilmenite (I) and other combinations, but also denotes something that is rough or lacking finesse. The specimens displayed a size variation, ranging from 4.75 to 10 millimeters.

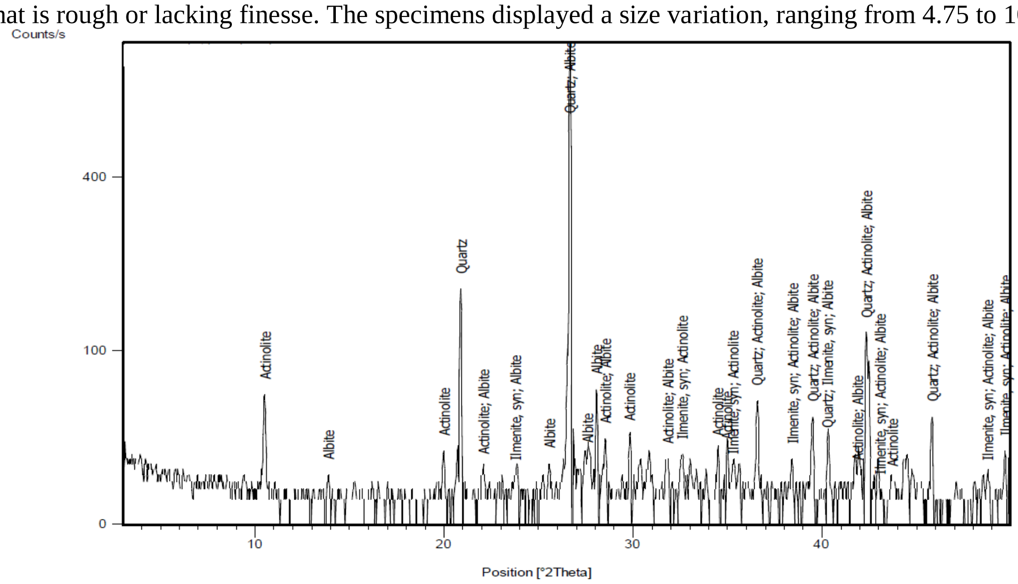


Figure1. black sand XRD analysis

Superplasticizer (SP): Super-plasticizers, also known as high-range water-reducing admixtures (HRWR) [41], make concrete flow better without water. Third-generation superplasticizer for concrete and mortar. It meets ASTM C-494 Type F and E.S.S. 1899-1/2006 [35]. RCAs was gathered to represent diverse regions and sources in the North Sinai. In order to get recycled aggregates from concrete that had been thrown away, they were first crushed in a jaw crusher. The size and gradation of RCA were examined according to ASTM C136 methods[36].

Table 1: Physical properties of aggregates.

Physical Properties	CA Value	RCA Value	standard
Water absorption %	1.4%	2.7%	ASTM C127 [24]
Bulk Specific Gravity, gm/cm^3	2.7	2.30	ASTM C127 [24]
SSD Specific Gravity, gm/cm^3	2.40	2.40	ASTM C127 [24]
Bulk Density , Kg/m3	1685	1565	ASTM C29 [25]
Apparent specific gravity, gm/cm^3	2.55	2.56	ASTM C127 [24]

III. Mix proportions and methodology

The proportions of the three concrete compounds utilized in this experimental program are detailed in Table 2. The variations in these mixtures with respect to graduation are illustrated in Table 3, with two types of sand natural sand and black sand as shown in Fig.2. Mix1 consists entirely of original Gradation without any modifications; however, the mixtures were altered in accordance with the properties of TDOT paving concrete techniques in order to enhance the graduation as shown in table3. For the compression test, twenty four concrete cubes measuring 100 mm x 100 mm x 100 mm were fabricated. The curing of concrete cubes was evaluated at 7 and 28 days according to ASTM C39 techniques [39].

In order to evaluate the flexural behavior of reinforced concrete beams (100 mm × 100 mm × 50 mm) for 28 and 56 days , the beams were subjected to the same number of cube tests. Flexural strength test was conducted on 100x100x500 mm concrete beams to ASTM C78. Testing concrete beams with three-point loading [40].

Figure2. Photographs show Natural and Black Sand.

Table 2: Mix proportions and concrete mix design output

Mix code	Mix propotions (kg/m3)				
	Cement	Sand	Coarse Aggregate	WATER	Super-plastisizer
RCA	350	750	1100	160	5

Table 3: The characteristics of the gradation of recycled aggregates

RAP Symbol	RAP content
RCAN1, RCAB1	100% original Gradation
RCAN2, RCAB2	15% #1" improved gradation S1
RCAN3, RCAB2	15% # 1" + 15% #4 +Reduction15% # 3/8" S2

IV. Results and Discussion

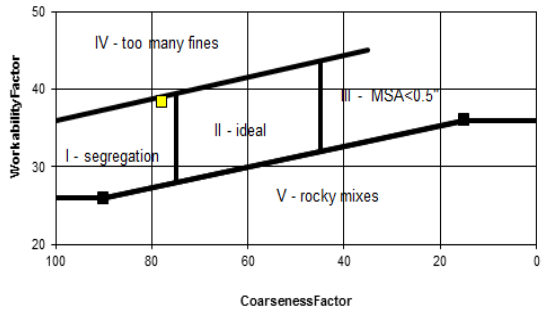
4.1RCA gradation Particles and Coarseness Curve as TDOT paving concrete techniques

Most (RCA) particles contained adhered paste, which acceptable results for the density and workability of RCAs. As a result, the adhered paste were important properties for RCAs and to evaluate packing aggregate on concrete through slump and compare the results with Coarseness Curve as TDOT paving concrete techniques [41]. For original grading, TDOT Class CP mix's combined aggregate gradation and workability were assessed.

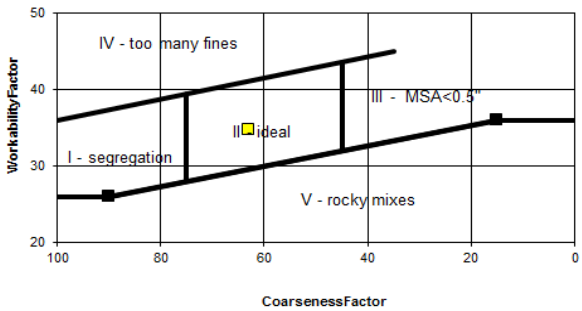
Table 4: Sieves analysis of Gradation according to Coarseness Curve as TDOT paving concrete techniques

Sieve size (inch)	Egyptian code	Original Gradation	S1 Gradation	S2 Gradation
2 1/2"	100	100	100	100
2"	100	100	100	100
1 1/2"	95-100	100	100	100
1"	45-80	100	80.8	81
3/4"	45-80	100	63	62.5
1/2"	45-80	100	46.6	46.5
3/8"	25-50	100	30.1	31.5
#4	25-50	98.2	16.4	17
#8	25-50	80.8	9.6	4
#16	25-50	57.8	4.1	3
#30	8-20	41.5	2.7	2
#50	8-20	23.3	0	1
#100	0-8	3.0	0	0
#200	0	1.0	0	0

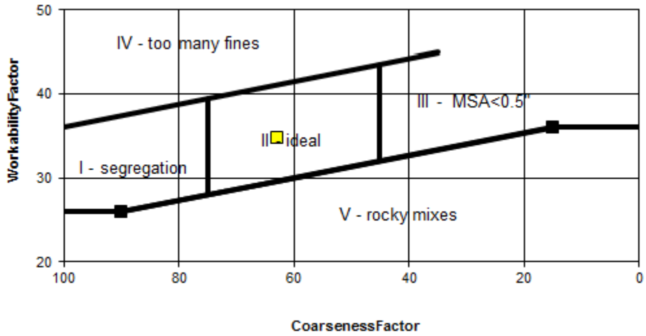
Table 4 shows the predicted results. Except for the upper and lower borders of the coarseness curve, the combined gradation was clearly inside the upper and lower limits of the coarseness curve. This suggests that the aggregates were inadequately appraised using this criterion. The aggregate appeared somewhat coarse, gap-graded, and sensitive to segregation based on the coarseness factor, as shown in Fig.3a. As shown in Fig. 3b and Fig.3c the enhancement of the workability factor due to the coarseness factor resulted in optimal outcomes. Furthermore, the improvement in the workability factor due to the coarseness factor resulted in excellent outcomes, as TDOT Class CP mix had good workability while being classified as coarse and gap-graded on the Coarseness Factor Chart.



(a)



(b)



(c)

Fig.1. Coarseness Factor Chart for RCA Aggregate and Workability of the original Gradation

The results are shown in table.5 and Fig.3b, indicated that the improvement was achieved by adding 15% #1" improved gradation S1, the results of combined gradation was clearly inside the upper and lower limits of the Coarseness Curve except # No.4, # No.8, # No.16, # No.30, # No.50, # No.100 and # No.200 which not to satisfy the Egyptian code for size RCA aggregate. This indicates that the aggregates were evaluated well based on this criterion for coarse aggregates sizes rather than small size aggregates. The results as shown in table.6 and Fig.3c, with modifying of coarse aggregates with 15% improvement in # 1" + 15% reduction in #4 +Reduction. 15% # 3/8" Except for # No.30 size RCA aggregate, S2, the aggregate appeared relatively coarse, ideal, and sensitive to segregation. Furthermore, as a result the upper and lower limits of the Coarseness Curve except # No.4, # No.8, # No.16, # No.30, # No.50, # No.100 and # No.200 that results not satisfy the Egyptian code for size RCA aggregate, but had a good-graded in the Coarseness Factor Chart, according to TDOT Class CP.

4.2 Hardened Concrete Properties

According results Coarse RAC using natural sand and black sand had insignificant impacts on the mechanical properties of TDOT paving concrete as shown in table.5. for high compressive strength due to crushed from the demolished structural concrete, which was relatively strong. This could be related to the preexisting cracking. It should be noted that the 28-day compressive strength of RCA concrete was substantially above 25MPa for all mixtures, meeting the TDOT specification for paving concrete.

Table (5) results of fresh and hardened concrete

Mix NO	Compressive strength (MPa)		Flexure strength (MPa)		Slump test (mm)
	7 days	**28 days**	**28 days**	**56 days**	
RCAN1	23.0	26.7	1.7	1.9	70
RCAN2	26.8	28.3	1.8	2.2	90
RCAN3	29.2	33.8	2.4	2.8	110
RCAB1	25	27	1.8	2	65
RCAB2	29	31	2.1	2.3	80
RCAB3	33	35	2.8	3.2	95

4.2.1 Compressive Strength

In concrete compositions with varying coarse aggregate gradations, the variations of the compressive strength of (RCA) was presented in Fig.4 which shows the different results during different curing ages, thus for RCA with natural sand, the compressive strength for mix RCAN3 were 29.2 and 33.8 MPa for 7 and 28 days curing age respectively with different 13.6%, which represent the highest compressive strength compared to others mixes of RCA. The concrete mix bond strength is mostly produced in the mortar phase, aggregate phase, and cement matrix contact; therefore, aggregates play a crucial role in this regard. The RCA particles in the ITZ are inferior to those of conventional concrete due to the presence of mortar from the parent concrete [28]. on the other hand, the compressive strength for mix RCAN2 were 26.8 and 28.3 MPa at 7 and 28 days curing age respectively with different 5.3%. Finally, the compressive strength for mix RCAN1 were 26.7 and 23 MPa at 7 and 28 days curing age respectively with different 13.86%, which represent the lowest compressive strength compared to others mixes of RCA. The difference between compressive strength for highest and lowest results were 26.95 %and 26.59% for 7 and 28 days. Also, for RCA with black sand, the highest compressive strength was for mix RCAB3. the results of compressive strength were 33 and 35 MPa for 7 and 28 days curing age respectively with different 6%, which represent the highest compressive strength compared to others mixes. while, the compressive strength for mix RCAB2 was 29 and 31 MPa at 7 and 28 days curing age respectively with different 7%. Finally, the compressive strength for mix RCAB1 was 25 and 27 MPa at 7 and 28 days curing age respectively with different 8%, which represent the lowest compressive strength compared to others mixes of RCA. The difference between compressive strength for highest and lowest results were 29.62 %and 32% for 7 and 28 days.For comparison Between the natural and black sand in compressive strength the highest compressive strength were for black sand mixes RCAB1, RCAB2 and RCAB3 rather than natural sand mixes RCAN1, RCAN2 and RCAN3 in difference between 1.1%,9.5% and 35% at 28 days curing ages. it was noticed that the difference ranges were increased with improvement the gradation of aggregates as TDOT paving concrete techniques. but, for 7 days curing ages the difference between 8.6%,8.2% and 13%, It is evident that the percentages of difference are similar, hence assessing the disparity solely based on the age of days is imprecise and unjust.

4.2.2 Flexure Strength

The flexure strength of (RCA) was presented in Fig.5 which shows the different results during different curing conditions, the flexure strength for mix RCAN3 was 2.4 and 2.8 MPa at 28 and 56 days curing age respectively with different 16.6%, which represent the highest flexure strength compared to others mixes of RCA. the flexure strength for mix RCAN1 was 1.7 and 1.9 MPa at 28 and 56 days curing age respectively with different 11.7%. The flexure strength for mix RCAN2 was 1.8 and 2.2 MPa at 28 and 56 days curing age respectively with different 22.2%, which represent the lowest flexure strength compared to others mixes of RCA. The difference between flexure strength for highest and lowest results were 41.17 %and 47.3% for 28 and 56 days.Also, for RCA with black sand, the highest flexure strength was for mix RCAB3. the results of flexure strength were 2.8 and 3.2 MPa for 28 and 56 days curing age respectively with different 12.5%, which represent the highest flexure strength compared to others mixes. While, the flexure strength for mix RCAB2 was 2.1 and 2.3 MPa at 28 and 56 days curing age respectively with different 9.5%. Finally, the flexure strength for mix RCAB1 was 1.8 and 2 MPa at 28 and 56 days curing age respectively with different 11.11%, which represent the lowest flexure strength compared to others mixes of RCA. The difference between flexure strength for highest and lowest results were 55.5 %and 60% for 28 and 56 days. For comparison Between the natural and black sand in flexure strength the highest flexure strength were for black sand mixes RCAB1, RCAB2 and RCAB3 rather than natural sand mixes RCAN1, RCAN2 and RCAN3 in difference between 5.2%,4.5% and 14.2% at 56 days curing ages. it was noticed that the difference ranges were increased with improvement the gradation of aggregates as TDOT paving concrete techniques. but, for 28 days curing ages the difference between 5.8%,16.6% and 16.6%.

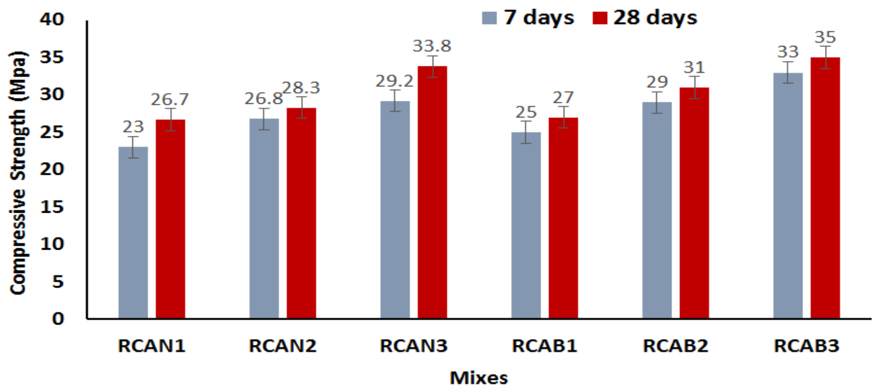


Figure.4. Compressive Strength of RCA

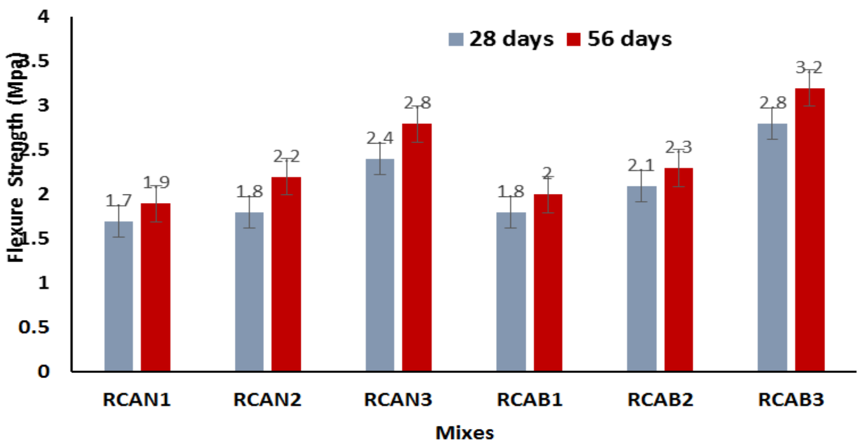


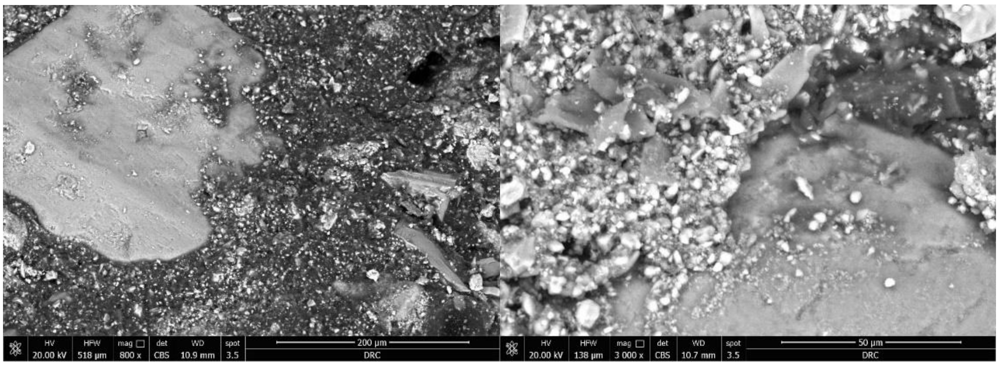
Figure.5. Flexural Strength RCA

4.2.3 Workability

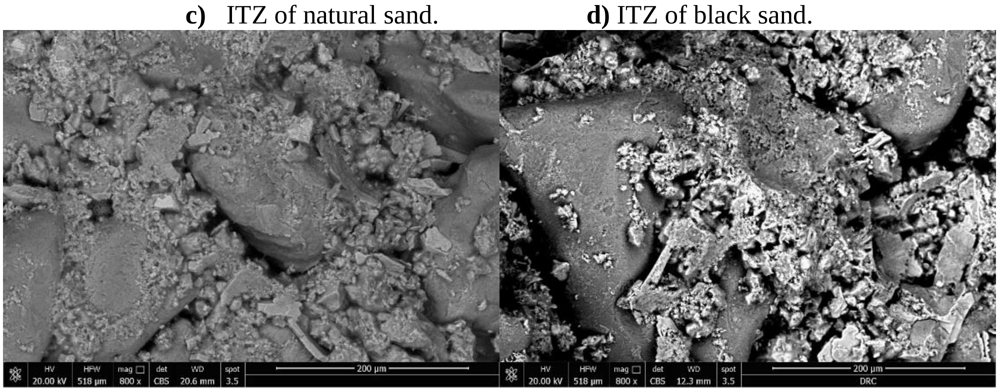
As shown in table.7, With the constant of the water content of cement w/c ratio and the content of superplastisizer with recycled aggregate, which in turn affects the slump of concrete, the result showed that the use of black sand cause to disrupt the grains of the recycled aggregate and the slump result values become less than that use of natural sand. Through results, it was shown that the slump using Natural sand is more fluidity than black sand, so for RCAN1 and RCAB1 the slump values were 70 mm and 65mm respectively in difference range 8%, also for RCAN2 and RCAB2 the slump values were 90 mm and 80 mm respectively in difference range 12%with natural sand, finally, for RCAN3 and RCAB3 the slump values were 110 mm and 95 mm respectively in difference range 15.7%.

4.2.4 SEM Analysis

The basic abrasion and hydration products of sulfate assault on concrete include plate portlandite CH, needle ettringite, fibrous and gel C-S-H, and calcium aluminate hydrate C-A-H [42]. After the cement hydrates, additional phases such as portlandite, calcium silicate hydrates, gypsum, and ettringite develop [43, 44]. Apart from solid elements such as recycled aggregates, cement particles do not blend properly in fresh concrete. Aggregates in concrete are formed by shear pressures acting on cement paste, resulting in natural aggregates with superplastsizer water separation from cement particles. As a result, the narrow space between the recycle aggregates and the cement paste has fewer cement particles and more water than the rest of the concrete. that might appear in improvement mix of # 1" + 15% reduction in #4 +Reduction. 15% # 3/8" gradation S2. The interfacial transition zone (ITZ) is the name given to this region. The ITZ is a transitional zone that is not constrained by the various categories, quantities, and sizes of concrete ingredients, as well as mixing and pouring conditions. The ITZ is a non-uniform zone that varies in position depending on its distance from the aggregate's surface [45, 46]. The ITZ size surrounding coarse aggregate is larger than around fine aggregate, ranging from 15 to 20 m [45]. In comparison to cement paste, the ITZ comprises big pores that are filled with massive crystals of calcium hydroxide for mixes as 100% original Gradation and 15% #1" improved gradation S1. and because of the addition of black sand and recycled aggregates to the cement paste, the volume of the hydrated cement is reduced from 0 to 3um. The volume of un-hydrated cement increases as the distance between the aggregates and the cement paste surface increases [46]. As a result, the area of the ITZ of OPC concrete is larger than that of SRC



c) ITZ of natural sand. **d)** ITZ of black sand.



e) cracks and voids of natural sand. **f)** cracks and voids of black sand.

Figure. 6. Micrographs of natural and black sand with recycle aggregates concrete.

V. Conclusion

1. According to the grading standards of the Egyptian code and ASTM C33, all of the coarse RCAs revealed gradations that were fairly satisfactory.
2. Improvement of recycle coarse aggregate RCA gradation in TDOT hindered workability and increase compressive and flexure strength.

3. using natural sand with different recycle coarse aggregate RCA gradation in TDOT improve the workability and increase slump results.
4. using black sand with different recycle coarse aggregate RCA gradation in TDOT hindered workability and decrease slump results.
5. At late ages (7 and 28 days), the gradation of RCAN3 and RCAB3 improvement in # 1" + 15% reduction in #4 +Reduction. 15% # 3/8" gradation S2, increased concrete compressive and flexure strength rather than 15% #1” improved gradation S1. Most of the RCA concrete mixes evaluated in this study met TDOT paving concrete standards with 28-day compressive strengths over 25 MPa.

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