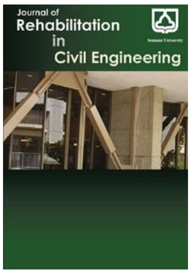
Journal of Rehabilitation in Civil Engineering 8-3 (2020) 158-170



journal homepage: http://civiljournal.semnan.ac.ir/

In Situ Strength Assessment of Concrete Using Recycled Aggregates by Means of Small Diameter Cores

S. Idriss Javadein[1], Rahmat Madandoust[2*], S. Mohammad Mirhosseini[1]

1. Department of Civil Engineering, Arak Branch, Islamic Azad University, Arak, Iran
2. Department of Civil Engineering, University of Guilan, P.O. Box 3756, Rasht, Iran

Corresponding author: *rmadandoust@guilan.ac.ir*

ARTICLE INFO

Article history:
Received: 18 November 2018
Accepted: 10 April 2020

Keywords:
Drilled cores,
Recycled concrete,
Mechanical properties,
Recycled aggregates.

ABSTRACT

By increasing the demolition of old concrete structures and the interest of civil industries to consume cheaper materials, using Recycled Concrete Aggregate (RCA) can cause environmental protection and decrease the construction costs. On the other hand, the high potential of Recycled Aggregate Concrete (RAC) in concrete industry was established by extensive experimental researches were performed to examine the properties of RAC. Like in conventional concrete, core test cut from RAC can be used to assess the in-place concrete compressive strength and sometimes it becomes an important test for monitoring in-situ properties of concrete to taking up retrofitting/strengthening measures. So the core test is often mentioned in most codes for concrete testing. The layout of this study includes four concrete mixes, two concrete grades (20 and 40 MPa), three core diameters (46, 69, and 100 mm), five length-to-diameter (L/D) ratios (1, 1.25, 1.5, 1.75, and 2), two sizes of maximum coarse recycled aggregates (10 and 20 mm), two directions of core drilling which are vertical and horizontal and three ages of specimen (14, 28 and 90 days). The core test results were compared to cylindrical and cube specimens. Results imply that the core strength of recycled concrete reduces with the increase in aspect ratio, by decreasing the core diameter, increasing the size of coarse aggregates in recycled concrete. By analyzing the results a comparison was made between recycled concrete in this study and conventional concrete in other studies, as well as code instructions.

1. Introduction

The demolition of old buildings to reconstruction them due to population growth has generated a large volume of Construction and Demolition Waste (CDW) all over the world. In Tehran, Over 20 million tons of CDW materials are produced annually [1].

DOI: 10.22075/JRCE.2020.16540.1310

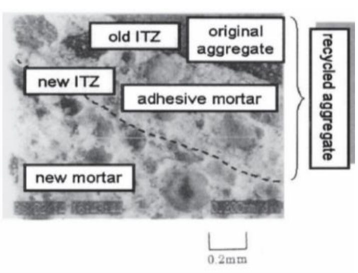
The expanding potential of Recycled Concrete Aggregate (RCA) for application in various projects with a low or moderate amount of initial changes has been experimented with numerous tests and approved by many researchers [2-6]. Substitution of Recycled Aggregate (RA) with natural aggregate was established to consider the properties of RCA in concrete production to achieve adequate fresh and hardened properties, comparable to those of Normal Concrete (NC). Kho Pin Verian et. al. [5] evaluate multiple techniques to improve the performance of RCA.

CDW reuse and recycle techniques are improving day by day and many solutions have been proposed in order to reuse them in concrete industries and recover raw materials consumption, reducing pollution of ecosystems, decreasing the environmental drawbacks linked to excessing use of natural resources and also inhibits the landfills of resting materials out coming of CDW [7].

Always the compressive strength of concrete is a preferable characteristic among many other properties of this material that require to hold specified applied forces for design considerations or taking up retrofitting/strengthening plans.

To achieve minimum required concrete quality, standard test specimens are evaluated during the constructions period. These concrete samples, which make a good estimation of concrete's potential strength, are fabricated, kept in standard curing conditions and examined according to related standards and codes. Sometimes it could be important to evaluate the in-situ strength of an active structure to estimate whether the mechanical and durability properties meet the requirements for its future utilization when the quality of concrete is under suspicion owing to overloading, fatigue (e.g. bridge structures, etc.), chemical destructions, fire or explosion and weathering or the structure is considered for a higher level of loading conditions and to plan the rehabilitation and retrofitting/strengthening of the building. For these kind of situations, the testing methods for in-situ strength assessment vary from non-destructive and destructive such as removing cores. The core test is the most practical and trust worthy technique to evaluate the mechanical properties of the concrete in place [8, 9].

The compressive strength of Recycled Aggregate Concrete (RAC) is influenced significantly to several factors related to the use of RA, such as size, type, RA replacement levels, moisture content, quality of the original material, water to cement ratio, use of admixtures and additions and age [10].



(a) (b)

Fig. 1. RAs in two sizes (20mm & 10mm) and graphical representation of the ITZ of RA [18].

A few investigations show no strength loss by incorporation of RCA [4, 11] but some studies indicate that when the replacement levels of RA increase, the compressive strength of concrete decreases gradually [10, 12-13]. However up to about 30% of coarse RA incorporation, there are no significant effects on the strength loss of RAC [13]. The influence of RA on mechanical and durability properties is reviewed by Kisku. N. et al. [2] and Guoliang Bai et. al [14]. Obviously, according to Fig.1.a. the adhered cement paste that consist about 30-35 % by volume of RCA make lower specific gravity, higher porosity and water absorption, higher angularity and rough surface texture, weak bond of RCA with the new cement paste that result lower density, workability, elasticity modulus and strength of

RAC [14-17]. Otsuki. et. al. [18] showed Interfacial Transition Zone (ITZ) of the RAC in graphical representation (Fig. 1.b). In addition, some of the ways to improve the microstructures of recycled aggregate have been well illustrated by Ruijun Wang et. al [19].

Although the most commonly used standard codes recommended the minimum core diameter of 100 mm [20- 23], in some cases, small diameter cores are selected because of drilling, handling and storing the specimens are easier and during the operation, makes lower possibility of cutting reinforcing bars and causing less damage to the structure [24-28]. Therefor testing in the larger area of concrete members by adequate number of small cores is possible.

Besides a few researches is reported some mechanical and durability properties of cores removed from RAC [28, 30], but the relationship between core strength and the corresponding standard sample analogous to normal concrete [8,22,27,31] that is influenced by some factors such as core diameter, length to diameter (L/D), direction of drilling, aggregate size, age and strength level of the concrete can be considered in RAC._It has been tried to study the effect of these factors on the strength of recycled aggregate concrete by means of small diameter cores.

2. Experimental Program

A comprehensive testing layout on cores extracted from concrete slabs made by RCA was considered to study on the impact of various parameters affecting the core test results and comparison with cylindrical and cube specimens' compressive strength. Parameters considered are as core length-to-diameter ratio (L/D), core diameter (D), direction of drilling, maximum size of aggregates, age of tests and compressive strength level of the concrete.

Table 1. Properties of aggregates.

Aggregate Size (mm)	Water Absorbsion, 24h (%)	Oven Dried Density (kg/m^3)	SSD Apparent Density (kg/m^3)
0-5 (Natural)	1.05	2550	2576
5-10 (RA)	6.27	2270	2412
10-20 (RA)	6.45	2310	2459

The fine natural aggregate used in this study was river sand in size 0-5 mm. The Fig.1.b shows the coarse recycle aggregates was used in two sizes 10mm and 20 mm that came from crushing of source concretes from concrete laboratories located in the Rasht city (target 28 days cube 20-25 MPa). Table 1 shows properties of aggregates.

The difference between water absorbsion and density in RA and NA is due to high porosity of the adhered old cement mortar that is attached to the natural aggregate.

However, concrete with similar grades has been used in this study, but some researcher such as Hansen et al. [32] reported that water absorbsion and density of RA did not depend on the grade of the original concrete.

Four different concrete mix designs were considered in this study by including two sizes of recycled coarse aggregates and two different classes of strength. Ordinary Portland cement type I with the specific gravity 3.15 cm2/g and specific surface area 3510 cm2/g, was used. Concrete mix proportions are given in Table 2. For mixing of concrete the Two Stages Mixing Approach (TSMA) that proposed by Tam et al. [33] is considered. In this approach, as shown in Fig 2, a thin layer of cement slurry covered the surface of recycled aggregates at the first stage and leads to filling up the micro cracks and voids in the old cement past. This process can improve the properties of concrete.

In this study prototypes of slabs and blocks were used for core sampling. The examined structural elements were1.0×1.0m-concrete slabs with specified thicknesses; 25 cm. The slabs were made of the two concrete strength classes mentioned above. Furthermore, concrete blocks having a cross-section of 40 × 40 cm and 40 cm height were constructed

Table 2. Concrete mixes used in this study.

	Mix Proportion(Kg/m^3)					
Mix	Coarse Agg.	Fine Agg.	Cement	Water	W/C	Slump (mm)
C*20A*20	950	790	350	230	0.66	73
C20A10	990	750	350	220	0.63	78
C40A20	950	790	430	195	0.45	58
C40A10	990	750	430	185	0.43	65

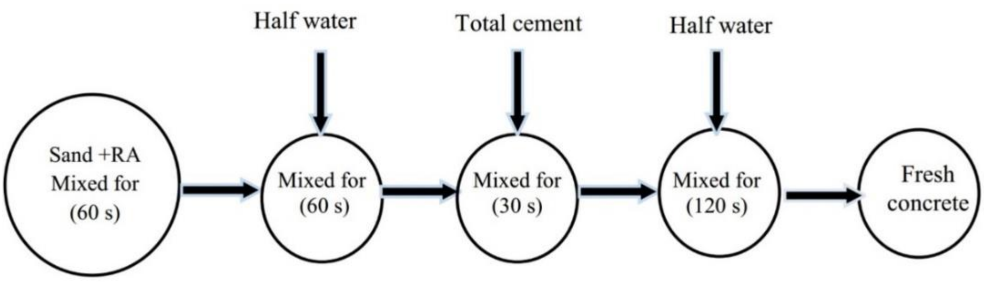


Fig. 2. Two stage mixing approach [33].

using two strength classes. Slabs and blocks were cast and cured in the laboratory condition simultaneously with corresponding 15 cm-standard cubes and three different diameters of cylinders including 50, 70 and 100 mm were introduced to evaluate the damage effect due to drilling. After hardening, cores with different diameters (46, 69 and 100 mm) were extracted from slabs and blocks with a diamond-tipped drill machine, then have cut and caped to give overall aspect ratios (L/D) between 1.0 and 2.0. The aspect ratios of cut core specimens were 1.0, 1.25, 1.5, 1.75 and 2.0. The compressive strengths of cores and other molded specimens were determined at comparable ages of 14, 28 and 90 days using an automatic compression testing machine. The loading rate for all specimens was 0.25 MPa/s as recommended by most codes. Each strength value reported is the average of at least three core or molded specimens.

A total number of about 600 cores in addition to 200 molded cubes and cylinders were examined in this study.

3. Results and Discussion

Test results for numerous drilled core specimens were obtained and analyzed to determine the effects of parameters on relations between core strength and compressive strength of corresponding similar sized cylindrical and cube specimens.

Table 3. Strength of 15 cm cube specimens (MPa).

Mix	The age of concrete			
	14 days	28 days	42 days	90 days
C20A20	17.6	24	26.5	27.6
C20A10	19.9	24.6	27.7	29.3
C40A20	33.8	45.1	48.6	50.7
C40A10	35	47.7	50	53.3

The extracted results are presented and similar studies were performed by other researchers on normal concretes which have useful data to comparison for these results [8, 24, 27]. The compressive strength of 15 cm cube specimens for several mix proportions is shown in table

3.1. Effect of Parameters on Core Strength

3.1.1. Effect of Length/Diameter Ratio (L/D)

Evaluating the effect of length to diameter ratio (L/D) for drilling core specimens, is an old research subject that has a prime value in determination of in situ concrete strength. Factors for strength correction of (L/D) ratio ($F_{L/D}$) are determined usually by Codes' given formulas or regression of experimental data [20, 22, 23]. The compressive strength of a core specimen with an (L/D) between 1 and 2 is specified either by experiments or conversion like is mentioned in common standards for the strength of a similar standard specimen with the ratio of 2. Increase of L/D ratio leads to decrease in measured strength which brings the possibility of inhibitory effect of supporting surfaces, shape and geometry of the specimen on stress distribution. This decrease is more pronounced in 46 mm diameter than the larger core diameters.

Figs. 3 and 4 explain the relation between aspect ratio (L/D) and correction factor ($F_{L/D}$) according to class of strength and core diameter compared with ACI and BS Codes and some studies. The figures obviously illustrate that the factor ($F_{L/D}$) is relatively more for higher class of concrete's strength.

As illustrated in Figs. 3 and 4, the coring results due to both effects of recycled aggregate weakness in bonding with new cementitious matrix as previously mentioned (weaker ITZ) and the more damage effect of Coring, lead to drastically lower results (especially in 46 mm) than other studies [8, 22-24].

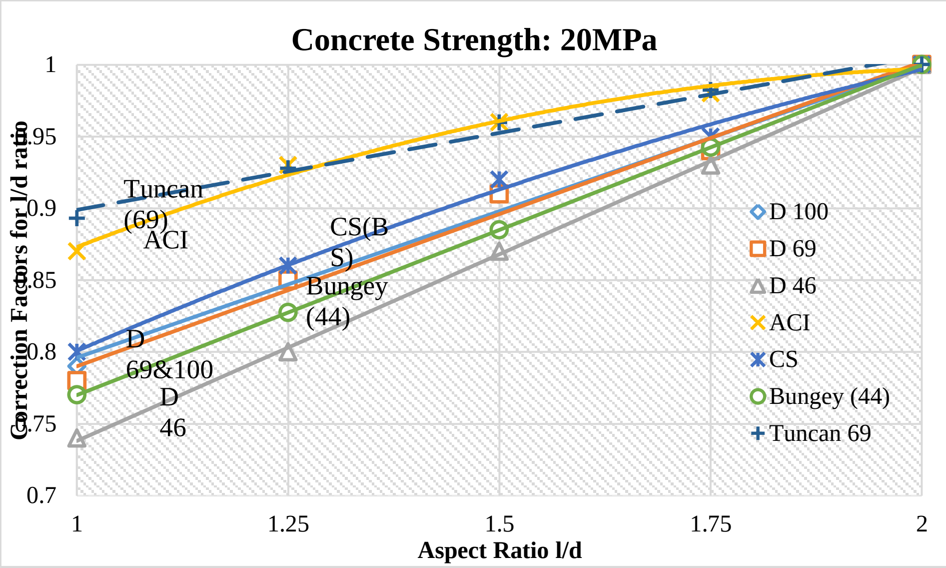


Fig. 3. Relation between correction factor $F_{l/d}$ and aspect ratio compared with ACI and BS Codes and some studies for Class C20.

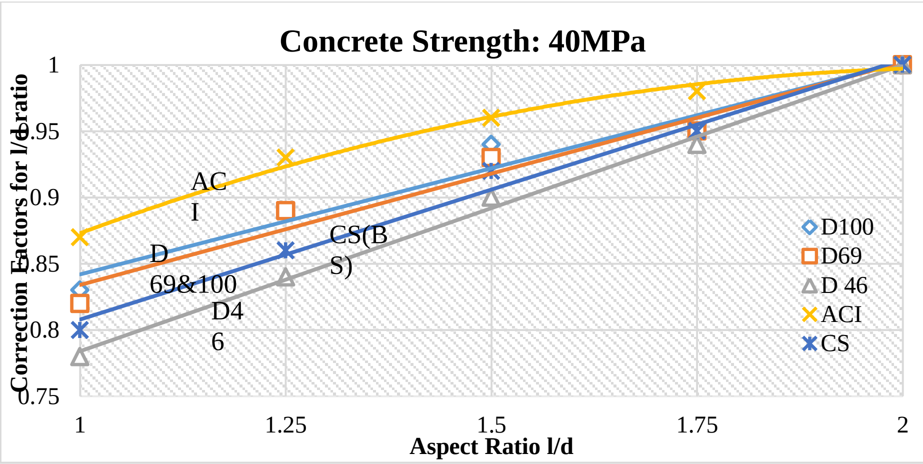


Fig. 4. Relation between correction factor $F_{l/d}$ and aspect ratio compared with ACI and BS Codes for Class C40.

The results of 69 and 100 cores are roughly the same and close to BS in low strength, and slightly higher in C40 class strength. The results of 46 mm core are different from the rest. It is even lower than the results of Bungey et al. [8] for 44 mm in low strength and almost the same in the higher strength.

3.1.2. Effect of Core Diameter (D)

The core diameter is a key player in determination of core strength results. It's a general rule that concrete strength decreases as the specimen diameter for cylindrical shapes increases. However, in the case of drilling cores, the inverse result is not odd. In the small cores, the probability of strength reduction due to increase the ratio of cut surface area to volume and any aggregate loosened by cutting and heterogeneity of material in the specimen will be increased [25, 34]. Fig. 5 shows the mean ratio between 46, 69 mm and 100 mm core strengths for different aspect ratios in two strength classes (C20 and C40). A general discussion could be that smaller diameters for cores have lower strengths. It was also found that this trend was not affected by ratios of L/D significantly. This strength reduction is also visible in Fig. 6 while the diameter of cores decreases.

Tuncan et al. [24] show that the relative strengths of 46 and 69 mm diameter cores with L/D=2, 28-day age and C20 strength target to standard cube specimens are 0.68 and 0.73 respectively while according to Fig. 6 these ratios are lower for RAC (0.6 and 0.69 respectively). Also, ACI 214.4-10 [31] suggested the strength correction factor equal to 1.06 to convert 50 mm core strength to 100 mm. This coefficient is 1.07 in Khoury. et.al investigations. These recommendations seem insufficient for RAC and it needs to be revised.

It is also clear from Fig. 6 that, at all sizes, the ratio of core strength to 15 cm cube in C40 class is lower than C20 at the same age. It should also be noted that this ratio increases as concrete became older. This means that RAC with higher strength is more vulnerable in coring operation, especially in the early ages.

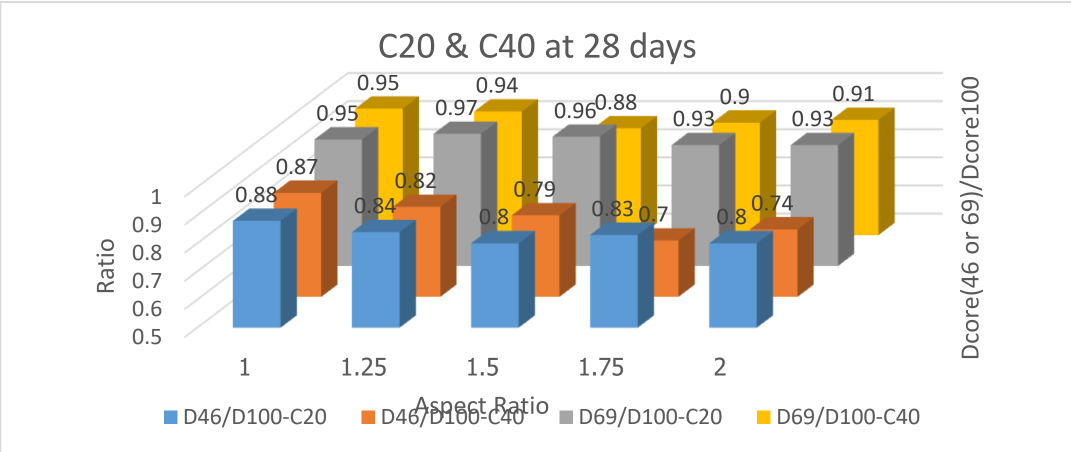


Fig. 5. Mean ratio between small cores and 100 mm core strengths for different aspect ratios, 28 days and two classes of strength.

3.1.3. Effect of Damage due to Drilling

The damage effect of coring of concrete is an inevitable phenomenon which decreases the apparent mechanical strength of cores compared to similar cylindrical specimens. This kind of damage, mostly happens because of the impact and pressure due to drilling and leads to micro cracks in concrete as shown in Fig.7. Literatures show [25, 34], by decreasing the core diameter the amount of damage increases and the corresponding strength will reduce. The current results for recycled concrete also demonstrate less than the similar results in normal concrete [25].

As it is obvious in Figs. 8 and 9, in two classes of strength, the specimens with smaller diameter and higher (L/D) ratio have lower strength in comparison to similar size cylindrical specimens.

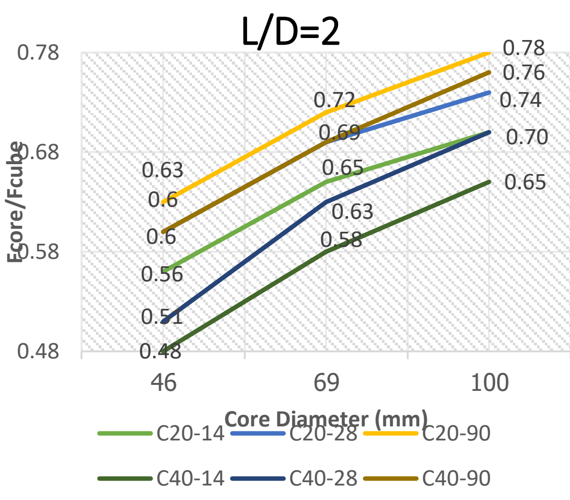


Fig. 6. Mean ratio between core and cubical specimens strengths for 14, 28 and 90 ages, L/D=2 and two classes of strength.

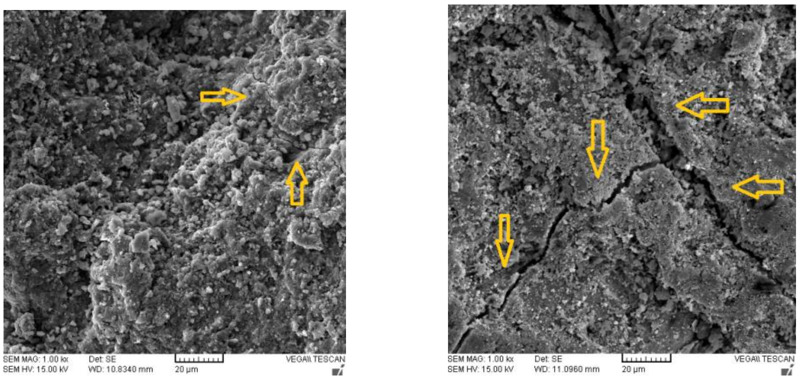


Fig. 7. Micro cracks in RAC due to cutting.

Although the effect of (L/D) ratio on core damage is not so noticeable, but the l/d ratio of 2 has a considerable difference with other ratios and reaches at least 80% and 74% for 46 mm core diameter in C20 and C40 respectively. Figs. 8 and 9 show the results of class C40 are similar to class C20 but the difference is slightly increased. This might be due to the further shear force applied to cutting RAC with higher strength that leads to more damage to the bonding of concrete components. Therefore, the results in Section 3.1.2 that stronger RAC is more vulnerable to coring operations are reaffirmed.

In contradictory the results obtained by Arioz et al. [35] and Khoury et al. [27] in NC that high strength cores have less damage during the drilling. Also, ACI 214.4-10 [31] and CEN-1998-3, [34], recommended constant coefficients (Fd) for damage due to drilling equal to 1.06 and 1.1 respectively.

These coefficients do not seem adequate for recycled concrete. These could increase to 1.15 and 1.25 depending on the class of strength.

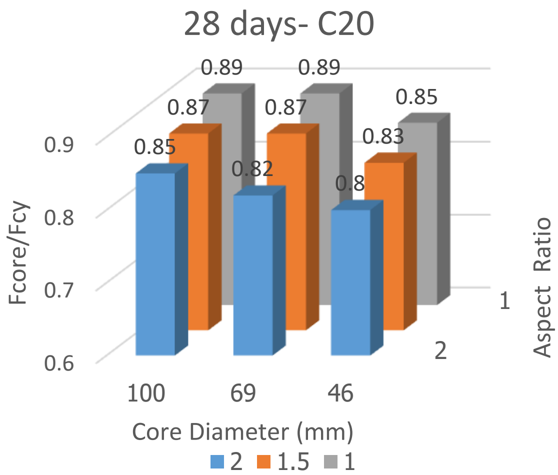


Fig. 8. Mean ratio between cylindrical and core specimen strengths for different aspect ratios and core diameters at the age of 28 days and C20 class of strength.

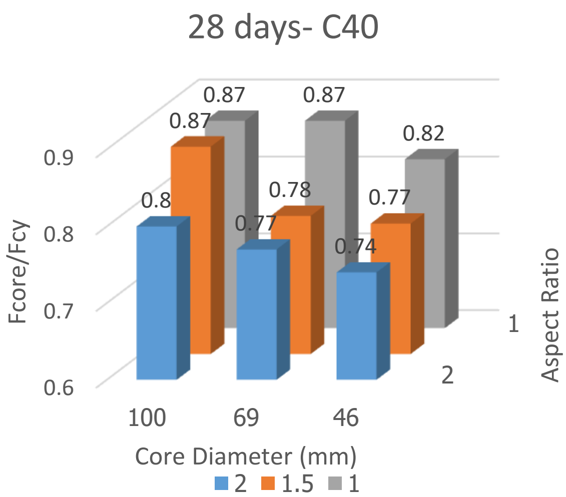


Fig. 9. Mean ratio between cylindrical and core specimen strengths for different aspect ratios and core diameters at the age of 28 days and C40 class of strength.

3.1.4. Effect of Coring Direction

Based on some researches [8, 27] vertically drilled cores (in the direction of placement and compaction) have higher strength than horizontally drilled cores (perpendicular to direction of placement) which one of the main reasons presented [37] is the water bleeding effect of concrete in fresh state that produce a plane of weakness in the bottom of the coarse aggregates that can be seen in Fig.10.

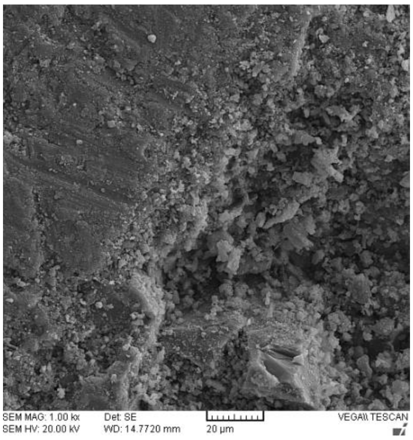


Fig. 10. Plane of weakness in the bottom of the aggregate.

When cores that are drilled perpendicular to direction of placement, the plane of weakness is parallel to the applied test load and it is expected that lower strength will be achieved [37]. Based on mean ratio between vertical and horizontal drilled core strengths for different ages and core diameters with L/D=2 and C20 class of strength (Fig. 11) by increasing core diameter, the difference between vertical and horizontal cores has been slightly higher and at the highest amount of parameters (100 mm core diameter at 14 days) 15% difference is observable. For C40 class of strength as illustrated in Fig.12, there is a similar trend, but some anomalies are traceable which mostly happen in 69 mm core.

Some documents considered a decrease in horizontally drilled core strength compared to vertically drilled core strength at around 8% in NC [20, 22, 27, 38]. Although this result can be used for cores from RC at 90 days, it is slightly low, especially for cores with 14 and 28 days and C20 class.

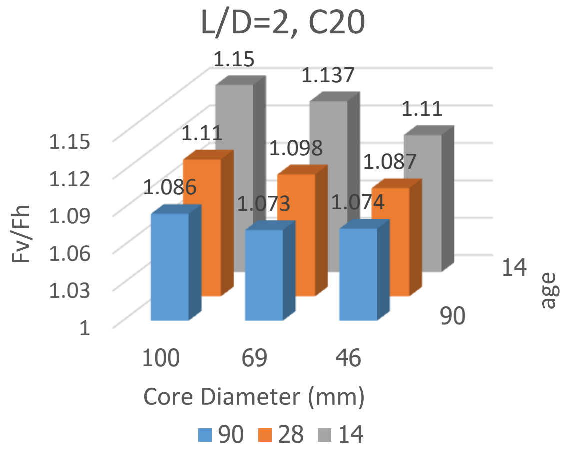


Fig. 11. Mean ratio between Vertical and horizontal drilled core strengths for different ages and core diameters with L/D=2 and C20 class of strength.

Also, a few researches indicate that the coring direction is not significant effect on the apparent strength of the core [23, 34].

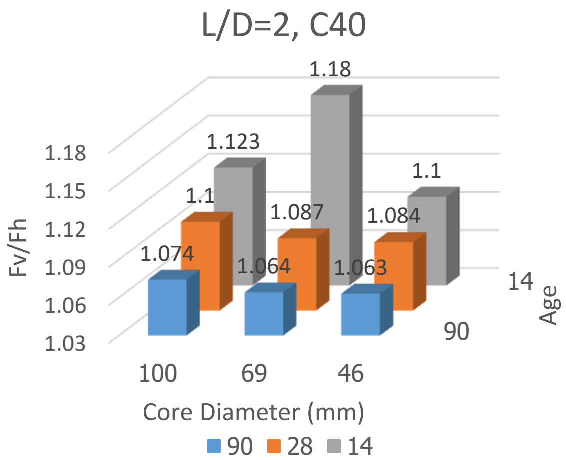


Fig. 12. Mean ratio between Vertical and horizontal drilled core strengths for different ages and core diameters with L/D=2 and C40 class of strength.

From Figs. 11 and 12, it is clear that at older age with smaller core diameters, the difference in strength between horizontally and vertically drilled core, gets less. It is possible that in the removing of cores with smaller diameters, fewer planes of weakness are subjected to the cutting load and at early ages the effect of bleeding water to the weakness of the ITZ is greater.

3.1.5 Effect of Aggregate Size

Fig.13 shows the mean ratio between the A20 and A10 class of aggregate core strengths for different aspect ratios and core diameters at the age of 28 days.

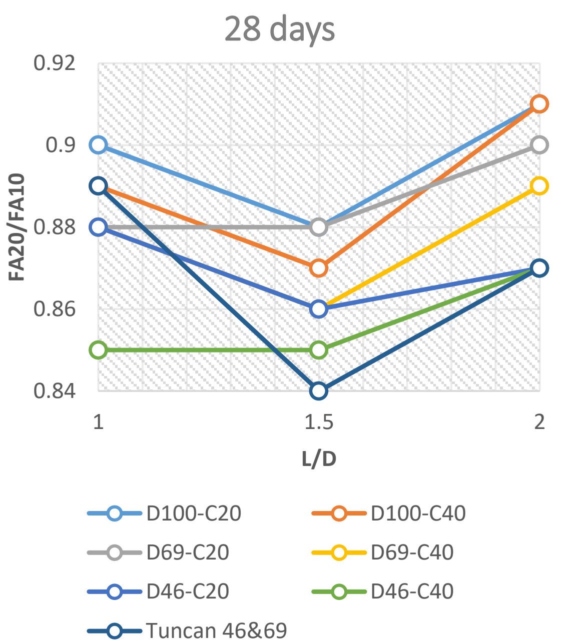


Fig. 13. Mean ratio between A20 and A10 class of aggregates core strengths for different aspect ratios and core diameters at the age of 28 days.

It could be seen by increasing the aggregate size, decreasing in strength is observable that results have ratios less than 1 in general. Some of researches have confirmed this [24, 35, 37]. It is explained that the water cement ratio in the ITZ around the larger coarse aggregate is higher than the fine aggregate and leading to decrease of concrete's strength [37]. Also, Fig.13 present that the relative strength is not dependent on the ratio of L/D and class of strength significantly, but also noted that as the core diameter increased the effect of aggregate size was lessened slightly.

4. Conclusions

Based on the experimental programs and tests performed in numerous core and molded specimens from RAC, the following results are concluded:

1. Recycled Aggregate Concrete has a high potential in the concrete industry for its perfect and near to normal concrete properties. The economical and environmentally friendly purposes, make RAC a great alternative candidate for usual constructions.

2. Core test as an old and trustworthy tool for obtaining real in situ compressive strength of concrete in structures by some correction factors as mentioned in many codes and upgrading them for recycled concrete could be used successfully.

3. Results show that the core compressive strength decreases more in comparison with NC by increasing in the core aspect ratio (L/D) and decreasing of core diameter. This is more pronounced in 46 mm diameter than the larger core diameters. It's slightly different for higher classes of strength. However, the correction factors for l/d ratio given by BS are closer to the results obtained in this study than ACI. As well as, strength correction factors to convert small core strength to 100 mm core that applied in NC, need to be revised for RAC.

4. By decreasing the core diameter, the scale of damage increases and the corresponding strength will reduce. The current results for recycled concrete also demonstrate less than the similar results in normal concrete. The L/D ratio of 2 has a considerable difference with other ratios and reaches as high as 26% for 46 mm core diameter and C40 class. It should also be noted that RAC with higher strength is more vulnerable in coring operation, especially in the early ages. In addition,

constant coefficients that recommended by some regulations for damage due to drilling (F_d) are not adequate for recycled concrete. They could increase to 1.15 and 1.25 depending on the class of strength.

5. Based on the mean ratio between vertical and horizontal drilled core strengths for different ages and core diameters in two classes of strength, by increasing the core diameter, the difference between vertical and horizontal cores gets more obvious. This trend decreases with the growth of the age. For a higher class of strength (C40), some anomalies are traceable which mostly happen in 69 mm core diameter. Also, difference between strength of horizontal and vertical cores taken from RAC has been slightly higher from 8% that some regulations and documents suggested especially in the early ages and C20 class.

6. By decreasing the aggregate size an apparent increase in strength is observable that the relative strength is not dependent on the ratio of L/D and class of strength significantly, but also noted that as the core diameter increased the effect of aggregate size was lessened slightly.

REFERENCES

[1] Naderpour, H., Rafiean, A.H. and Fakharian, P., 2018. Compressive strength prediction of environmentally friendly concrete using artificial neural networks. Journal of Building Engineering,16, pp.213-219, https://doi.org/10.1016/j.jobe.2018.01.007.

[2] Kisku. N, Joshi. H, Ansari. M, Panda. S.K, Sanket Nayak, Sekhar Chandra Dutta, (2017), A critical review and assessment for usage of recycled aggregate as sustainable construction material. Construction Building Material, Vol.131,721-740, https://doi.org/10.1016/j.conbuildmat.2016.11.029.

[3] Silva. R. V, Brito. J. D, Dhir. R. K, (2014) The influence of the use of recycled aggregates on the compressive strength of concrete: a review, European Journal of Environmental and Civil Engineering, Vol. 19, 825-849, https://dx.doi.org/10.1080/19648189.2014.974831.

[4] Brito. J. D, Ferriera. J, Pacheco. J, Soares. D, Guerreiro. M, (2016) Structural, material, mechanical and durability properties and behavior of recycled aggregate concrete. Journal of Building Engineering, Vol. 6, 1-16,https://dx.doi.org/10.1016/j.job.2016.02.003.

[5] Kho Pin Verian, Warda Ashraf, Yizheng Cao, (2018), Properties of recycled concrete aggregate and their influence in new concrete production, Resources, Conservation & Recycling, 133, 30- 49. http://doi.org/10.1016/j.resource.2018.02.005.

[6] Gholampour, A., Gandomi, A.H. and Ozbakkaloglu, T., 2017. New formulations for mechanical properties of recycled aggregate concrete using gene expression programming. Construction and Building Materials, 130, pp.122-145, https://dx.doi.org/10.1016/j.conbuildmat.2016.10.114.

[7] Castorina Silva Vieira, Pereira. Paulo M., (2014), Use of recycled construction and demolition material in geotechnical applications: A review, Resources, Conservation and Recycling, Vol.103, 192-204,https://dx.doi.org/10.1016/j.resconrec.2015.07.023.

[8] Bungey. J.H, Millard. S.G, Grantham. M.G, (2006), Testing of concrete in structure (4th edition), Taylor & Francis, London and New York.

[9] Neville. A (2001) Core tests – Easy to perform, not easy to interpret. Concrete International, Vol. 23(11), 59–68.

[10] Silva. R. V, Brito. J. D, Dhir. R. K, (2014), Properties and composition of recycled aggregate from construction and demolition waste suitable for concrete

production. Construction Building Material, Vol. 65,201-217,https://dx.doi.org/10.1016/j.conbuildmat.2014.04.117.

[11] Fonseca N, Brito. J. D, Evangelista L, (2011), The influence of curing conditions on the mechanical performance of concrete made with recycled concrete waste. Cement and Concrete Composites, Vol. 33(6), 637-43, https://doi:10.1016/j.cemconcomp.2011.04.002.

[12] Akbarnezhad, A, Ong. K. C. G., Zhang. M. H., Tam. C. T, Foo, T. W. J, (2011), Microwave assisted beneficiation of recycled concrete aggregates. Construction and Building Materials, Vol.25, 3469–3479, https://doi.org/10.1016/j.conbuildmat.2011.03.038.

[13] Dhir R. K, Paine K. A, (2004), Suitability and practicality of using coarse RCA in normal and high strength concrete. Paper presented at the 1st International Conference on Sustainable Construction: Waste Management, Singapore, 108–123.

[14] Guoliang. Bia, Chao Zho, Chao Liu, Biao Liu ,(2020), An evaluation of recycled aggregate characteristic and the recycled aggregate concrete mechanical properties. Construction and Building Material, 240, 117978,http://doi.org/10.1016/j.conbuildmat.2019.117978.

[15] Lima. C, Caggiano. A, Faella. C, Martinelli. E, Pepe. M, Realfonzo. R, (2013), Physical properties and mechanical behaviour of concrete made with recycled aggregates and fly ash. Construction Building Material, Vol.47,547–559,DOI: 10.1016/j.conbuildmat.2013. 04.051.

[16] Evangelista L, Bravo M, Agrela F, (2013), Influence of water reducing admixtures on the mechanical performance of recycled concrete. J Clean Prod., Vol.59, 93–98.

[17] Li. W.X, Zhang. X, Liu. X, (2009), Mechanical properties of recycled aggregate concrete. Study of the impact of factors. Chin Concr. J, Vol.10, 60–63.

[18] Otsuki. N, Miyazato. S, Yodsujai. W, (2003), influence of recycled aggregate on interfacial transition zone, strength, chloride penetration and carbonation of concrete, J. Mater. Civil Eng., Vol. 15(5), 443-45,https://doi.org/10.1061/(ASCE)0899-1561(2003)15:5(443)

[19] Ruijun Wang, Ningning Yu, Yang Li, (2020), Methods for improving the microstructure of recycled concrete aggregate: A review, Construction and Building Material, 242, 118164, http://doi.org/10.1016/j.conbuildmat.2019.118164.

[20] BS (1983) 1881: Part 120: Method for determination of the compressive strength of concrete cores. British Standards Institution, 8 pp.

[21] BS EN 12504-1(2009): Testing concrete in structures. Cored specimens. Taking, examining and testing in compression. British Standards Institution.

[22] Concrete Society (CS), (1987), Concrete core testing for strength. Tech. Rept.11, London.

[23] ASTM C42 (2012), Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete, Philadelphia: ASTM International.

[24] Tuncan. M, Arioz. O, Ramyar. K, Karasu. B, (2008), Assessing concrete strength by means of small diameter cores, Construction and Building Materials, Vol. 22,981–988,doi:10.1016/j.conbuildmat.2006.11.020.

[25] Bungey. J. H, (1979), Determining concrete strength by using small diameter cores. Mag. Concrete Research, Vol. 31(107), 91–98.

[26] Bartlett. F. M, MacGregor. JG, (1994), Effect of Core Length-to-Diameter Ratio on Concrete Core Strengths, ACI Materials Journal, Vol. 9 (4), 339-348.

[27] Khoury. S, Aliabdo. A, Ghazi. A, (2014), Reliability of core test- Critical assessment and proposed new approach, Alexandria Engineering Journal, Egypt, Vol.53,169-184, http://dx.doi.org/10.1016/j.aej.2013.12.005.

[28] Mostefa Kazemi, Rahmat Madandoust, Jorge de Brito, (2019), Compressive strength assessment of recycled aggregate concrete using schmidt rebound hammer and core testing, Construction and Building Material, 224, 630-638, http://doi.org/10.1016/j.conbuildmat.2019.07.110.

[29] Sadati. S, Khayat. K.H, (2016), Field performance of concrete pavement incorporating recycled concrete aggregate, Construction and Building Materials, Vol.126,691-700, https://dx.doi.org/ 10.1016/ j.conbuildmat.2016.09.087.

[30] Bonifazi. G, Palmieri. R, Serranti. S, (2016), Concrete drill core characterization finalized to optimal dismantling and aggregate recovery, Waste management, Vol.60, 301-310, doi: 10.1016/j.wasman.2016.10.008

[31] ACI Committee 214.4R-10 (2010): Guide for Obtaining Cores and Interpreting Compressive Strength Results. Farmington Hills: American Concrete Institute.

[32] Hansen. T. C, Henrik. N, (1983), strength of recycled concrete made from crushed concrete coarse aggregate, Concr. Int., Vol. 5(1), 79-83.

[33] Tam. V.W, Gao. X.F, Tam. C.M, (2005), Microstructural analysis of RAC produced from two- stage mixing approach, Cement Concrete Research, Vol.35 (6), 1195-1203, https://doi.org/10.1016/j.cemconres.2004.10.025.

[34] Bartlett. F.M, MacGregor. J.G, (1994), Effect of core diameter on concrete core strengths. ACI Mater. J., Vol. 91(5), 460–470.

[35] Arioz, O, K. Kamyar, M. Tuncan, A. Tuncan, I. Cil, (2007), Some Factors Influencing Effect of Core Diameter on Measured Concrete Compressing Strength. ACI Material Journal, Vol.104(3), 291-296.

[36] Comite Europeen de Normalisation (CEN), (2005), Design of structure, part 3: Assessment and retrofitting of building, EN1998-3.

[37] Mehta. P.K., Monteiro. J.M., (2014), Concrete Microstructure, Properties and Materials. New York: McGraw Hill Education.

[38] Munday, J.G.L, R. K. Dhir, (1984), Assessment of in situ concrete quality by core testing. American Concrete Institute.