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The Impact of Rice Husks Ash on Some Mechanical Features of Reactive Powder Concrete with High Sulfate Content in Fine Aggregate

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Abstract – *The sulfate issue in fine aggregate grows with time and it is not easy to gain a fine aggregate with sulfates amount within the specifications of Iraqi standard. Internal sulfate attack is regarded as a significant problem in concrete construction in Iraq and the Middle East countries. One of the modern generations in ultra-high performance concrete is Reactive powder Concrete (RPC) that has been prepared for cemented materials using microstructure improvement methods. RPC has gained attention from both academia and engineering fields with extensive applications. This study presents an experimental research on the impact of Rice Husks Ash (RHA) as replacement percentage of cement upon some mechanical features of RPC with high sulfate content in fine aggregate (Three percentages of SO_3 = 0.16, 0.5 and 1.2%). Three percentages of RHA (0, 10 and 15%) as a partial substitution of cement weight have been used in this research. The compressive and the flexural strengths have been adopted to attain the impact of adding RHA. The outcomes have showed that the incorporation of RHA has an important influence on the compressive-strength for both with and without internally sulfate attacking. The result has indicated that using 10% of RHA as a partial cement substitution has increased the effectiveness of RPC by its mechanical features (compressive and flexural-strengths) without internal sulfate attacked.*

***Keywords**: Compressive Strength, Flexural Strength, Internal Sulfate Attack, Reactive Powder Concrete (RPC), Rice Husks Ash (RHA)*

Nomenclature

M	SO_3 in fine aggregate [%]
N	SO_3 in the used natural gypsum [%]
R	Acceptable SO_3 in fine aggregate [%]
RPC	Reactive Powder Concrete
RHA	Rice Husks Ash
S	Weight of fine aggregate [kg]
W	Required natural gypsum [kg]

I. Introduction

Both the high compressive and the flexural strengths of Reactive Powder Concrete (RPC) promote a wide range of applications in construction management as structure elements, architecture design and works as materials of finishing or defensive elements in interior decorating work, in request for tanks of liquid, military buildings or even nuclear reactor requirements [1].

Richard and Cheyrezy first established reactive powder concrete, and RPC was first created by researchers at Bouygues' lab in France in the early 1990s. On the Pedestrian/Bikeway Bridge in Sherbrooke, Quebec, Canada, an RPC field application was carried out. For the 1999 Nova Awards from the Building Innovation Forum, RPC was nominated. RPC was extensively utilized in Europe in order to separate and contain radioactive waste attributable to its exceptional impermeability. RPC has been engineered in order to achieve high strengths of flexural and compressive (40-60) and (120-180) MPa, respectively [2]-[4]. The RPC manufacturing process includes two required limits like a collection of appropriate elements and curing type [5].

As the coarse aggregates have been withdrawn, the water cemented content proportion has decreased. In the RPC, the CaO to SiO_2 ratio has been lowered by the addition of the silica components and the combination of steel micro-fibres [6]. The activity of sulphates on concrete is probably the most prevalent and popular type of chemical attack. Sulphate attacks have been one of the most frequent aggressive actions that contribute to concrete deterioration. The ions of sulphate from an externally source typically penetrate the concrete, leading to an increase in expansive ettringite being formed later by their reaction with cement alumina. Calcium silicates can also be targeted with thaumasite formation under certain situations [7]. The deterioration of cement by sulfate attack is well known [8]. The internal sulphate attack results from a reaction between sulphate in cement, fine and coarse aggregates and concrete or cement paste containing calcium-aluminate (C3A) and water in order to create calcium-sulphoaluminate. The

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danger is demonstrated in the components that lead to high tensile stresses that lead to concrete disruption and expansion. The potency of sulphates has decreased with fine aggregate fineness improved [9], this research [9] has suggested a solution to take into consideration the efficacy of sulphates in fine aggregates based on their fineness modulus. The sulphate amount in fine aggregate is greater than the reasonable limits in many other fine aggregates in Countries of the Middle East [10]. The increase in sulfate concentration in fine aggregate increasing the rate of sulfate attack [9]. However, at a low percentage of sulfate, the strength increases with the increase in sulfate amount up to an optimum value of sulfate content, after which the strength of concrete begins to decrease gradually [9].

Due to the considerable stresses caused, the presence of sulfates in the fine aggregate might be dangerous to the concrete structure.

This dangerous impact has been proved by a greater decrease in compressive strength at an early age. With time, this decrease will rise if the sulphate amount is high [11].

Al-Salihi has detected that increasing the sulphate amount in fine aggregate has affected the strengths of flexural and compressive, and the dimensional changes of concrete. It has been concluded that the activity of sulfates in a concrete mix on its features depends on the sulfates behaviour constituents [12]. The impact of sulphate amount depends on the granular size of gravel, sand, and cement. The smaller the material's particle size is the more it suffers from sulphate within it. Hence, it is preferred to adopt the Iraqi requirement for maximum possible sulphate, since it gives greater freedom for using gravel and sand with greater sulfate level. Results of 90 days have demonstrated that compressive-strength of high strength concrete affected by maximum possible SO_3 level (3.424, 2.992, 2.647)% corresponding to total sulphate (4.528, 3.294, 3.778)% decreases compressive-strength by (14.59, 11.44,7.53)% respectively [13].

Additionally, the use of cement in the production of RPC has many negative environmental issues such as the high CO_2 emissions [14], [15] that are estimated to be around 7% [16]. Therefore, the significance of this investigation is to realize the impact of internal sand sulfates (0.16%, 0.50% and 1.20%) on some mechanical features of RPC by using natural gypsum as a preplacement to fine aggregate and RHA to replace partially the cement (0, 10 and 15%) by cement weight.

The samples of concrete have been identified at the age of 7, 28 and 90 days for strength of compressive and flexural.

This paper has been structured as follows. The materials properties, the mixing proportions and the details of the conducted tests have been presented in Section II. The results of the investigated parameters along with discussion of the findings are presented in Section III. Eventually, the conclusion of this research along with some recommendations for future works can be seen in Section IV.

II. Experimental Program

II.1. Materials

Portland cement (Ordinary kind I) manufactured in Iraq brand of (KARASTA) has been used in this research. Iraqi requirement [IQS 5-1984] and the EN 197-1:2011 CEM II/A-L 42.5 R, the international standards [17], have been followed. Throughout this research, the natural sand supplied from Al-Ekhaider has been utilized as the fine aggregate with distribution of particle size around 150-600 μm. Silica fume is a waste material produced from the Silicon metals and from Ferrosilicon alloys in the oven with electric arc. Table I shows the physical features and the chemical analysis of the applied silica fume associated with the specifications of ASTM C1240 [18]. The applied micro fibers (steel) have length=1.3 cm and diameter = 0.02 cm. This kind of micro steel fibers has been supplied from China by Ganzhou Daye Metallic Fibers Company. The steel fibers have been imported in 25 kg bags. The utilized steel fibers features are shown in Table II. In order to achieve the appropriate SO_3 level, Gypsum has been applied to the fine aggregate. The introduced Gypsum is a natural stone of gypsum (taken from the cement plant in Kufa). It has been crushed and ground to get almost the same fine aggregate gradation set that has been utilized in the mixture. This gypsum has been utilized as a partial substitution by fine aggregate weight with small percentage. The amount of natural gypsum has been determined and introduced to the sand depending on the following formula [19]:

$$W = \left(R - M\right)S / N \tag{1}$$

where W is the required natural gypsum weight to add on the fine aggregate, R is the SO_3% acceptable in fine aggregate, S is the fine aggregate weight utilized in the mixture, M=SO_3 is the actual amount in fine aggregate (0.16%), N=SO_3 % is the used natural gypsum (SO_3%=42). RHA has been produced from the rice husk burned in an oven with temperature-controlled in order to obtain a pozzolanic material with a high amorphous silica amount.

The optimal level of the burning condition has been usually 500 °C for 120 minutes [20]. The fineness has been identified by the Blaine air permeability technique according to ASTM C204-84 [21]. Table III lists the Chemical Characteristics of RHA.

TABLE I
CHEMICAL COMPOSITION OF SILICA FUME

Composition	Oxides Content, %	ASTM C-1240
SiO_2	89.4	≥ 85
Al_2O_3	0.33	-
Fe_2O_3	1.28	-
CaO	0.95	< 1
MgO	2.47	-
K_2O	0.07	-
SO_3	1.19	< 2
L.O.I.	3.4	≤ 6.0
Blaine fineness	200000 (m^2/kg)	

TABLE II
THE FEATURES OF THE USED STEEL FIBRES

Property	Specifications
Relative Density	7825 kg/m^3
Tensile Strength	Minimum 2400 MPa
Form	Straight
Average Length	13±1 mm
Diameter	0.2mm±0.05mm
Aspect ratio	65

TABLE III
CHEMICAL COMPOSITION OF RHA

Oxides Composition	Content, %
SiO_2	89
CaO	1.31
MgO	1.7
SO_3	0.1
K_2O	3.77
Na_2O	1.5
AL_2O_3	4.1
P_2O_3	0.56
CL	0.36
Fe_2O_3	0.31
MnO	0.2
L.O. I	2.51

II.2. Mix Design

The materials proportions utilized in this research are presented in Table IV. The following components have organized the RPC considered in this investigation: a Portland cement ordinary type, fine aggregate, silica-fume, superplasticizer (type PC 200) micro steel fibers and high reactive Rice husk ash.

II.3. Tests of Hardened Concrete

The test of compressive-strength has been conducted depending on ASTM 109-11 [22] using (50×50×50) mm cubes that have been tested at 7, 28 and 90 day ages.

Additionally, in compliance with ASTM C293-06 [23], the Flexural-strength test has been performed utilizing prism samples with measurements 10×10×40 cm by taking the two prisms average for every test [24]-[27].

III. Results and Discussions

III.1. Compressive Strength

Compressive-strength is the most vital feature of concrete, which determines the suitability of different structural members to carry the expected loads. The results of compressive-strength test of the concrete samples have been identified at the age of 7, 28 and 90 days with various percentages of RHA and 3% of gypsum amount in the fine aggregate as demonstrated in Table V and Figs. 1 to 7. The current data shows that the optimal SO_3 amount for these mixtures is approximately 0.5% (by fine aggregate weight) for mixes with 10% RHA as a partial cement replacement. From the compressive-strength outcomes demonstrated in Table V, and Figs. 1 to 6, the following can be detected. Fine aggregate with 0.50% SO_3, has resulted in increasing the compressive-strength approximately by 7.90%, 6.87%, and 1.75% after 7, 28 and 90 days, respectively for mixes with 0% RHA. This has been reported by many researchers who had referred to the optimal gypsum amount existence [9]. The increase in the concrete compressive-strength could be attributed to the ettringite creation that is created because of a chemical reaction of water with both SO_3 and C3A. It blocks some voids within the cement past and increases the strength. The increase in the SO_3 content in fine aggregate from 0.50% to 1.2% has resulted in decreasing compressive-strength approximately by 14.40%, 14.87% and 9.16% % at ages 7, 28 and 90 days, respectively for mixes with 0% RHA due to the creation of more ettringite that induces internal stresses and reduces the compressive-strength. Moreover, the data presented in Table V clearly indicate that the use of 10% RHA in RPC has been the best in comparison with other mixtures for all the SO_3 content investigated within this research. The results also shows that increasing the SO3 content from 0.50% to 1.2% for mixtures with 10% RHA has resulted in decreasing the compressive strength by 8.4%, 7.74% and 4.93% at the ages of 7, 28 and 90 days, respectively. At all the ages of curing, the mixtures with 10% RHA have provided the highest compressive-strength in comparison with other RHA combinations (0% and 15%). This performance is the result of RHA pozzolanic reaction that reacts with the calcium progressive throughout the cement hydration and cause the matrix densification of concrete in a substantial increase in strength and a decrement in permeability [21].

Besides, the pore-size and the grain size refinement process related with pozzolanic reaction could efficiently decrease the microcracking and strengthen the area of transition [21].

TABLE IV
THE MIX PROPORTIONS USED

Mixes description	Cement kg/m^3	Water kg/m^3	Fine aggregate kg/ m^3	S.F. %	RHA by wt. of cement%	Micro Steel Fiber *Vf* %	SO_3 content in the sand (by weight of sand) %	Superplasticizer (by wt.of cementitious) %	Curing period (days)
R0S0.16	960	163	1030	20	0	1	0.16	6	7,28,90
R10S0.16	960	163	1030	20	10	1	0.16	6	7,28,90
R15S0.16	960	163	1030	20	15	1	0.16	6	7,28,90
R0S0.50	960	163	1030	20	0	1	0.50	6	7,28,90
R10S0.50	960	163	1030	20	10	1	0.50	6	7,28,90
R15S0.50	960	163	1030	20	15	1	0.50	6	7,28,90
R0S1.20	960	163	1030	20	0	1	1.20	6	7,28,90
R10S1.20	960	163	1030	20	10	1	1.20	6	7,28,90
R15S1.20	960	163	1030	20	15	1	1.20	6	7,28,90

TABLE V
COMPRESSIVE-STRENGTH OF RPC

Mixes description	Compressive strength (MPa)		
	7-d	28-d	90-d
R0S0.16	55.3	80.0	97.1
R10S0.16	58.3	84.4	99.2
R15S0.16	54.7	79.8	96.1
R0S0.50	59.8	85.5	98.8
R10S0.50	60.7	89.2	101.5
R15S0.50	56.8	81.1	97.5
R0S1.20	47.3	68.2	88.2
R10S1.20	55.6	82.3	96.5
R15S1.20	46.9	64.3	86.2

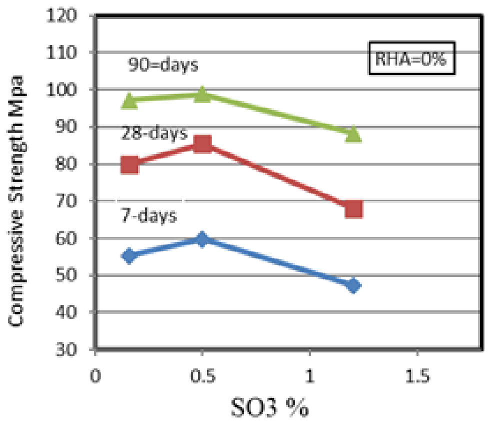

Fig. 1. RPC Compressive-strength with RHA=0%.

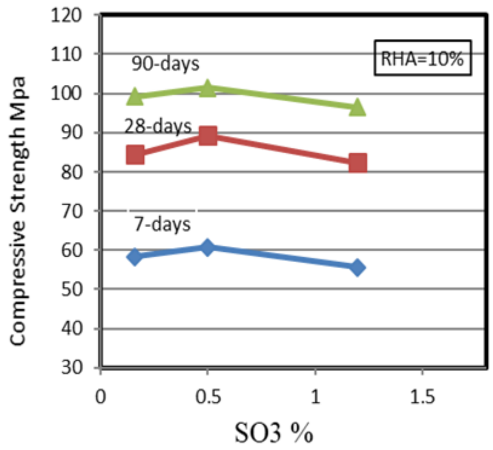

Fig. 2. RPC Compressive-strength with 10% of RHA

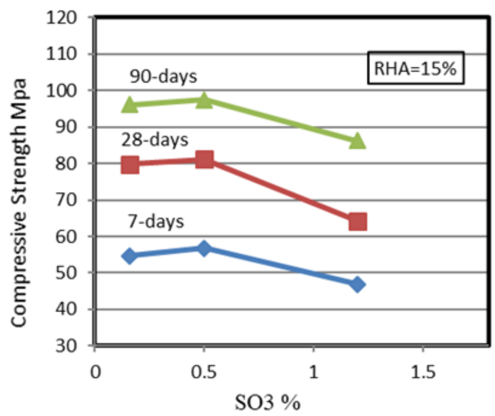

Fig. 3. RPC Compressive-strength with 15% of RHA

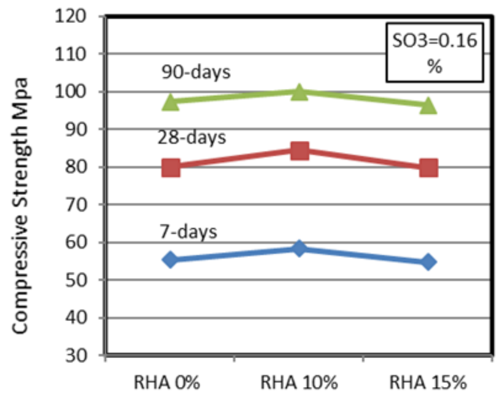

Fig. 4. RPC Compressive-strength with SO_3=0.16%

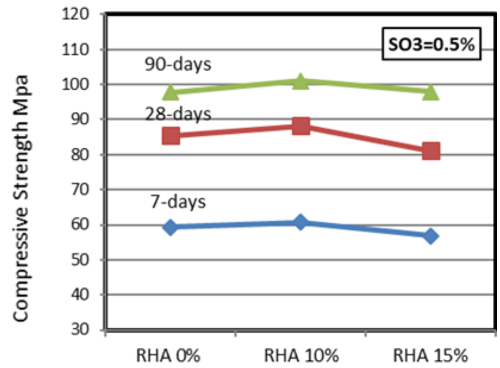

Fig. 5. RPC Compressive-strength with SO_3=0.50%

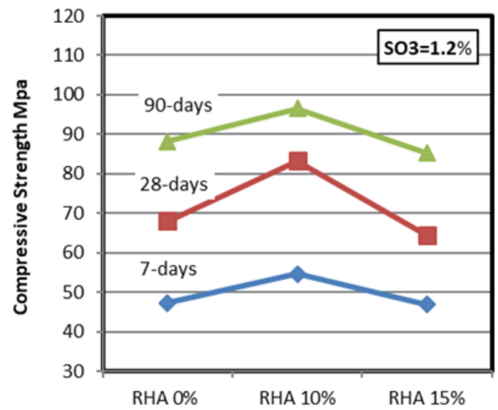

Fig. 6. RPC Compressive-strength with SO_3=1.20%

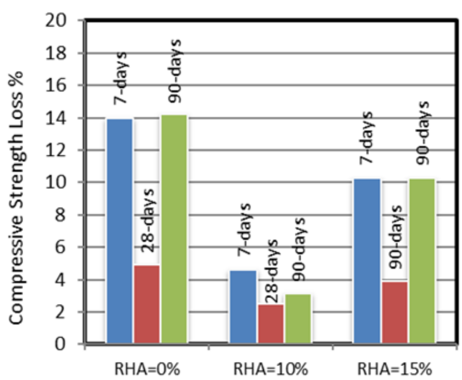

Fig. 7. RPC Loss % in Compressive-strength
for different RHA % and SO3=1.2%

According to the obtained results from the compressive-strength test for all the investigated mixtures, it could be stated that the mixture of 10% RHA and SO_3 content of 0.50% (R10S0.50) is the optimum mixture since it has demonstrated to have the highest compressive-strength at all the selected curing ages.

III.2. Flexural Strength

The flexural-strength test findings are demonstrated in Table VI and Figs. 8 to 13. The results have indicated that the flexural-strength performance of all the selected mixes have been similar to the one of the compressive-strength at all the investigated ages of curing. For example, the mixtures with 10% RHA have demonstrated the highest flexural-strength at all the selected ages regardless the SO_3 content. In addition, the results have indicated that for the same RHA content, the mixtures with SO_3 content of 0.50% have the highest flexural-strength. The results have also demonstrated that at the age of 90 days, increasing the SO_3 content from 0.16% to 0.50% has resulted in improving the flexural-strength by about 7.8%, 1.4% and 3.9% for mixtures with 0% RHA, 10% RHA and 15% RHA, respectively.

Additionally, increasing the RHA content from 10% to 15% has resulted in decreasing the flexural-strength by about 10%, 7.7% and 10.1% for mixtures with SO_3 content of 0.16%, 0.50% and 1.20%, respectively at the age of 90 days.

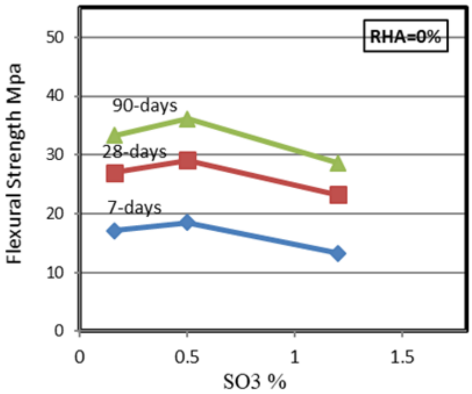

Fig. 8. RPC Flexural-strength with RHA=0%

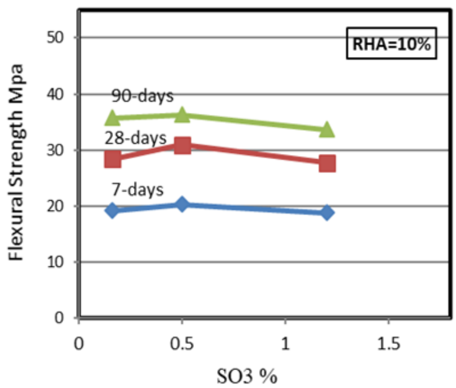

Fig. 9. RPC Flexural-strength with RHA=10%

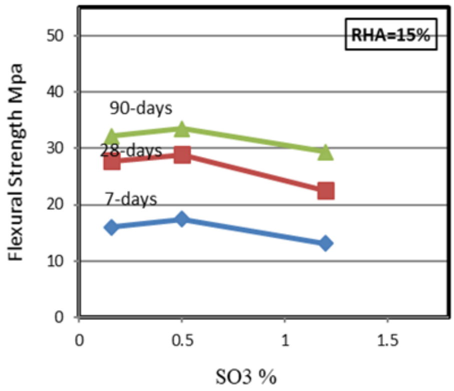

Fig. 10. RPC Flexural-strength with RHA=15%

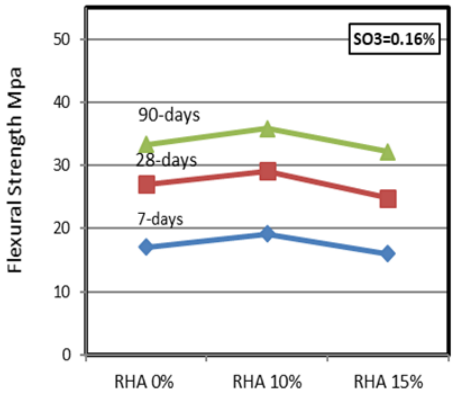

Fig. 11. RPC Flexural-strength with SO3=0.16%

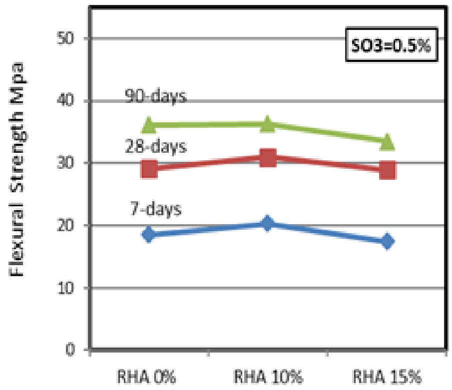

Fig. 12. RPC Flexural-strength with SO3=0.50%

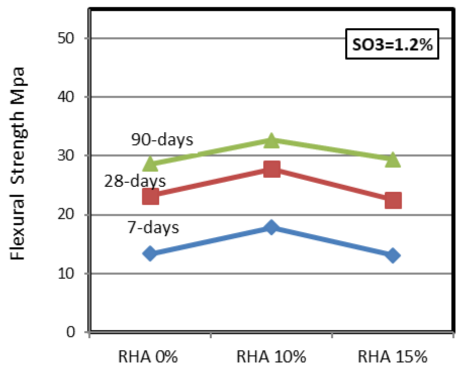

Fig. 13. RPC Flexural-strength with SO3=1.20%

TABLE VI
FLEXURAL STRENGTH OF RPC

Mixes description	Flexural Strength (MPa)		
	7-d	28-d	90-d
R0S0.16	17.1	27.0	33.3
R10S0.16	19.2	28.4	35.8
R15S0.16	16.0	27.8	32.2
R0S0.50	18.5	29.1	36.1
R10S0.50	20.3	31.0	36.3
R15S0.50	17.4	28.9	33.5
R0S1.20	13.3	23.2	28.6
R10S1.20	17.8	27.8	32.7
R15S1.20	13.1	22.5	29.4

In conclusion, the optimum mixture that has provided the best flexural-strength at all the ages of curing is mixture R10S0.50 (with 10% RHA and 0.5% SO_3 content). It has showed an improvement in the flexural-strength by approximately 152.7% and 178.8% with increasing the age of curing from 7 days to 28 days and 90 days, respectively. These findings have been in good arrangement with the results obtained from the compressive strength.

IV. Conclusion

This research has been carried out with the aim of investigating the effect of various sulphat content in fine aggregate and different RHA content on the mechanical features of RPC. Depending on the obtained experimental results, it has been found out that the optimum SO_3 content in fine aggregate has been 0.5% since it has demonstrated the highest compressive-strength and flexural-strength at all the ages.

Additionally, the usage of 10% RHA as a partial cement substitution has enhanced the hardening mechanical features (compressive and flexural strengths) for different SO_3 content. Moreover, increasing the RHA content from 10% to 15% has resulted in decreasing the mechanical features of the RPC at all the ages.

Furthermore, it has been found out that the optimum combination for the production of RPC with enhanced properties is by using 10% RHA as a partial cement substitution and SO_3 content of the fine aggregate of 0.50%. For future investigations, the authors highly recommend studying the effect of RHA on some mechanical features of reactive powder concrete with external sulfate attack. Additionally, the effect of using other supplementary cementitious materials such as Ground Granulated Blast Furnace Slag (GGBFS) and metakaolin with different percentages of partial replacement of cement on internal and external sulfate attack should be studied.

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