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Behavior of Steel Slag Concrete Subjected to Elevated Temperature

Ahmed Atef, Khaled samy, Mohamed Kohail, Omar El Nawawy

Abstract: *Recycling of materials has become a major interest for engineers. At present, the amount of slag deposited in storage yard adds up to millions of tons/year leading to the occupation of farm land and serious pollution to the environment, as a result of the rapid growth in the steel industry. Steel slag is made at 1500-1650°C having a honey comp shape with high porosity. Using steel slag as the natural aggregate with a lower waste material cost can be considered as a good alternative for sustainable constructions. The objective of this study is to evaluate the performance of residual mechanical properties of concrete with steel slag as coarse aggregate partial replacement after exposing to high temperatures .This study investigates the behavior of using granulated slag as partial or fully coarse aggregate replacement with different percentages of 0%, 15%, 30%, 50% and 100% in concrete when subjected to elevated temperatures. Six groups of concrete mixes were prepared using various replacement percentages of slag exposed to different temperatures of 400 °C, 600 °C and 800 °C for different durations of 1hr, 1.5hr and 2hr. Evaluation tests were compressive strength, tensile strength, and bond strength. The steel slag concrete mixes showed week workability lower than control mix. A systematic increasing of almost up to 21.7% in compressive strength, and 66.2% in tensile strength with increasing the percentage of steel slag replacement to 50%. And the results showed improvement on concrete residual mechanical properties after subjected to elevated temperatures with the increase of steel slag content. The findings of this study give an overview of the effect of steel slag coarse aggregate replacement on concrete after exposed to high temperatures.*

Keywords: *Residual mechanical properties Granulated steel slag, elevated temperatures, durations.*

I. INTRODUCTION

Industrial by-product obtained from the steel manufacturing industry during melting of steel scrap from the impurities and fluxing agents, which form the liquid slag floating over the liquid crude steel in electric arc furnace. The produced EAF steel slag is obtained by cooling the electric arc furnace steel slag liquid in air at production site [1]. The composition of slag varies upon the type of furnace and iron raw, the desired grade of steel purity and the furnace operation conditions. The electric arc furnace steel slag is still under investigation to find potential applications in the construction industry. Possibility of recycling by-products in construction mainly depends on its chemical composition, volume stability and physical and mechanical properties. Steel making process in electric arc furnaces generates up to 15 % of slag per ton of steel, which is, based on its properties, classified as nonhazardous waste [2, 22]. Major components of steel mill slag include Ca-silicates, Ca-Al-ferrites, molten oxides of calcium, iron, magnesium, and manganese, The use of slag as preserve the natural resources of raw materials, and avoids the environmental problems that may result from the disposal of such large quantities materials which requires large areas to store , if used as raw material in industries or constructions it would prevent environmental pollution and save natural raw materials, where an estimated amount of steel slag produced about 30 millions of tons/year. The electric arc furnace steel slag (EAFSS) produced during the direct production of the iron in an electric arc furnace is being utilized in the asphalt concrete mix and for the construction of sub-bases and aggregate base course in pavements worldwide. Utilizing steel slag in concrete mixes has provided to be useful in solving some of the problems encountered in concrete industry. Steel slag uses in concrete to improve its mechanical properties. Special specifications, sufficient records of its use and performance on major projects around the world, indicate that the utilization of steel slag has resolved several environmental issues. In addition, the use of such product in some special applications has been a successful step in finding good quality material as a partially or fully replacement of the ever-diminishing natural materials [15, 16, 19, 20, 21, 23]. From previous researches that focused on studying the behavior of using steel slag as partial coarse aggregate in concrete mixes and expose it to high temperatures, the factors that have significant effect on mechanical properties were identified, authors [3, 4] indicated the influence of slag replacement percentage on concrete, authors [5, 6, 7] indicated the influence of heating degree and time of exposure will be studded due to its importance when constructions subjected to fire issues. In recent years, it was found that the replacement of 15% coarse aggregate with steel slag would keep same workability without using any super plasticizers, and up to 63% could improve compressive strength [8, 9]. In other researches discuss the behavior of concrete under different heating degrees which reduces concrete strength by different rates [6, 10, 17, 18].

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* Correspondence Author

Ahmed Atef*, Department of Civil Engineering, The higher institute in 5th settlement, Cairo, Egypt. Email: ahmedmadin15@gmail.com

Omar El Nawawy, Structural Engineering Department, Ain Shams University, Cairo, Egypt. Email: nawawyomar@hotmail.com

Mohamed Kohail, Structural Engineering Department, Ain Shams University, Cairo, Egypt. Email: m.kohail@eng.asu.edu.eg

Khaled Samy, Department of Civil Engineering, The higher institute in 5th settlement, Cairo, Egypt. Email: eng_kh83@yahoo.com

Due to researches we found that optimum replacement percentages was 40-70 % of coarse aggregate which gave highest mechanical properties [11, 12].`variations in mechanical properties of concrete exposed to real standard fire were investigated in a temperature range of 200–800oC, Properties like compressive strength, tensile strength and bond strength [5, 13 , 17, 18, 24].

It's known that concrete affected with high temperatures reduces its characteristics but weak knowledge drive others to investigate concrete behavior with sustainable coarse aggregate like steel slag as particles which have characteristics that could improve concrete residual mechanical properties when exposed to high temperatures so it would be good reason to study this type of concrete under estimated thermal conditions that simulate affecting high temperatures ,these determined parameters aim to predict mechanical behavior of concrete when subjected to high temperatures for different times , for mixes with different slag replacements.

This research consists of six guided mixtures for obtaining best replacement percentages and expose it to different degrees of temperatures 400-600-800 ºC for 1-1.5-2 hours on test cubes and cylinders and study the behavior of concrete residual mechanical properties.

II. MATERIALS AND EXPERIMENTAL PROCEDURE

Materials

Ordinary Portland Cement (OPC) used in this research was CEM I (42.5 N) in according to ASTM C150 [14]. The EAF steel slag in processed form is a dense black aggregate material of angular shape, [2]. The properties of the electric arc furnace slag materials depends on melting process, methods of cooling and slag treatment. Steel slag in this research was a waste materials from delta steel company, Mostord, Egypt .The composition of slag varies upon the type of furnace and charge, the desired grade of steel purity and the furnace operation conditions. Steel making slag shows a considerably higher content of iron, manganese, and magnesium along with the lower silicon content i.e. higher CaO/ SiO2 ratio, and, finally, it contains almost no sulphur at all.

Electric arc furnace slag (EAFS) used in this research was a coarse aggregate particle. Chemical composition of used (EAFS) are shown in Table [I], the particles size distribution of sieve analysis are shown in Fig.1 The (EAFS) average particle size of 20.4mm with specific gravity 3.1g/cm³, Absorption of EAF slag is in the range of 1 - 3 % by weight. Natural sand is used as fine aggregates with particles size below 0.5mm with specific gravity of 2.55g/cm³, and fineness modulus of 2.25. Natural gravel used as coarse aggregate of maximum size of 20.3 mm and specific gravity of 2.65g/cm³.

Table I: the Chemical Composition of Used EAFS

Analystic	Compound formula	Concentration %	Analytic	Compound formula	Concentration %
Na	Na_2O	0.0104	Mn	MnO	7.296
Mg	MgO	5.710	Fe	Fe_2O_3	3.747
Al	Al_2O_3	4.547	Co	Co_3O_4	0.034
Si	SiO_2	16.969	Cu	CuO	0.17
P	S_2O_5	0.918	Sr	SrO	0.089
S	SO_3	0.900	Zr	ZrO_2	0.042
Ca	CaO	37.761	Nb	Nb_2O_5	0.12
Ti	TiO_2	0.530	Ba	BaO	0.236
V	V_2O_5	0.080	Ci	Ci	0.032
Cr	Cr_2O_3	0.084			

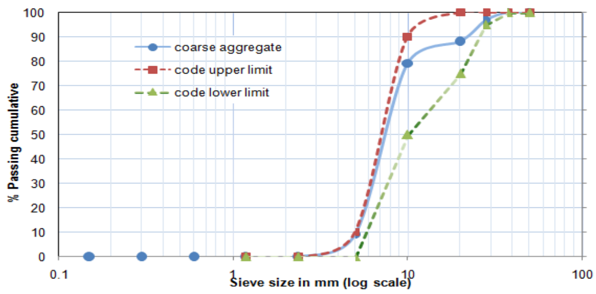

Fig. 1 the particle size of Used EAFS

III. MIXTURES PROPORTIONS

The mixtures are prepared with coarse aggregate substitution by different percentage of steel slag particles 0%, 15%, 30%, 50%, and 100%, Table [II].

Table II: Mixtures content for 1 m3

MIXES COMPONENTS OF (EAFS) CONCRETE MIXES						
mix	C	W	FA	CA	Slag	REP%
c	350	175	622	1244	0	control
15%	350	175	622	1057.4	204.7	15%
30%	350	175	622	870.8	394.78	30%
50%	350	175	622	622	681.2	50%
100%	350	175	622	0	1361	100%

IV. EXPERIMENTAL PROGRAM

The current experimental program consists of designing and preparing of five different concrete mixes to establish the effect of using EAF steel slag aggregate replacement, locally produced in Egypt on the mechanical properties of the different concrete mixes of normal concrete. And its behavior when subjected to different temperatures and exposure time's. The designed mixes reflected the considered key variables. Six groups consisted of thirty mixtures with replacement percentages 0%, 15%, 30%, 50% and 100% by volume of the coarse aggregate with cement contents (350 kg/m3). Effect of exposure to elevated temperatures (400, 600, 800) ºC for several times (1, 1.5, 2) hours were studied by compressive and tensile strength. Finally, it should be mentioned that, all steps of experimental work including casting, curing were performed in the laboratory of New Cairo Academy. Testing of the Concrete specimens were performed at the materials laboratory in National Research Center in Egypt shown in Table [III].

Table III: The Experimental Program

Group	rep%	temp	time	parameter
G1	0	——	——	control
	15			
	30			
	50			
	100			
G2	0	400	1.5hr	400

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	15			
	30			
	50			
	100			
	0			
	15			
G3	30	600	1.5hr	600
	50			
	100			
	0			
	15			
G4	30	800	1.5hr	800
	50			
	100			
	0			
	15			
G5	30	600	1hr	1hr
	50			
	100			
	0			
	15			
G6	30	600	2hr	2hr
	50			
	100			

V. TESTING PROCEDERES

The workability test is executed (slump test), Cubes of (150×150×150) mm³ are prepared and casted for implementing compressive strength test after 28 days. Cylinders of (150 mm diameter and 300 mm in height) are prepared and casted for implementing splitting tensile strength test after 28 days according to ASTM C 496 [28]. Cubes of (150×150×150) mm³ are prepared and casted for implementing the bond strength test after 28 days for steel re-bars of diameter of 12 mm. In order to investigate the effect of the presence of (EAFS) particles on the bond strength modes of failure.

VI. MIXING PROCEDURE AND CURING

The aggregate and steel slag were mixed for a duration of one minute in dry condition, then adding the cement and sand and continue the dry mixing for one more minute. The super plasticizer was finally added to the mixing water, after that the mixing water had been poured to the mix, the mixing continued for about 3-4 minutes.

The mixture molded in slandered cubes and cylinders with compaction performed in three layers. After one day of casting at 20°C, the specimens were de-molded and submerged into a water tank to be cured at a temperature of 20°C for 28 days till day of testing.

Universal Testing Machine 1000 KN was used to conduct the tests. Cubes were exposed to compressive strength to evaluate the effect of steel slag replacement percentage on compressive strength, and analyzed before and after affected to high temperatures for several durations. cylinders were prepared to study the indirect tensile strength. A steel bars with diameter of 12 mm was used in cube molds to study the bond strength on concrete with steel slag particles before and after exposed to 600°C for 1.5 hrs.

VII. RESULTS AND DISCUSSION

A. Slump test

Fig. 2 shows the slump of concrete mixes. Generally, increasing the slag substitution percentages by coarse aggregate decreased its workability. The lowest slump reading reached 11 mm for 100% slag substitution by gravel, maximum slump value 83mm of the control mix (without EAFS). The noticed decrease in slump test reading because of rough surface texture that plays strong rule in making the mixture drier as it increases the slag particles content so mixes needed super plastizers to reduce that effect.

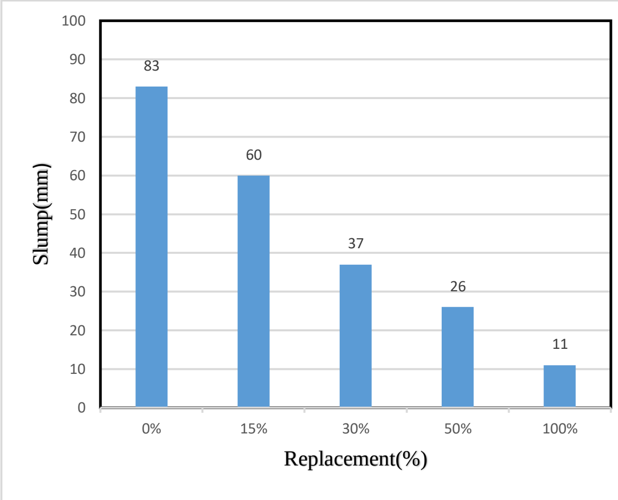

Fig. 2 Slump test

B. Compressive strength

Fig. 3 shows the compressive strength results of 28 days treatment concrete with steel slag replacement after exposing to temperatures 400, 600 and 800 ºC for same time of exposure up to 1.5 hrs. At 0% replacement compressive strength decreased gradually by increasing degree of temperature to 400,600 and 800 ºC. Compressive strength decreased 15.17, 41.91, and 54.73 % respectively than control. The compressive strength showed the most noticed effect after exposing to 600 ºC by 26.73% after exposed to 400ºC.

At 100% replacement compressive strength decreased gradually by increasing degree of temperature to 400,600 and 800 ºC, Compressive strength decreased 11.76, 27.32, and 35.50% respectively than control. That results showed that major effect of heating appears at 600 degree at 0 % and 15% mixers, while 100% replacement give the highest residual compressive strength. The maximum residual compressive strength recorded was for the control mixture (0% steel slag replacement) with 18.32 MPa, while the minimum residual compressive strength recorded was for 100% mixture steel slag replacement with 15.49MPa.

The compressive strength increased gradually by increasing the slag replacement percentage 15%,30% 50% and 100% by 3.6% ,7.2% ,21.65% and 30.3% respectively than control.

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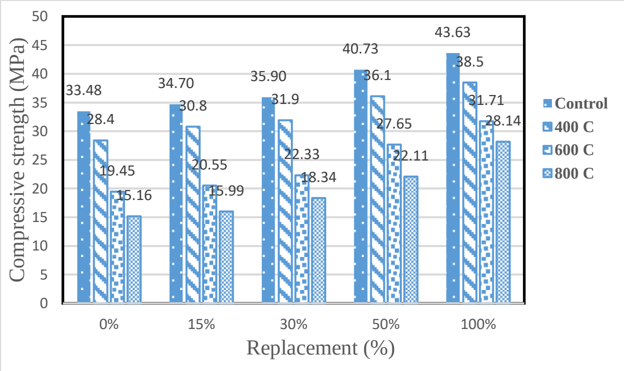

Fig. 3 Compressive strength affected by increased temperatures for constant time 1.5 hrs.

Fig. 4 shows the compressive strength results of 28 days treatment concrete with steel slag replacement after exposing to several duration of heating with same degree of 600ºC.

At 0% replacement compressive strength decreased gradually by increasing heating duration 1, 1.5 and 2hrs. Compressive strength decreased 25.03, 41.9, and 72.79% respectively than control. The compressive strength showed the most noticed effect after exposing to 600 ºC for 2hrs by 30.89%.

At 100% replacement compressive strength decreased gradually by increasing heating duration for 1, 1.5, and 2hrs, Compressive strength decreased 12.9, 27.3 and 46.05% respectively than control. That results showed that major effect of heating appears after 2hrs at 0% and 15% mixers, while 100% replacement give the highest residual compressive strength. The maximum residual compressive strength recorded was for the control mixture with 24.37 MPa, while the minimum residual compressive strength recorded was for 100% mixture steel slag replacement with 20.1 MPa. The compressive strength increased gradually by increasing the slag replacement percentage 15%,30% 50% and 100% by 3.5% ,7.2% ,21.65% and 30.3% respectively than control.

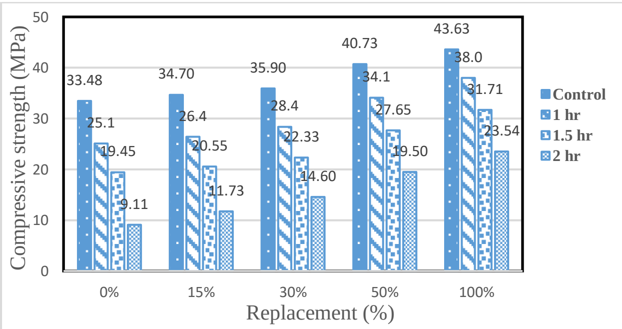

Fig. 4 Compressive strength affected by increased Heating duration for constant degree of 600ºC

C. Indirect tensile strength

Fig.5 shows the tensile strength results of 28 days treatment concrete with steel slag replacement after exposing to temperatures 400, 600 and 800 ºC for same time of exposure up to 1.5 hrs. At 0% replacement tensile strength decreased gradually by increasing degree of temperature. Tensile strength decreased 11.76, 23.53, and 27.94 % respectively than control. The tensile strength showed the most noticed effect from 400ºC to 600ºC by 11.74%.

At 100% replacement tensile strength decreased gradually by increasing degree of temperature, tensile strength decreased 12.59, 25.93, and 26.77% respectively than control.

The maximum residual tensile strength recorded was for the control mixture 0% steel slag replacement) with 0.19 MPa, while the minimum residual compressive strength recorded was for 50% mixture steel slag replacement with 0.20 MPa.

The tensile strength increased gradually by increasing the slag replacement percentage 15%,30% 50% and 100% by 2.94% ,33.82% ,66.17% and 86.76% respectively than control.

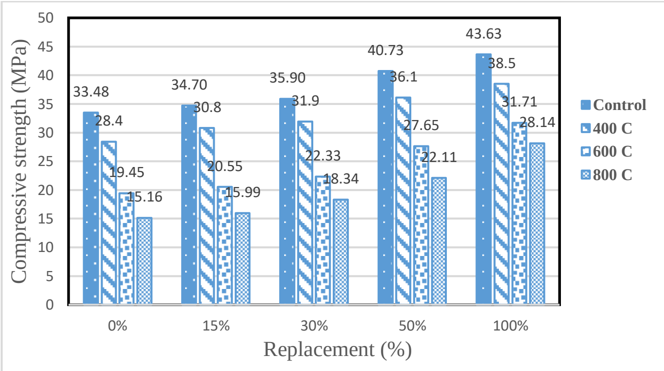

Fig. 5 Compressive strength affected by increased temperatures for constant time 1.5 hrs.

Fig. 6 shows the tensile strength results of 28 days treatment concrete with steel slag replacement after duration of exposure 1, 1.5 and 2hrs for same temperature of 600ºC.

At 0% replacement tensile strength decreased gradually by increasing time of exposure. Tensile strength decreased 13.23, 23.52, and 33.82% respectively than control. The tensile strength showed the same effect from 400ºC to 600ºC and from600ºC to 800ºC by 10.29%.

At 100% replacement tensile strength decreased gradually by increasing time of exposure, tensile strength decreased 17.32, 25.98, and 69.33% respectively than control.

The maximum residual tensile strength recorded was for the control mixture 0% steel slag replacement) with 0.23 MPa, while the minimum residual compressive strength recorded was for 30% mixture steel slag replacement with 0.42 MPa.

The tensile strength increased gradually by increasing the slag replacement percentage 15%,30% 50% and 100% by 2.94% ,33.82% ,66.17% and 86.76% respectively than control.

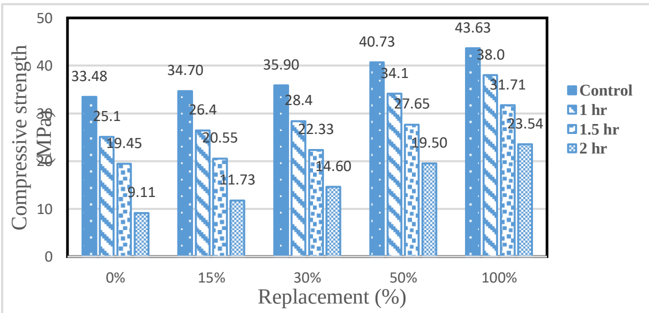

Fig. 6 Compressive strength affected by increased heating duration for constant degree of 600ºC

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D. Bond strength

According to ASTM, Concrete cover affects whichever behavior of the bond strength will prevail. If there is enough concrete cover around the bar (more than 4.5 the rebar diameter), the pull out behavior will occur. While in the absence of enough concrete cover (less than 4.5 the rebar diameter), the splitting behavior will occur. Although adhesion and friction are present when a deformed bar is loaded for the first time, these bond-transfer mechanisms are quickly lost, leaving the bond to be transferred by bearing on the deformations of the bar. Equal and opposite bearing stresses act on the concrete, Fig. 7.

Fig. 7 Bond strength

Fig. 8 shows the effect of exposing G2, G3 and G4 with 50% replacement to 400,600 and 800°C for 1.5 hours on bond strength. At 50% replacement bond strength decreased gradually by increasing degree of exposure with same duration. Bond strength decreased by 13.27, 33.62and 35.39% respectively by increasing degree of exposure to 400,600 and 800°C.

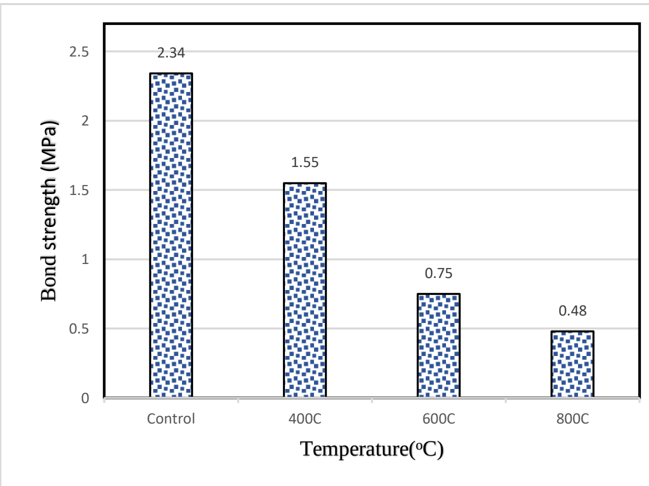

Fig. 8 Bond strength affected by increased degree of heating for constant time of heating 1.5 hrs

Fig. 9 shows the effect of exposing G3, G5 and G6 with 50% replacement for 1, 1.5 and 2hrs with 600°C on bond strength.At 50% replacement bond strength decreased gradually by increasing degree of exposure 400,600 and 800°C. While bond strength decreased by 13.27, 33.62 and 42.47 % respectively from its bond strength values before heating by increasing degree of exposure to 400,600 and 800°C.

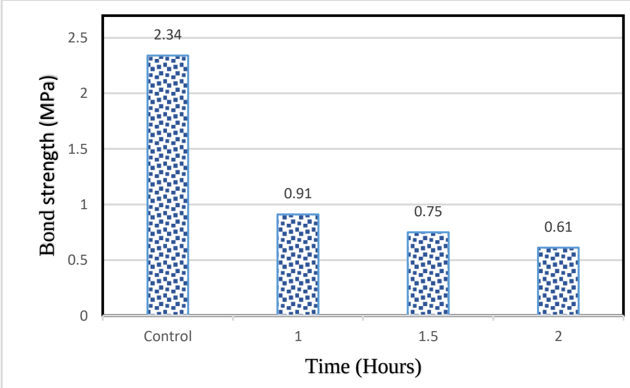

Fig. 9 Bond strength affected by increased time of heating for constant temperatures of 600°C

VIII. CONCLUSIONS

The following conclusions can be drawn from the test results:

1) Increasing the slag substitution by gravel decreased the workability compared to the control mixture.
2) Increasing slag particles replacement decreases slump flow values from 83mm to 11mm by 86.74%. Mixture 15% keeps workability acceptable by 60 mm, while increasing slag make mixtures drier and gave lower workability, mixture 100% slag gave the worst workability up to 11 mm.so obviously slag concrete needs super plasticizers to decreases that effect.
3) The compressive strength of concrete increases as steel slag particles increases.
4) The residual compressive and tensile strength increases in steel slag concrete compared to ordinary concrete after being exposed to different temperatures.
5) Increasing slag particle gave more compressive strength properties, mixtures 100% and 50% gave the best replacement percentages by 43.63 and 40.73MPa in compressive strength compared to 33.4 MPa of plain concrete after curing 28 days by increasing of 23.44% and 17.99% respectively.
6) Increasing slag particle gave more tensile strength properties, mixtures 100% and 50% gave the best replacement percentages by 1.27 and 1.13MPa compared to 0.68 MPa of plain concrete after curing 28 days by increasing of 46.45% and 39.82% respectively.
7) Heating 400°C after 1.5 hrs showed that mixture 30% slag replacement gave the best residual compressive strength up to 88.85% compared to its compressive strength before heating, while mixture 30% gave the lowest residual tensile strength by 83.51%. Mixture 15% gave the height residual tensile strength by 87.15%.
8) Heating 600°C for 1.5 hrs showed that mixture 100% slag replacement gave the best residual compressive strength up to 72.68% compared to its compressive strength before heating. While mixture 15% gave the highest residual tensile strength by 75.72 %.

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9) Heating 800°C for 1.5 hrs showed that mixture 100% slag replacement gave the best residual compressive strength up to 64.5% compared to its compressive strength before heating. While mixture15% gave the highest residual tensile strength by 71.43 %.
10) Heating 600°C for 1 hr showed that mixture 100% slag replacement gave the best residual compressive strength up to 87.18% compared to its compressive strength before heating. While mixture 30% gave the highest residual tensile strength by 91.77%
11) Heating 600°C for 2 hrs showed that mixture 100% slag replacement gave the best residual compressive strength up to 53.92% compared to its compressive strength before heating. While mixture 30% gave the highest residual tensile strength by 65.72 %.
12) Major effect of increasing temperatures appears at 600°Cin mixtures 0%and 15%. Mixture100% replacement gave the highest residual compressive strength.
13) Major effect of increasing time of heating appears at 2hrs in mixtures 0% and 15%. Mixture 100% replacement gave the highest residual compressive strength.
14) Major effect of increasing temperatures appears at 2hrs in mixtures 50% and 100%, Mixtures 0% and 15% replacement gave the highest residual tensile strength.
15) Major effect of increasing temperatures appears at 800°C in mixtures 30% and 50%, Mixtures 0% and 100% replacement gave the highest residual tensile strength.

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AUTHORS PROFILE

Ahmed Atef Eng Ahmed Atef is a teaching assistance, Structural Engineer Department, Higher institute for engineering and technology in fifth settlement, Cairo, Egypt.

Khaled samy, Dr. khaled Samy Abdallah is an Associate Professor, Structural Engineer Department, Higher institute for engineering and technology in fifth settlement, Cairo, Egypt. He specialized in design of reinforcement concrete, strengthening and reinforcement of RC elements with fiber reinforcement polymer (FRP). He got many supervisions and sharing on many searching in this area, so many international publications in these areas.

Mohamed Kohail, Dr. Mohamed Kohail is an Associate Professor, Structural Engineer Department, Faculty of Engineering, Ain Shams University, Egypt. He specialised in construction materials, sustainability, and nano technology. He got many international publications in these areas. He is an editor for Ain Shams Engineering Journal (ASEJ under Elsevier), he also reviews many papers for high ranked journals.

Omar El Nawawy, Prof. Dr. Omar El Nawawy is a professor of concrete structures, Structural Engineer Department, Faculty of Engineering, Ain Shams University, Egypt. He specialised in concrete structures analysis, construction management, and nano technology. He got many international publications in these areas. He is a reviewer at many journals.

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