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The Effect of Recycled Coarse Aggregate and Industrial Wastes on the Compressive Strength at Normal and Elevated Temperatures

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Abstract

In this paper, Silica Fumes (SF) and Fly Ash (FA) resulted from industrial wastes and Recycled Aggregate Concrete (RAC) was used as partially replacement materials instead of ordinary cement and natural aggregate (NA) respectively. The effect of water/cement ratio (W/C), FA%, SF%, RAC% and temperature on the concrete compressive strength have been studied. Two SF % (5 %and 10%), one FA% (35%) and three RAC % (10%, 20% and 30%) have been used. The obtained compressive strength results reveal that, the highest values of the concrete compressive strength were 12.3 % and 7.8 % for concrete mixes casted with 30% RAC over that casted with NA only at 25 ºC and 400 ºC respectively. The replacement of cement by 5% SF increased the concrete compressive strength increasing the ratio of cement replacement from 5% to 10% SF or using 35% FA decreased the concrete compressive strength. The concrete compressive strength for concrete mix casted with 20 % RAC and 10% SF tested at room temperature increased by 23% over that casted with 10% SF and NA while the concrete compressive strength for concrete mix casted with 10 % RAC and 10% SF and tested at 400 ºC increased by 21.1% over that casted with 10% SF and NA.

Keywords: recycled aggregate; waste; replacement; compressive strength; silica fume; fly ash

INTRODUCTION

In the earlier years, the properties of the recycled aggregates and the effects of their combination in concrete have been studied [1–5]. From these studies, it was found that the concrete properties highly influenced by the source of recycled aggregates. A percentage of approximately 15–35% decreasing in the mechanical properties of recycled aggregate concrete compared to the conventional concrete was found. This may be attributed to the high porosity of the outer layers of the crushed concrete particles [4].

Recycled aggregate and plastic waste has been used as replacement materials or filler in concrete. The possibility to use plastic waste, recycled crushed glass, mineral additives, crushed seashells and rice husk in concretes or mortars was studied by several researchers [6–14]. Remadnia et al. [15] studied the use of animal proteins as foaming agent in cementitious concrete composites manufactured with recycled Polyethylene Terephthalate (PET) aggregates. The obtained results showing that, the substitution of sand by the same volume of PET aggregates clearly increases the workability of the mortar. On the other hand, the use of PET particles and proteinic admixture affected greatly the porosity, mechanical properties and bulk density of the composites.

Pešic et al. [16] studied the mechanical properties of concrete reinforced with recycled High-Density Polyethylene (HDPE) plastic fibers in structural concrete. Seven series of specimens were used to study the mechanical and serviceability properties of concrete. Different fibers diameter and volume fraction of fibers were used. The results of this study showed no effect on the compressive strength and the elastic modulus of concrete. On contrary, tensile strength and flexural modulus were slightly increased by 3% and 14% in the presence of HDPE fibers. The obtained results recommend that recycled HDPE fibers can be used in construction industry.

Christian et al. [17] investigated the ability of using Peruvian Scallop Crushed Seashell (CSS) as fine aggregate in concrete. The obtained results showed that the effect of CSS replacement on concrete properties depends on the size particle distribution of the global aggregate after replacement. On the other hand, for CSS with particle size ranging between 1.19 to 4.75 mm, the maximum replacement ratio of 40% can be suggested while 5% can be considered optimum for all cases. The durability of pervious concrete with or without the crushed seashells was also studied [10]. Crushed seashells were used with 60% by mass from the natural aggregates to create shell pervious concrete. The shell pervious concrete experienced lower freeze-thaw resistance than the control pervious concrete. Moreover, pervious concrete with and without crushed shells can be used in low traffic load with sound durability.

The effect of Rice husk ash (RHA) in high strength concrete containing micro silica as a partial replacement of cement was also recently studied [18]. From the test results it was found that the water absorption decreased to reach 3 % at 28 days for concrete mixtures with 25% RHA. The tensile and compressive strengths of concrete increased with cement replacement by RHA up to 25% afterwards, it decreased. Furthermore, in [19] the effect the closed-loop recycling of recycled concrete aggregates on concrete tensile and compressive strengths was studied. The obtained results reveal that the slump of normal concrete was higher than that of first and second generation concrete (RCA and R-RCA). The compressive and tensile strength of concrete incorporating RCA and R-RCA was lower than that of normal concrete. Besides, the strength of R-RCA is higher than that RCA. The effect of elevated temperature on the concrete properties was studied elsewhere [20-23]. In [21], the fire resistance of Normal Strength Concrete (NSC) and High Strength Concrete (HSC) was examined. The obtained results specified that mechanical strength of NSC and HSC decreased in a similar manner at temperature ranged between 400 and 800 °C. Finally the use of combination of RAC and SF was studied elsewhere [24-27]. The results generally assured that the concrete compressive strength decreased as the RAC increased while increasing with the incorporation of SF.

Although there were several studies discussing the effect of RAC on concrete properties, studding the effect of the combination between SF, FA and RAC as replacement materials at elevated temperature is still limited. In this paper, the ability of using the recycled aggregate and industrial wastes as replacement materials in concrete is studied. Silica fume and fly ash are partially used as replacement materials instead of cement with different percentages. The normal aggregate is replaced with recycled aggregate by different percentages. The concrete compressive test and slump test are performed for studied concrete mixes. Then, the effect of elevated temperature on the concrete compressive strength is also evaluated. The results are recorded and briefly explained.

EXPERIMENTAL PROGRAM

Material properties

The Coarse aggregate is crushed basalt stones with MNS of 19 mm while the fine aggregate is natural sand. Sieve analysis tests were performed to obtain the grading curves of Coarse and fine aggregates, see Fig. 1. The Physical properties of Natural and Recycled aggregate is shown in Table 1. The Recycled Aggregate Concrete (RAC) with MNS =19 mm was used as partial replacement of Natural Coarse Aggregate (NCA). The recycled aggregate concrete grading curve was prepared to be compatible with the ACI specification as shown in Fig. 1.The fineness modulus of fine aggregate obtained from the sieve analysis is 2.86. Ordinary Portland cement is used to cast all mixes. The fly ash and silica fume are obtained from Saudi Company for Chemical Industries. The chemical and physical properties of cement and silica fume according to supplier are shown in Table 2.

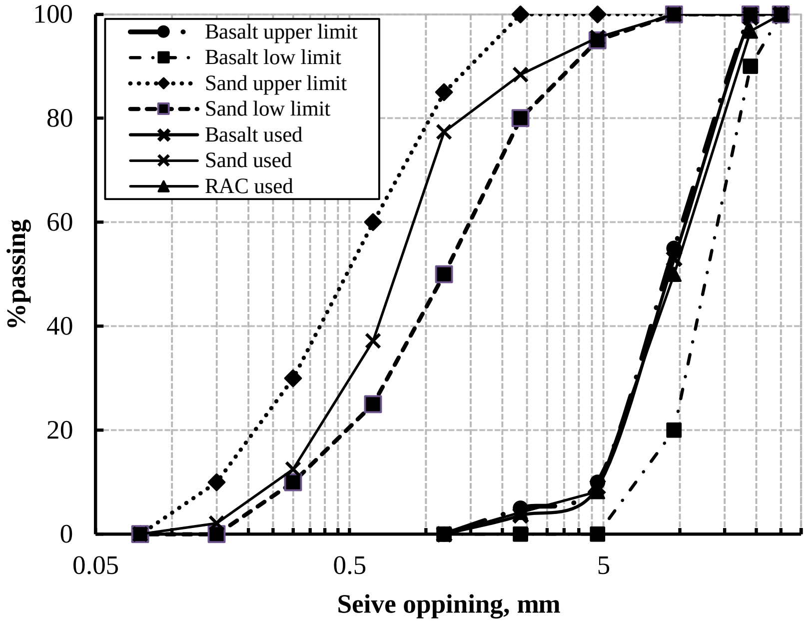


Figure 1: Sieve analysis for NCA, RAC and sand.

Table 1: Physical properties of Natural and Recycled aggregate

Properties	Specific bulk Density (EN 1097-6) (kg/m3)	Water absorption (EN 1097-6) (%)	Fineness module (EN 933-1) (-)
NA	1875	1.102	6.35
RCA	2452	5.312	6.32

Table 2: Physical and chemical properties of Portland cement, Silica Fume and Fly Ash

Material	Chemical properties							Physical properties			
	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	Na_2O	Specific Surface	Compressive strength (N/mm^2)		
								(m^2 / kg)	3 d	7 d	28 d
Portland Cement	63.13	20.07	5.23	3.77	2.53	2.77	0.49	363	21.3	28.4	35.5
Silica Fume	0.20	87.4	0.29	0.94	0.36	5.12	0.52	23000	-	-	-
Fly Ash	2.5	57.6	24.8	6.5	1.3	0.6	0.62	2140	-	-	-

Specimens details and tests

Cubes specimens 100 mm edges were casted and tested. The water- cement contents were adjusted by two ways, the first one depending on a constant slump ranged between 50 to 70 mm using trials. The water cement ratio was changed according to the mix components. Slump test was performed for each concrete mix. The final W/C ratio used to keep the slump ranged between 50 to 70 mm as reported in Table 3. In the other way, water content is kept constant, i.e. W/C = 0.60**.** The details of the concrete mix components are illustrated in Table 3. All concrete mixes were casted with 300 kg/m^3cementitious content. The cement was partially replaced by weight with two percentages 5 and 10 % of silica fume and one percentage 35 % of fly ash. On the other hand, the natural aggregate was also partially replaced by crashed recycled concrete with three percentages 10%, 20% and 30 %. The casted cubes was de-molded after 24 hrs and cured in water till 28 days. To study the effect of elevated temperature on the residual compressive strength of concrete, four cubes from selected casted concrete mixes were heated to 400 and 600 ºC. The cubes were placed inside the kiln until the heat reached to the desired temperatures (400 or 600 ºC) then the cubes kept in these temperatures for 2 hrs. Afterwards, the kiln is turned off and opened leaving the cubes to slowly cooling inside it for 24 hrs. Then, the cubes are tested in compression. The concrete compressive test was performed for all the tested cubes at 28 days using concrete compression test machine according to UNE-EN 12390-3:2003 [28].

Table 3: Combination of the concrete mixes.

Name	Cement, kg	Sand, kg	NCA, k g	RAC%	SF%	FA%	$(W/C)_1$	$(W/C)_2$
R00	300	787 natural sand with FM= 2.86	1020	0	Non	Non	0.67	0.60
R10			918	102			0.77	
R20			816	204			0.77	
R30			714	306			0.77	
R00F35	195		1020	0		35%	0.67	
R10F35			918	102			0.77	
R20F35			816	204			0.77	
R30F35			714	306			0.77	
R00S05	285		1020	0	5%	Non	0.77	
R10S05			918	102			0.77	
R20S05			816	204			0.77	
R30S05			714	306			--	
R00S10	270		1020	0	10%		0.77	
R10S10			918	102			0.77	
R20S10			816	204			--	
R30S10			714	306			--	

RESULTS AND DISCUSSIONS

In this section, the effect of different components of concrete on the concrete compressive strength (f_{cu}) has been discussed. The effect of three percentages of RAC (10%, 20 % and 30 %) on the concrete compressive strength and water absorption has been explained. In addition, the effect of fly ash and silica fume on the concrete compressive strength has been also discussed. Moreover, the effect of the combination between RAC and FA or SF on the concrete compressive strength has been clarified and compared. The previous factors have been discussed for the two water contents $(W/C)_1$ and $(W/C)_2$ as shown in Table 4. On the other hand, the effect of elevated temperature on the casted cubes has been studied.

Table 4: The results of compressive strength for the casted concrete mixes.

Name	$(W/C)_1$			$(W/C)_2$		
	f_{cu}, MPa	f_{cu}, Mpa	f_{cu}, Mpa	f_{cu}, MPa	f_{cu}, Mpa	f_{cu}, Mpa
	T= 25 ºC	T= 400 ºC	T= 600 ºC	T= 25 ºC	T= 400 ºC	T= 600 ºC
R00	36.8	38.0	31.5	42.1	46.2	40.7
R10	33.8	34.7	25.1	36.4	34.6	30.7
R20	31.7	32.2	23.2	46.4	44.6	33.4
R30	27	30.4	21.4	47.3	49.7	23.7
R00F35	19	22.6	16.8	28	35.2	25.3
R10F35	21.7	22.8	18.2	33.4	37.3	29.0
R20F35	16.2	16.9	12.7	34.9	44.1	33.4
R30F35	16.9	18.2	14.9	18.6	36.2	26.8
R00S05	22.3	24.8	19.5	44.4	45.2	36.0
R10S05	29.2	31.4	23.1	41.9	45.4	43.3
R20S05	25.1	30.4	23.2	43.8	47.1	T
R30S05	-	-	-	43.0	42.2	39.9
R00S10	20.4	23.7	16.1	39.3	43.6	34.9
R10S10	19.3	20.8	17.6	45.8	53.6	T
R20S10	-	-	-	47.6	49.1	40.3
R30S10	-	-	-	45.1	38.6	32.1

T = the cubes were destroyed when heated to heat more than 400 ºC

Effect of W/C ratio

From Table 4, it is clear that the concrete compressive strength increased as the W/C decreased for the corresponding concrete mixes. For mixes incorporating FA and RAC, the highest value of increase for f_{cu} was 217% for concrete mix R20F35 as W/C ratio reduced from 0.77 to 0.60. On the other hand, for mixes incorporating SF and RAC, Reducing W/C ratio from 0.77 to 0.60 increased the concrete compressive strength by 143% and 200% for concrete mixes R10S05 and R00S05 respectively. The W/C ratio had to effect on the compressive strength of concrete when heated to 400 ºC and 600 ºC, see Table 4. All concrete mixes heated to 400 ºC (tested after cooling in air to room temperature, RM) experienced higher values of concrete compressive strength than that tested without heating. On contrast, all concrete mixes heated to 600 ºC (tested after cooling in air to RM) experienced lower values of concrete compressive strength than that tested without heating, see Table 4. In the following section the effect of RAC, SF and Fly ash on concrete compressive strength at normal and elevated temperature for concrete mixes casted with constant W/C ratio will be discussed in details.

Effect of Cement Replacement by SF and FA.

Fig. 2 shows the effect of cement replacement by SF and FA on f_{cu} at different temperatures. The replacement of cement by 5% SF increased the concrete compressive strength compared to the corresponding mixes casted with Portland cement only. Moreover, increasing the ratio of cement replacement from 5% to 10% SF decreased the concrete compressive strength (Fig. 2). On the other hand, replacement of cement by 35% FA decreased the value of f_{cu} to lower level than concrete mix incorporating silica fume, see Fig. 2. This approved the chemical effect of SF as it contains higher values of SiO_2 and specific surface than FA and cement. In addition, the cubes casted from concrete mixes incorporating SF and FA and heated to 400 °C (tested at RT) experienced higher values of f_{cu} than the correspond cubes tested without heating. The higher difference in f_{cu} between the two previous conditions (cubes heated to 400 °C and that without heating) was observed for cubes incorporating FA. This may be due to the effect of heating on accelerating the hydration of FA. On contrast, the cubes heated to 600 °C experienced lower values of f_{cu} than the corresponding cubes heated to 400 °C and that tested without heating, see Fig. 2.

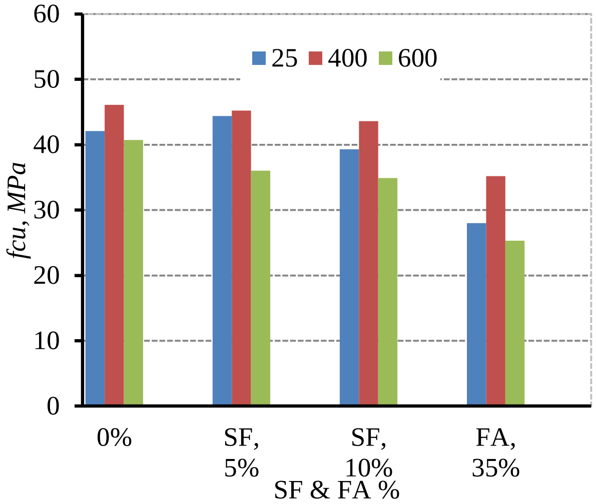
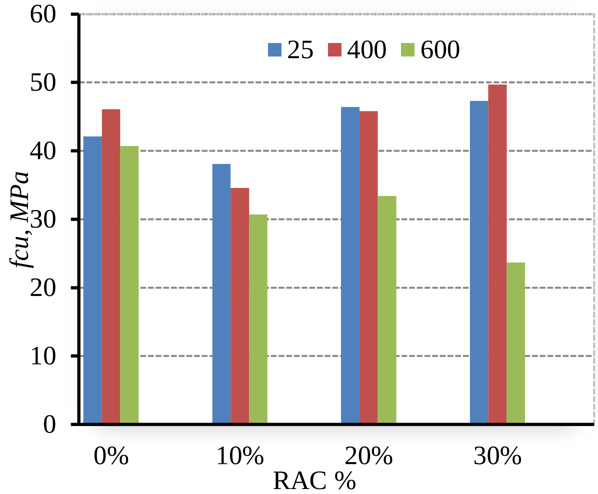


Figure 2: The effect of cement replacement by SF and FA on f_{cu} at different temperature.

Effect of NA replacement by RAC

The effect of partial replacement of natural aggregate by recycled aggregate concrete on the concrete compressive strength at different temperatures is shown in Fig. 3. From the figure, for it was illustrated that as the percentage of RAC increased from 10% to 30 % the concrete compressive strength increased. Only the value of f_{cu} for concrete mixes casted with 10% RAC was lower than that casted with NA only. The results reported in [24-27] concluded that as the value of RAC increased the compressive strength of the tested concrete mix decreased. This difference may be due to the dissimilar RAC sources or the RAC replacement ratio. In this work the RAC replacement ratios are ranged between 10 and 30% while in [24-27] the RAC replacement ratios was more than 30% except one case of 25% RAC in [27]. The highest values of the concrete compressive strength were 12.3 % and 7.8 % for concrete mixes casted with 30% RAC over that casted with NA only at 25 °C and 400 °C respectively. These results encourage the use of RAC as partially replacement coarse aggregate in concrete to reduce cost and decrease the use of natural aggregate as well as get rid of recycled concrete. Finally, heating the concrete incorporating RAC greatly decreased the value of f_{cu} than that casted with NA only. These observations assured that the concrete with NA is more durable than that with RAC at high temperature levels.



Figue 3: The effect of NA replacement by RAC on f_{cu} at different temperatures.

Effect of the combination between RAC and SF or FA replacement

The effect of RAC and (SF) on the concrete compressive strength and that of RAC and FA is shown in Fig. 4. From the figure the concrete mixes incorporating RAC and SF experienced higher values of f_{cu} than that casted with RAC and FA. The combination of SF and RAC increased the concrete compressive as reported also in [24-27]. This observation reveals the chemical effect of SF on enhancing the bonding among concrete components. The highest obtained value for concrete compressive strength at RT was 23% for concrete mix casted with 20 % RAC and 10% SF over that casted with 10% SF and NA, see Fig 4b. Meanwhile, the highest value of increase for concrete compressive strength at 400 °C was 21.1% for concrete mix casted with 10 % RAC and 10% SF over that casted with 10% SF and NA, see Fig 4b.

The concrete compressive strength was increased by the replacement of natural coarse aggregate with 10% and 20% RAC compared to that casted with natural coarse aggregate only in case of cement replacement by 10% SF and 35% FA (Fig. 4b and c). Moreover, concrete incorporating FA or combination of RAC and FA heated to 400 °C experienced higher concrete strength than that tested without heating. On contrast, for concrete incorporating RAC and FA, the obtained concrete strengths after heating to 600 °C were lower than that tested without heating. Cracks appeared on the concrete cubes after heating to 600 °C for specimens incorporating SF and RAC while others like R10S10 destroyed inside the kiln.

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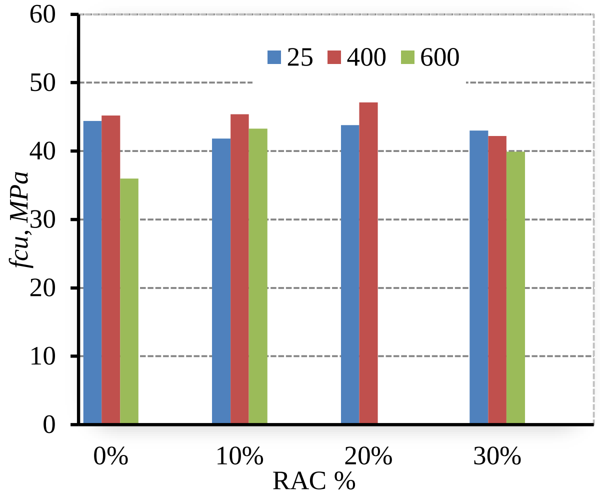
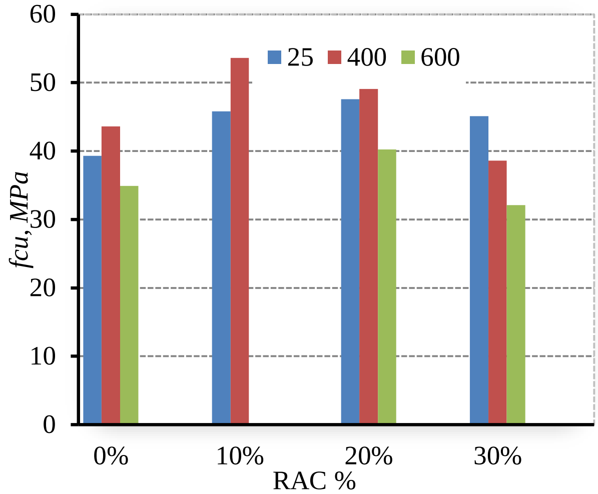
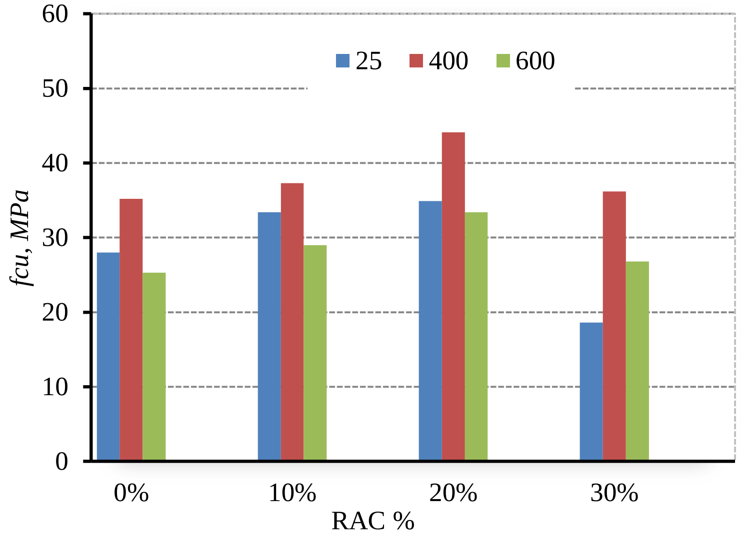


(a) At SF= 5%



(b) At SF= 10%



(c) At FA= 35%

Figure 4: The Effect of the combination of RAC, SF and FA replacement on f_{cu} at different temperatures.

CONCLUSIONS

In this paper, Silica Fume and Fly Ash have been used as replacement materials instead of cement with different percentages. The original aggregate is replaced with recycled aggregate by 10%, 20% and 30%. The water contents were adjusted by two ways, the first W/C ratio depended on a constant slump ranged between 50 to 70 mm. The other, W/C is kept constant and equal to 0.60. The casted cubes were heated to 400 and 600 ºC and slowly cooling to room temperature to study the effect of elevated temperature on the residual compressive strength of concrete. From the test results the following conclusions were obtained:

- The highest values of increase for concrete compressive strength obtained when reducing W/C ratio from 0.77 to 0.60 were 175% and 217% for concrete mixes R30 and R20F35 respectively.
- The replacement of cement by 5% SF increased the concrete compressive strength compared to the corresponding mixes casted with Portland cement only. Moreover, increasing the ratio of cement replacement from 5% to 10% SF decreased the concrete compressive strength. On the other hand, replacement of cement by 35% FA decreased the value of the concrete compressive strength to lower level than concrete mix incorporating silica fume.
- As the RAC% increased from 10% to 30 % the concrete compressive strength increased except mixes with 10% RAC experienced concrete compressive strength lower than that casted with NA only. The highest values of the concrete compressive

strength were 12.3 % and 7.8 % for concrete mixes casted with 30% RAC over that casted with NA only at 25 ºC and 400 ºC respectively.

- The concrete mixes incorporating RAC and SF experienced higher values of concrete compressive strength than that casted with RAC and FA. The highest obtained value for concrete compressive strength at RT was 23% for concrete mix casted with 20 % RAC and 10% SF over that casted with 10% SF and NA. Meanwhile, the highest value of increase for concrete compressive strength at 400 ºC was 21.1% for concrete mix casted with 10 % RAC and 10% SF over that casted with 10% SF and NA.

FUTURE WORK

The effect of elevated temperature on the concrete properties casted with and without industrial and aggregate wastes will be studied. The food residuals, Coal ash resulting from the burning wood will be used in concrete with and with recycled aggregates. Also the effect of elevated temperature on the properties of concrete containing Coal ash and food residuals will be studied.

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