CESARE'22

3rd Coordinating Engineering for Sustainability And Resilience
May 6th – May 9th, 2022, Irbid, Jordan
ISSN:2788-6204

CONCRETE WITH RECYCLED COARSE AGGREGATE UNDER THERMAL LOADS

Amin Almasri[1], Mohammad Nadeem Akhtar[2], Abdulsamee Halahla[3]

[1]Department of Civil Engineering, Jordan University of Science and Technology, Irbid, PO Box 22110, Jordan. On open leave at Fahad Bin Sultan University, Tabuk, PO Box 15700, Saudi Arabia.
e-mail: ahalmasri@just.edu.jo

[2]Department of Civil Engineering, Fahad Bin Sultan University, Tabuk, PO Box 15700, Saudi Arabia.

[3]Department of Civil Engineering, Palestine Polytechnic University, Hebron, Palestine.

Keywords: Recycled coarse aggregate; elevated temperature; compressive strength;

Abstract: *The goal of this study is to see how elevated temperatures affect the compressive strength of concrete made with recycled aggregate. Concrete samples from demolished buildings were obtained in Saudi Arabia from separate locations: Tabuk, Madina, Yanbu, and Riyadh. These concretes were crushed and turned into aggregates, which were then utilized to create new concrete samples. At ages 3 to 28 days, these samples were examined for axial compressive strength at room temperature. The compressive strength of the identical concrete mixtures was tested again after being exposed to a higher temperatures. The testing results show that recycled aggregate concrete samples have good quality at both ambient and elevated temperatures, and are comparable to natural aggregate concrete. However, at high temperatures, recycled aggregate concrete showed more strength deterioration than natural aggregate concrete, but the differences were not greater than 5% to 10%. Concrete samples built from recycled coarse aggregates met the design strength requirements as well. Given the wide range of temperature reactivity of concrete found in the literature, it can be regarded acceptable.*

1. INTRODUCTION

In the last two decades, billions of tons of demolished buildings waste have been generated worldwide. The main reason for generating such amounts of demolished waste is reaching the structure's end of life. Another reason for this could be the inadequate constructed structures. A building demolishing waste, recycled through reusing it as aggregate in concrete mixes, is a modern approach for reducing environmental pollution by reducing waste and conserving the aggregate natural reserve. It might also reduce the cost of new constructions in some cases even though the sources of good quality natural aggregate are considerably declining in some areas of the world. As a replacement for natural aggregate, the reuse of buildings waste is slowly implemented in the industry, despite large buildings' waste and significant changes in the available environmental regulations, such as the green building codes.

The recycled coarse aggregate has been used in the road industry for years but was implemented in buildings in limited cases. The experimental work carried out by [1] on replacing 100% recycled coarse aggregates in concrete found good strength characteristics. The study [2] on sustainable sand concrete made with recycled crushed fine aggregate showed good performance at an ambient and elevated temperature up to 300ºC. Reference [3] discloses the effect of recycled aggregate on compressive strength at different exposure conditions, with 20% recycled aggregate and treated wastewater as mixing water.

Although studies related to the usage of recycled coarse aggregate in concrete are numerous, limited experimental studies were found on long-term durability and recycled aggregate concrete under extreme conditions. It has been found that a detailed physical analysis of recycled concrete materials is not reported extensively. Also, the effects of high temperature on concrete performance made of recycled coarse material are minimal.

2. LITERATURE REVIEW

Many researchers have studied recycled aggregate utilization in concrete mixes as an alternative to natural aggregate due to this high demand. Many studies have shown that concrete made with recycled aggregate may have mechanical properties similar to that made with conventional natural aggregate [4, 5]. The recycled aggregate obtained from demolished concrete was angular, with a higher water absorption rate and higher specific gravity than natural coarse aggregate, and usually higher compressive strength [6]. Reference [7] carried out a study to evaluate the influence of demolished waste aggregate on the mechanical properties of concrete. A review of recent works of using recycled aggregate concrete is done by [8].

The constituent materials' properties positively influence the structural concrete response to fire, mainly the type and aggregate source used. Generally, it is believed that high temperature causes significant physical and chemical changes in concrete, such as smaller pores and increased calcium carbonate content [9]. Reference [10] observed that the weight of the concrete reduced significantly at temperatures above 800°C. Reference [11] studied the effect of high temperatures on the strength evolution of concrete made with natural aggregate at different ages.

Not too many researches had investigated the behavior of recycled aggregate concrete at high temperatures. Reference [12] made a review about research carried out on concrete with recycled materials after exposure to fire. They could only list few researches about recycled aggregate concrete at high temperatures. They recommended that more research is needed on this topic. Hence, the main goal of this research is to enhance the available limited knowledge concerning the compressive strength of concrete made with demolished concrete wastes as a substitute for natural aggregate under high temperatures. Table 1 reports the major studies on recycled concrete performance subjected to elevated temperatures. However, limited studies were found on 100% recycled coarse aggregate concrete subjected to elevated temperatures.

Table 1: major studies on concrete made by recycled aggregate exposed to elevated temperatures.

Study	Exposed Temperatures	Key Findings
[13]	0ºC, 50ºC, 100ºC, 200ºC, 300ºC, and 400ºC	The reduction of about 37% in strength was found in 100% recycled aggregate replacements with exposed temperatures of 300°C, with water to cement ratio of 0.6
[14]	25ºC, 200ºC, 400ºC, and 600ºC	The reduction of about 17% in strength was found in 100% recycled aggregate replacements with exposed temperatures of 200°C, compared to about 8% for normal concrete at the same elevated temperature. Water to cement ratio was 0.5
[15]	200ºC, 400ºC, 600ºC, and 800ºC	The reduction of about 20% in strength was found in 100% recycled aggregate replacements with exposed temperatures of 200°C, compared to about 6% for normal concrete at the same elevated temperature. Water to cement ratio was about 0.5
[16]	25ºC, 200ºC, 400ºC, 600ºC	The reduction of about 15% in strength was found in 100% recycled aggregate replacements with exposed temperatures of 200°C, compared to about 19% for normal concrete at the same elevated temperature. Water to cement ratio was 0.35
[17]	20ºC, 200ºC, 400ºC, 600ºC	The reduction of about 31% in strength was found in 100% recycled aggregate replacements with exposed temperatures of 200°C. Water to cement ratio was 0.43

3. METHODOLOGY

The present study collected demolished wastes from four different Saudi Arabia cities: Tabuk, Madina, Yanbu, and Riyadh. All demolished structures used in the study were commercial cum residential buildings, and the ages of buildings were estimated in the range of 20 to 25 years, where no written records were found in sites. Then, concrete cores were taken from these samples and tested for compressive strength. Besides, enough amounts of this old concrete were crushed to be used as aggregate for new concrete mixes. Physical properties were calculated for recycled aggregate since they are necessary for preparing the new concrete mixes. A control concrete sample of 100% natural coarse aggregate concrete has also been made. The design strength of all concrete mixes is 30 MPa, and the target strength is 38.5 MPa. The mixes were prepared by the absolute volume method. These prepared concrete samples were tested for axial compressive strength at 3, 7, 14, and 28 days at ambient temperature and elevated temperature of 300°C.

4. SAMPLE'S PREPARATION

4.1 CONCRETE CORING

Concrete cores are considered a semi-destructive method and are used to determine the strength of structures, such as the compressive strength, splitting tensile strength, and flexural strength of in-situ concrete. Selected samples from demolished buildings concrete from four cities mentioned earlier above were brought to Tabuk city. Core drill and saw were then used for drilling cores from specimens. The coring process was conducted at Independent Testing Laboratories of Soil and Foundation Ltd Co (Safco), Tabuk, Saudi Arabia. The coring process was done according to (ASTM-C-42/C-42M-04, 2004) standards [18]. The extracted cores were thoroughly inspected for cracks, delamination, deterioration, seepage, and corrosion. Three cuts have been made for each city sample.

Table 1 reports the dimensions of these cores. The core samples have different diameters because the demolished concrete collected from the different cities was not always big enough to take large cores. Core samples were then tested for uniaxial compressive strength (Fig. 1), and compressive strength results are also reported in Table 2. The acceptance criteria for core strength are to be established by the tester. Due to many factors, like the drilling process's destructive nature, core strength is less than the independent cast samples' strength. Some of the energy used to cut the samples could cause micro-cracks and bond weakening between cement matrix to aggregate surface in the core. The core test results are usually affected by many factors, such as the location of cores, orientation of cores, and the in-place temperature and moisture history. Hence, codes usually make corrections to core strength. According to the [19], the core test result can be used to calculate the in-place concrete strength using the formula:

$$f_c = F_{l/d} F_{dia} F_{mc} F_d f_{core} \tag{1}$$

where f_c is the equivalent in-place strength of demolished concrete samples

f_{core}: is the core strength

F_{dia}: diameter factor equals 1.06, 1.00, and 0.98 for a diameter of 50 mm, 100 mm, and 150 mm, respectively.

F_{mc}: Moisture condition factor, taken as 1 if standard treatment is followed.

F_d: Factor of damage sustained during drilling, including microcracking, which equals 1.06

$F_{l/d}$: length-to-diameter ratio factor, can be calculated from the equation:

$$F_{l/d} = 1 - \{0.130 - 0.00043 f_{core}\} \left(2 - \frac{l}{d}\right)^2 \tag{2}$$

Where l is the capped length of the core, d is the diameter of the core. These formulae are used to obtain the equivalent in-place strength, which is presented in Table 2.

The average equivalent in-place concrete strength ranges from 29.34 MPa (Yanbu samples) to 33.88 MPa (Tabuk samples). Assuming these concretes' target strength was 28 MPa or 30 MPa, which is a common practice in these cities, these core samples are considered achieving the standards, which requires the average strength of cores to be higher than 85% of specified strength (25.5 MPa). No individual sample is less than 75% of specified strength (22.5 MPa). It shall be noted that Yanbu city, which has the lowest core strength, is very humid, especially in the summer semester. Madina and Riyadh cities suffer high temperatures in the summer, but without humidity like that in Yanbu. Among the four cities, Tabuk has the most moderate climate. It could affect the strength of the concrete samples collected from these cities, but unfortunately, this cannot be determined since these concretes were made independently.

Figure 1: Concrete cores after testing.

Table 2: Cores tests data.

Sample No.	Length before capping (mm)	Length after capping (mm)	Average diameter (mm)	Uncorrected failure load (kN)	Uncorrected Stress (MPa)	Diameter factor F_{dia}	length-to-diameter ratio factor $F_{l/d}$	Equivalent in-place strength f_c	Average in-place strength
Tabuk 1	112.0	115.0	69.00	113.74	30.42	1.025	0.987	32.62	33.88
Tabuk 2	112.0	115.0	69.00	123.77	33.10	1.025	0.987	35.50	
Tabuk 3	112.0	115.0	69.00	116.9	31.26	1.025	0.987	33.53	
Madina 1	89.0	92.2	69.00	124.24	33.23	1.025	0.949	34.26	30.71
Madina 2	96.0	99.0	69.00	96.15	25.71	1.025	0.962	26.88	
Madina 3	90.0	93.0	69.00	112.21	30.01	1.025	0.950	30.98	
Yanbu 1	90.0	102.0	94.00	217.1	31.28	1.007	0.902	30.13	29.34
Yanbu 2	100.0	112.0	94.00	222.4	32.05	1.007	0.924	31.61	
Yanbu 3	40.0	52.0	94.00	225.7	32.52	1.007	0.757	26.28	
Riyadh 1	148.5	154.0	99.60	257	32.99	1.00	0.976	34.13	31.59
Riyadh 2	138.5	145.0	99.60	216	27.72	1.00	0.965	28.36	
Riyadh 3	158.3	163.0	99.60	241	30.93	1.00	0.985	32.28	

4.2 RECYCLING CONCRETE INTO AGGREGATE

Next step, demolished concrete obtained from the four cities was crushed into coarse aggregate. The specific gravity, water absorption rate, fineness modulus, bulk density, crushing value, and abrasion resistance for these aggregates were measured to compare these recycled aggregate physical properties with natural aggregate. The physical properties of natural and recycled aggregate are listed in Table 3. Specific gravity for the recycled aggregate is very close to that of the natural aggregate. Water absorption is much higher for recycled aggregate (around 7% to 8.7%) than natural aggregate (around 1%). It should be taken into account when design concrete mix is prepared for recycled aggregate. The fineness modulus shows no significant differences between samples. Bulk density also shows no significant differences, except for Madina concrete, which is significantly lower than the others. Also, Madina concrete aggregate shows a higher crushing value of 19% than other samples (between 8% and 11%). Abrasion resistance for all recycled aggregate samples is close to each other (between 20.7% and 22.4%) and slightly higher than natural aggregate (17.1%).

ISSN:2788-6204

Table 3: Physical properties of natural and recycled aggregate.

Properties	Natural aggregate	Tabuk	Madina	Yanbu	Riyadh
Specific gravity	2.806	2.695	2.720	2.788	2.722
Water absorption (%)	0.958	7.240	6.955	8.688	7.312
Fineness Modulus	7.680	7.880	8.668	9.535	7.958
Bulk Density (ton/m^3)	2.833	2.748	2.440	2.800	2.775
Crushing Value (%)	8.0	9.0	19.0	11.0	8.9
Abrasion Resistance (%)	17.10	22.20	20.720	22.50	22.422

Besides, sieve analysis was done for the recycled aggregate and the natural aggregate. The results of particle distribution are plotted in Fig. 2. The distribution shows that Madina, Yanbu, and Riyadh aggregate distribution is identical, and the three of them are a bit coarser than Tabuk aggregate. All four samples of recycled aggregate are also a bit more courses than natural aggregate particle distribution. However, the differences can be considered negligible. The distributions are well graded, covering all significant sizes for the concrete mix, with no size gaps, which is considered acceptable.

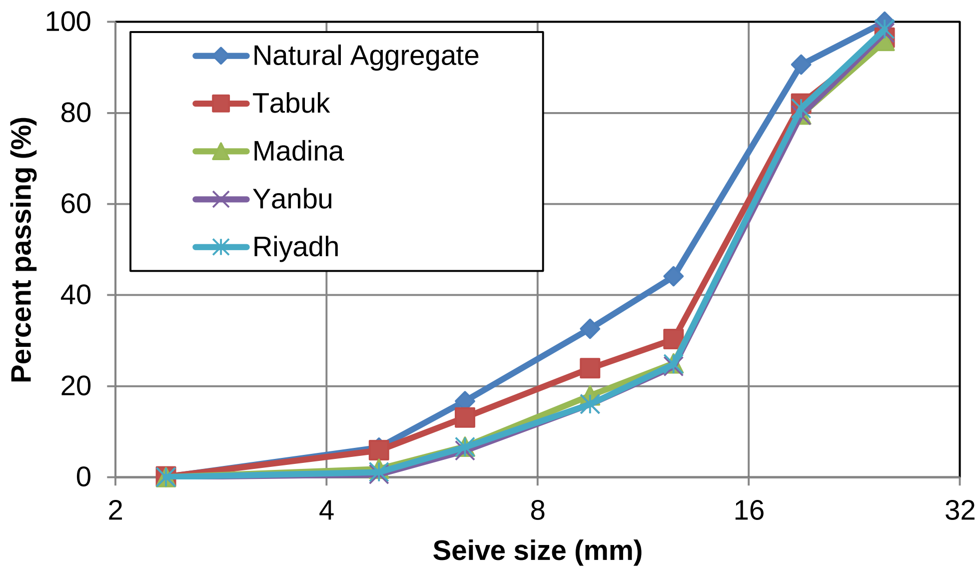

Figure 2: Particle size distribution of aggregate samples.

4.3 NEW CONCRETE SAMPLES

The recycled aggregate was used as a coarse aggregate to produce new concrete mixes, compared with natural aggregate concrete. The target strength is to produce 38 MPa concrete after 28 days of curing. Locally available ordinary Portland cement (type 1) was used in all samples. Fine dune sand is used as fine aggregate in the mixes for both natural and recycled aggregate concrete. No fine recycled aggregate was used in this study. Any impurities in both fine and coarse aggregate were removed by screening, sieving, and washing. Recycled aggregate with a diameter of less than 5 mm was discarded. No admixtures or additives were used in the study.

Five concrete mixes were prepared, four from recycled aggregate and one with natural aggregate to serve as a reference sample. The absolute volume method was used to prepare the design mix proportions for target characteristic compressive strength of 38 MPa. The mix proportions are: 460 kg/m3 cement, 762 kg/m3 fine aggregate, 1056 kg/m3 coarse aggregate, and 216 kg/m3 water. Aggregate sizes of 19 mm, 12.5 mm, and 9.5 mm were used in the mixes.

Demolished ones replaced only coarse aggregate with a volumetric replacement ratio of 1(9.5 mm): 2(12.5 mm): 3(19 mm). To substitute for the high-water absorption of recycled aggregate, about 8 % extra water was used in the recycled aggregate concrete mixes. Concrete cylinders having 75 mm diameter and 150 mm height were prepared from these mixes.

5. RESULTS AND DISCUSSION

Specimens were tested at normal room temperature to evaluate concrete's compressive strength at 3, 7, 14, and 28 days after casting. The test results are shown in Fig. 3, along with the results of the core tests. Samples of Tabuk aggregate showed the highest final strength (about 45.6 MPa) at 28 days, which is expected because the core tests also showed the strongest recycled aggregate. It is noticed that Madina's new concrete mix achieved about 40 MPa, which is about 12% less than other samples. The different things about Madina aggregate compared with other cities samples are the higher crushing value and lower density, which could mean less quality materials, which could be the reason for this discrepancy. So, the core test cannot be considered a good initial indicator for the new concrete mixes' final strength. One interesting notice is that the early strength at 3 days for Tabuk, Yanbu, and Riyadh samples (32 MPa, 32.5 MPa, and 31.7 MPa, respectively) was significantly higher than the natural aggregate sample (29.5 MPa). It could indicate an expedited chemical reaction and strength gain in recycled concrete mixes. Only Madina's sample strength was less than natural aggregate sample strength, but at all ages and not only at an early age. It can be attributed to the high bonding strength between the recycled coarse aggregate and surrounding paste due to the recycled aggregate's angularity and the residual cementation on the demolished aggregate's surface. The deviation of test results is considered acceptable.

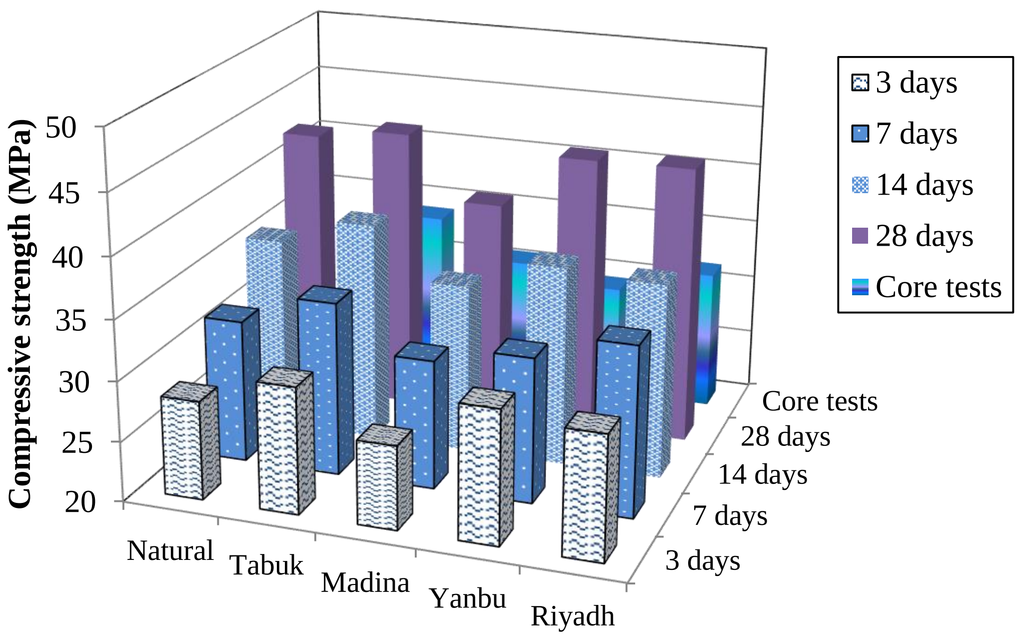

Figure 3: Concrete strength with natural and recycled aggregate at ambient temperature.

The high temperature usually causes aggregate damage; weakening of the cement paste-aggregate bond; weakening of the cement paste due to increased porosity on dehydration; the partial breakdown of the calcium silicate hydrate (the main product of cement hydration), and development of cracking.

Samples from the same previous concrete mixes were thermally treated. They were subjected to a temperature of 300ºC for two hours and then left to cool down. The next day they were tested for compressive strength. The results are illustrated in Figure. 4. It can be seen that all recycled aggregate concrete mixes show lower residual strength compared with a natural aggregate mix, after thermal loading, at all ages. It is expected since recycled aggregate mixes contain more cement content (from original crushed concrete) than natural aggregate mixes. Cement is the binding material in concrete, and it is more susceptible to damage due to high degrees of temperatures than natural aggregate particles. Unlike the samples tested at room temperature, which showed higher early strength (at 3 days) in recycled aggregate mixes, high temperature retards the early strength gain in recycled aggregate mixes compared with a natural aggregate mix.

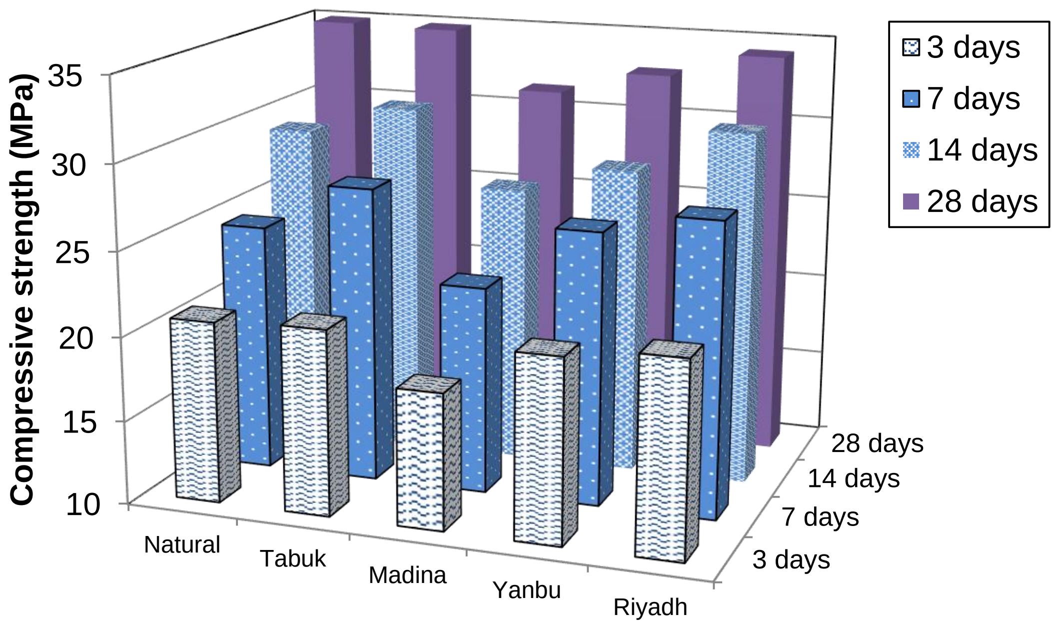

Figure 4: Concrete strength with natural and recycled aggregate at 300ºC temperature.

Figure 5 shows the loss in concrete compressive strength at different ages due to 300ºC temperature. For both recycled aggregate and natural aggregate mixes, it is seen that the loss percentage in strength is higher at early stages, ranging between about 27% and 33% loss in strength at 3 days. The loss decreases with increasing age. At age 28 days, the loss is 17% to 24%. Similar behaviour and values in percentage loss in compressive strength was seen by researchers listed in Table [1].

Figure 6 shows the effect of high temperatures on concrete compressive strength. References [20] and [21] collected so much experimental data in various research for natural aggregate concrete mixes and set an upper and lower limit for these data. These limits are presented in the Figure. Limits in [20] are a bit lower than the limits of [21], but the difference is acceptable. As shown, current study results lie within limits. In addition, they are above the mean of the experimentally collected data [20]. The design curve for natural carbonate aggregate concrete, with the unstressed sample extracted from (ACI-216.1M-07) [22], is also drawn in the Figure, along with the curve from (EN1992 Eurocode 2) [23]. Current study results are also above the ACI design curve. Although all current samples comply with ACI requirements, the recycled aggregate samples suffer higher degradation in strength (5% to 10% less strength than a natural aggregate mix). T indicates that recycled aggregate concrete under high temperatures should be used with caution if prepared using code design curves. However, Eurocode only allows a 10% reduction in compressive strength at 300ºC, so current samples do not comply with Eurocode.

ISSN:2788-6204

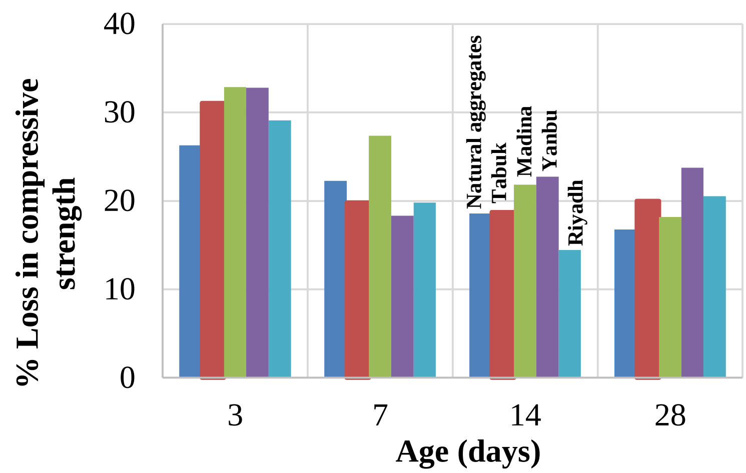

Figure 5: Loss in concrete compressive strength at different ages due to 300ºC temperature.

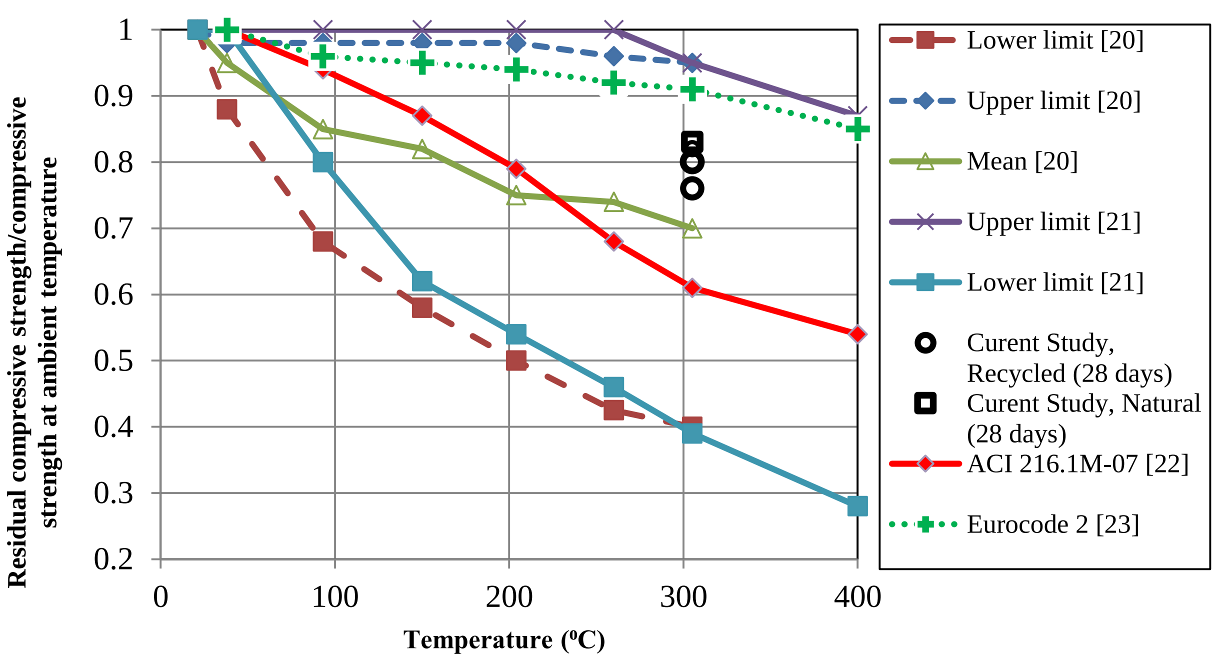

Figure 6: Effect of temperature on concrete compressive strength made with natural aggregate.

6. CONCLUSIONS

This research used recycled coarse aggregate formed from old concrete gathered from four separate areas to replace all natural coarse aggregate. At normal and increased temperatures of 300°C, the compressive strength of concrete specimens constructed from natural coarse aggregate and recycled coarse aggregate was tested. The following conclusions are drawn from the test results and discussions:

1. Recycled aggregate has a higher water absorption rate than natural aggregates, so it should be used in the design mix instead.

2. The high crushing value and abrasion resistance of recycled aggregate can be a direct indication of lower strength concrete.
3. At room temperature, the evolution of strength in recycled aggregate concrete is similar to that of natural aggregate concrete.
4. When concrete is exposed to high temperatures, it loses a significant percentage of its strength early on, which is more noticeable in recycled aggregate concrete than natural aggregate concrete. The percent loss in concrete strength owing to high temperature is smaller in late-aged concrete than in early-aged concrete. However, as compared to natural aggregate concrete, recycled aggregate concrete has a larger loss.
5. The current study samples meet the ACI code requirements but not the Eurocode requirements. It demonstrates significant discrepancies in the requirements of several codes for concrete in high temperatures.
6. When compared to regular aggregate concrete, recycled aggregate concrete has a good resistance to strength degradation due to thermal stress, only about 5% to 10% lower in value.

FUNDING STATEMENT

The authors received no specific funding for this study. Laboratories of Fahad Bin Sultan University and Abdin Construction Co. Ltd were utilized.

REFERENCES

[1] Halahla, A. M., Akhtar, M., & Almasri, A. H. (2019). Utilization of Demolished Waste as Coarse Aggregate in Concrete. *Civil Engineering Journal, 5*(3), 540-551.
[2] Akhtar, M. N., Ibrahim, Z., Bunnori, N. M., Jameel, M., Tarannum, N., et al. (2021). Performance of sustainable sand concrete at ambient and elevated temperature: Elsevier.
[3] Ahmed, S., Alhoubi, Y., Elmesalami, N., Yehia, S., & Abed, F. Effect of recycled aggregates and treated wastewater on concrete subjected to different exposure conditions. *Construction and Building Materials, 266*, 120930.
[4] Etxeberria, M., Vázquez, E., Marí, A., & Barra, M. (2007). Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete. *Cement and concrete research, 37*(5), 735-742.
[5] McNeil, K., & Kang, T. H.-K. (2013). Recycled concrete aggregates: A review. *International journal of concrete structures and materials, 7*(1), 61-69.
[6] Ramadevi, K., & Chitra, R. (2017). Concrete using recycled aggregates. *International Journal of Civil Engineering and Technology, 8*(9), 413-419.
[7] Akhtar, J., & Akhtar, M. (2014). Enhancement in properties of concrete with demolished waste aggregate. *GE-International Journal of Engineering Research, 2*(9), 73-83.
[8] Ibrahim, Y. E. (2019). Durability and Structural Performance of Recycled Aggregate Concrete: a Review. International Review of Civil Engineering. *10*(3), 135-141.
[9] Panedpojaman, P., & Tonnayopas, D. (2018). Rebound hammer test to estimate compressive strength of heat exposed concrete. *Construction and Building Materials, 172*, 387-395.
[10] Arioz, O. (2007). Effects of elevated temperatures on properties of concrete. *Fire safety journal, 42*(8), 516-522.
[11] Raheem, A. A., Olowu, O., Awe, E., Ebokaiwe, G., Akinniyi, I., et al. (2015). Assessment of Post Fire Structural Strengths of Normal Strength Concrete Subjected to Cyclic Thermal Loadings. *Civil and Environmental Research, 7*(9), 75-83.
[12] Cree, D., Green, M., & Noumowé, A. (2013). Residual strength of concrete containing recycled materials after exposure to fire: A review. *Construction and Building Materials, 45*, 208-223.
[13] Adebakin Idowu, H., & Ipaye Tajudeen, O. (2016). Effect of Elevated Temperature on the Compressive Strength of Recycled Aggregate Concrete. *Research Journal of Engineering Sciences E-ISSN, 2278*, 9472.
[14] Salahuddin, H., Nawaz, A., Maqsoom, A., & Mehmood, T. (2019). Effects of elevated temperature on performance of recycled coarse aggregate concrete. *Construction and Building Materials, 202*, 415-425.

[15] Wang, J., Xie, J., He, J., Sun, M., Yang, J., et al. (2020). Combined use of silica fume and steel fibre to improve fracture properties of recycled aggregate concrete exposed to elevated temperature. *Journal of Material Cycles and Waste Management*, 1-16.
[16] Guo, Y.-c., Zhang, J.-h., Chen, G.-m., & Xie, Z.-h. Y. (2014). Compressive behaviour of concrete structures incorporating recycled concrete aggregates, rubber crumb and reinforced with steel fibre, subjected to elevated temperatures. *Journal of Cleaner Production, 72*, 193-203.
[17] Tang, Y., Feng, W., Feng, W., Chen, J., Bao, D., et al. (2020). Compressive properties of rubber-modified recycled aggregate concrete subjected to elevated temperatures. *Construction and Building Materials*, 121181.
[18] ASTM-C-42/C-42M-04. (2004). Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete.
[19] ACI-214.4R-03. (2013). Guide for obtaining cores and interpreting compressive strength results, American Concrete Institute, Farmington Hills, Michigan.
[20] Kassir, M., Bandyopadhyay, K., & Reich, M. (1996). Thermal degradation of concrete in the temperature range from ambient to 315 {degree} C (600 {degree} F). Revision 10/96: Brookhaven National Lab., Upton, NY (United States).
[21] Freskakis, G. N., Burrow, R., & Debbas, E. (1979). Strength properties of concrete at elevated temperatures: Burns and Roe.
[22] ACI-216.1M-07. (2007). Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction.
[23] Narayanan, R. (2001). *EN1992 Eurocode 2: Design of concrete structures.* Paper presented at the Proceedings of the Institution of Civil Engineers-Civil Engineering.