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Mechanical properties of high strength concrete with steel slag aggregate

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ملخص البحث:
خبث الحديد الصلب هو عبارة عن مخلف صناعي ينتج اثناء عملية تصنيع الصلب (الحديد) حيث يتم صهر خردة الحديد مع او الحديد المنتج من الافران العالية مع مواد تساعد على عملية الانصهار وتساعد على فصل المخلفات عن منهر الصلب (الحديد)في افران تسمى افران القوس الكهربائي,حيث ان خصائص وانواع خبث الحديد يعتمد على نوع الافران المستخدمة لانتاج الحديد وكذاللك درجة نقاوة الحديد المطلوب ونوع الاضافات التي تضاف للمنصهر لتحسن خواص الحديد المنتج.
بسبب زيادة انتاج الحديد والصلب بسبب النمو الحاصل في مجال الصناعة ومجال البناء ادى الى زيادة مخلفات الصلب والحديد بشكل كبير حيث بلغ الانتاج العالمي لخبث الحديد والصلب عام 2006 (270 مليون طن) والانتاج في تزايد مما يشكل مشكلة وعبيء على البيئة لابد من وجود حل للتخلص منه.لهذ لابد من وجود طريقة لأعادة استخدام تلك المخلفات الثقيلة , توجد استخدامات كثيرة لمخلفات الحديد والصلب كأستخدامه مع الاسفلت في تبليط الطرق وكذالك في النتاج الاسمنت البورتلاندي وايضا استخدامه كركام في عملية انتاج الخرسانة.
يدرس هذا البحث تأثير استخدام خبث الصلب بدل الركام في الخرسانة عالية المقاومة على الخواص الميكانيكية للخرسانة, حيث تم اجراء الاختبارات على الخرسانة الطازجة والمتصلدة حسب الكود المصري لأختبارات الخرسانة , اشارت النتائج الى انه استخدام خبث الصلب في الخرساة عالية المقاومة كركام ناعم وخشن لايؤثر تاثير سلبي بل يحسن من الخواص الميكانيكية للخرسانة عالية المقاومة, حيث تحسنت مقاومة الانضغاط للخرسانة بمقدار 47% في الخلطة المثالية وتحسن مقاومة الخرسانة للشد الغير مباشر بمقدار 63% وتحسنت مقاومة الانحناء للخرسانة بمقدار 20%.

Abstract:
Steel slag is an industrial by product of steel production process, steel slag type depends on the type of furnace of manufactory, method of steel production and impurity of produced steel, steel slag occupies 15% from the total production of steel, in 2006 (270 million) ton of steel slag was produced as a by-product in the world and that huge amount of steel slag increases every year that cause environmental problem. This research investigated the effect of replaced fine and coarse aggregate with fine and coarse steel slag on mechanical properties of high strength concrete, compressive strength, split tensile and flexural strength was investigated and results indicated that compressive strength was improved by 47% and splitting strength was improved by 63% and flexural strength was improved by 20%.

1-Introduction:
Electrical arc furnace slag (EAFS) is an industrial by-product obtained from the steel slag manufacturing process after melting steel scrap and flexing agents to gather to separate the impurities from steel melt and the liquid which floating over the steel milt called steel slag melt, [1]. Steel slag type and properties depending on type of furnace of manufactory, the charge which used to improve the properties of produced steel, type of flexing agents which used to separate the impurities from steel melt and method of cooling steel slag.

Aggregate are the main incardinates of concrete occupies approximately 70% of concrete composition and its properties directly effect on the properties of fresh and hardened concrete, availability of good quality aggregate begin to deplete by the time due to the quick growth of Egypt construction industry then it is the appropriate time to identify alternative source of aggregate with good properties.

Because of good properties of steel slag like stiffness and low absorption of water make the steel slag good alternative of normal aggregate in of concrete and as replacement with Portland cement and as aggregate of asphalt of road paving.

Previous study investigated the utilization of steel slag in production of cement clinker which add 10.5% of steel slag to the row meal of production of Portland cement clinker and tested tow samples first one without steel slag and the other on contained steel slag, result of mechanical tests and setting time indicated that steel slag did not caused any harm when used in production of Portland cement clinker, [2]. Other research investigated the effect of use steel slag as aggregate of hot mix asphalt which is used for road paving after tested different mixes with different proportions of steel slag reached that optimum mix improved stability of asphalt and decrease flow value and when used steel slag with aggregate improved stiffness and resistance of deformation and improved the electrical conductivity, split tensile and stiffness modulus, [3].

Samir I. Abu-Eishah et al, [4] study the effect of replaced coarse aggregate of concrete by coarse steel slag of different grading strength concrete (30 MPa, 50MPa and 70MPa) and tested the samples of mechanical properties, results indicated that compressive strength improved in 30MPa mix of concrete by 60%, in 50MPa concrete mix compressive strength improved by 80% and at 70MPa concrete mix compressive strength improved by 100%.

Other previous study investigated the effect of replaced steel slag with fine aggregate of normal concrete with proportions of (15%, 30%, 50% and 100%) and found that the best replacement level is 30%-50% which improved split tensile strength and best level of improved compressive strength was of 15% t0 30%, [5].

V. Subathra Devi et al, [6], investigated the effect of used fine and coarse steel slag as replacement with fine and coarse concrete aggregate after prepared five different mixes with different proportions of fine and coarse steel slag and studied the mechanical properties of hardened concrete, results indicated that best improvement of compressive strength was in the mix of replaced coarse aggregate by 50% with coarse steel slag and flexural strength improved by 48% at 30% replacement level of coarse steel slag, at replaced 40% of fine aggregate with fine steel slag flexural strength improved by 74%.

Other research investigated the effect of replaced fine and coarse aggregate by fine and coarse steel slag with proportions of (50% and 100%), five mixes were prepared of fine, coarse and fine and coarse steel slag together, all samples of different mixes was tested of mechanical tests and results indicated that best improvement in compressive strength was in the mix which contained 50% fine steel slag, best improvement in split tensile strength was in the mix of 100% coarse steel slag and 50% fine steel slag and best improvement in young modulus was in the mix of 50% coarse steel slag and 50% fine steel slag.

2. Experimental work: 2.1. Material: 2.1.1Cement:

Ordinary Portland cement (OPC) CEM I 42.5 N used. Testing of cement was carried out according to Egyptian standard specification ES 2421/2005 [9], Table (2-1) shows the physical and mechanical properties of used cement.

Table (1): mechanical and physical properties of cement

Property		Result	specification
Compressive strength of standard mortar (Mpa)	2days	20.5	No less than 10
	28days	51.9	No less than 42.5
Soundness (la Chatelier)(mm)		1	No more than 10
Setting time (min)	Initial	155	No less than 60
	Final	170	

Limits of ES 4756-2009

2.1.2. Aggregate:

Electrical arc furnace slag(EAFS) form (Beshy steel group) is a byproduct obtained from steel manufacturing crushed in two size like coarse and fine aggregate, hematite iron ore from (Wadi Hoof region) crushed as one size like coarse aggregate, crushed dolomite coarse aggregate and silicon sand fine aggregate.

Table (2) Physical and mechanical properties of coarse aggregate:

Aggregate type	Specific gravity	Bulk density (t/m^3)	Water absorption	Los Anglos Abrasion Coefficient
Crushed dolomite	2.65	1.7	2	19
EAFS (coarse)	3.55	1.981	1.00	13
Hematite	3.3	1.86	2.3	-

The limits according to the Egyptian standard specification no (1109/2002)

Table (3) grading of crushed dolomite coarse aggregate:

Sieve size	37.5mm	20mm	14mm	10mm	5mm	2.36mm
Passing %	100	90	76.5	36.55	5.00	0

The limits according to the ESS no (1109/2002)

Table (4) grading of coarse electrical arc furnace slag:

Sieve size	37.5mm	20mm	14mm	10mm	5mm	2.36mm
Passing%	100	98	78	29.5	4.7	0.8

The limits according to the ESS no (1109/2002)

Table (5) Mechanical and physical properties of Fine aggregate:

Property	result
Specific weight	2.63
Bulk density (t/m^3)	1.8
Fineness modulus	2.9
Clay and fine dust content	1.4

The limits according to the Egyptian standard specification no (1109/2002

Table (6) grading of fine aggregate:

Sieve size	10mm	5mm	2.36mm	1.18mm	0.6mm	0.3mm	0.15mm
Passing%	100	97.6	95.5	85.3	32.4	9	1.8

The limits according to the ESS no (1109/2002)

Table (7) grading of fine slag:

Sieve size	10mm	5mm	2.36mm	1.18mm	0.6mm	0.3mm	0.15mm
Passing%	100	98.3	94	40.7	19	12.6	2.5

The limits according to the ESS no (1109/2002)

Table (8) chemical composition of slag:

Sample name	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	k_2O	TiO_2	p_2O_5	Cr_2O_3	MnO	L.O.I^{xxx}	Total
slag	17.90	7.17	31.30	32.60	3.19	0.25	0.22	0.05	0.34	0.70	1.63	3.99	0.21	99.64

According to ASTM C114-00

Table (9) chemical composition of hematite:

Sample name	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	k_2O	TiO_2	p_2O_5	BaO	L.O.I^{xxx}	Total
Hematite	2.34	0.32	81.70	0.66	0.04	2.79	0.18	0.03	0.09	0.94	4.91	5.78	99.96

According to XRF analysis

2.1.4. Chemical admixtures:

A high performance superplasticizers admixture of aqueous solution of modified polycarboxylate basis (viscocete 3425) complies with ASTM-C-494 type G and BSEN 934

Part 2:2001

The properties of viscocrete 3425 are obtained from the manufactured data sheet as follows:

•Chemical base aqueous solution of modified polycarboxylate copolymers

•Appearance / Color: Liquid / Turbid, Yellowish

•Density at +20 °C 1.05 ± 0.01 kg/L

•Compatibility: all types of Portland cement

Key word of table (10): •C.S: coarse slag •F.S: fine slag •w: water •C.A: coarse aggregate •F.A: fine aggregate •C.H: coarse hematite •S.F: silica fume •S.P: superplasticizer

3.1. Mix design: Table (10) explain the proportions of thirteen mixes which investigated in this study, in this research prepared these mixes to study the behavior of concrete when replace (fine, coarse) aggregate by (fine, coarse) EAFS with different proportions.

Table (10) design of concrete mixes

Mixes	Cement	W 30%	S.F 15%	S.P 2%	C.A	F.A	C.S	F.S	C.H
Control	500 Kg/m³	150 liter	75 Kg/m³	10 liter	935 Kg	779 Kg	_	_	_
C.S25%	500 Kg/m³	150 liter	75 Kg/m³	10 liter	701 Kg	779 Kg	284 Kg	_	_
C.S50%	500 Kg/m³	150 liter	75 Kg/m³	10 liter	468 Kg	779 Kg	567 Kg	_	_
C.S75%	500 Kg/m³	150 liter	75 Kg/m³	10 liter	234 Kg	779 Kg	853 Kg	_	_
C.S100%	500 Kg/m³	150 liter	75 Kg/m³	10 liter	_	779 Kg	1137 Kg	_	_
F.S25%	500 Kg/m³	150 liter	75 Kg/m³	10 liter	935 Kg	584 Kg	_	237 Kg	_
F.S50%	500 Kg/m³	150 liter	75 Kg/m³	10 liter	935 Kg	390 Kg	_	474 Kg	_
F.S75%	500 Kg/m³	150 liter	75 Kg/m³	10 liter	935 Kg	195 Kg	_	710 Kg	_
F.S100%	500 Kg/m³	150 liter	75 Kg/m³	10 liter	935 Kg	_	_	947 Kg	_
100% C.S+F.S	500 Kg/m³	150 liter	75 Kg/m³	10 liter	_	_	1137 Kg	947 Kg	_
50% C.S+F.S	500 Kg/m³	150 liter	75 Kg/m³	10 liter	467.5 kg	389.5 kg	568.5 kg	473.5 kg	_

3-2 mixing procedure

To get high strength concrete, water/binder materials ratio must be minimized, therefore special mixing procedure must be executed to get good quality of concrete. From previous researches and trails in the current experimental work many of steps were conducted to get good quality high strength concrete:

-step one: putting fine aggregate progressively, after that putting coarse aggregate in the mixer and mixing them for minute.

-step two: adding fine components (cement and silica fume) progressively and mixing components two minutes.

-step three: stirring the superplasticizer with half amount of water and added them to the wanted amount and mixing them for two minutes.

-step four: adding the remainder half amount of water to the mixer gradually until getting homogenous concrete.

4-Results and discussions:Concrete properties

4-1 properties of fresh concrete

4-1 Slump test

Slump test was carried out according to ES 1658/2006, [1], according to slump test procedure

Table (11) shows the slump test value of different mixes and figure (1) shows the slump value as pictures

Figure (1) slump value of different mixes

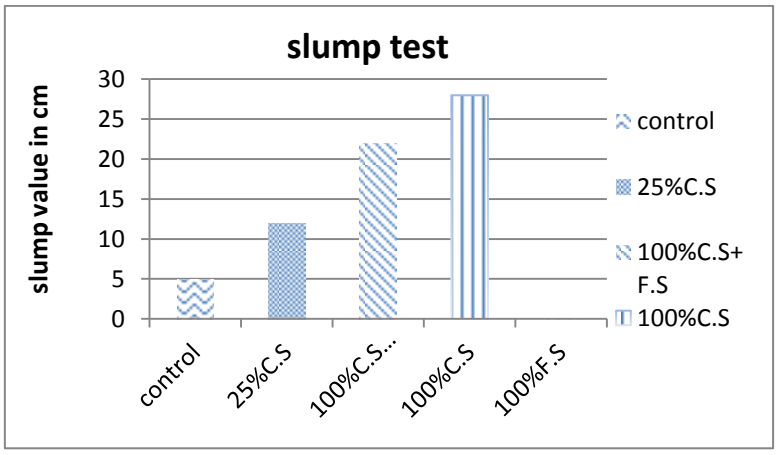


Table (11) slump value of concrete mixes

Mix type	Slump value in (cm)
Control mix	5
25% C.S	12
100% C.S	28
100% F.S	1
100% C.S+100 %F.S	21

Slump test was achieved on optimum mixes which have best results of compressive strength, split tensile and flexural strength, as results which showed in table (11) control mix have slump value of (5 CM) and mix of replaced 25% coarse aggregate with coarse slag had slump value of 12CM and the mix of 100% coarse slag had slump value of 28 CM these results means the slump value increased with increased coarse steel slag proportion in concrete because the steel slag have unit weight of (3.5) heavier than normal aggregate and have water absorption (lower than normal aggregate) of 1%, these properties caused increased in slump value.

From results of slump test noticed that fine steel slag caused decrease in slump value, replaced 100% fine aggregate with 100% fine steel slag caused increased in slump value from 5CM to 1CM, steel slag have porous surface and the surface aria of fine steel slag is more than coarse steel slag, that is mean more of porous in concrete caused more of voids these voids made nesting concrete and decreased slump value.

4-2 mechanical properties of hardened concrete

4-2 compressive strength, split tensile and flexural strength

Compressive strength were achieved at (7 days, 28 days and 91 days) on the cubes of (100*100 mm), all samples tested by a calibrated hydraulic machine with capacity of

2000 KN, Indirect tensile strength of hardened concrete cylinders of 100 mm diameter and 200 mm height at age of 28 days carried out by calibrated hydraulic machine of 1000 KN capacity, flexural strength tested on beams 100*100*500 mm at age of 28 days and carried out by calibrated hydraulic machine of 1000 KN capacity. Mechanical tests carried out according to ES1658/2006[8].

In replacement of coarse aggregate with coarse steel slag, compression strength increased with increased steel slag proportion and result showed that 100% coarse steel slag proportion improved compressive strength by 13%, 25% and 28.6% at 7days, 28days and 91 days respectively. Compressive strength increase with increase replacement proportion of coarse steel slag because steel slag is more hardness from other type of aggregate, coarse steel slag have absorption lower than normal aggregate and its surface more roughness than of normal aggregate, Split tensile and flexural strength are a percentage from compression strength and they increased with increased compressive strength.

Fig (2) compressive strength of concrete with coarse slag

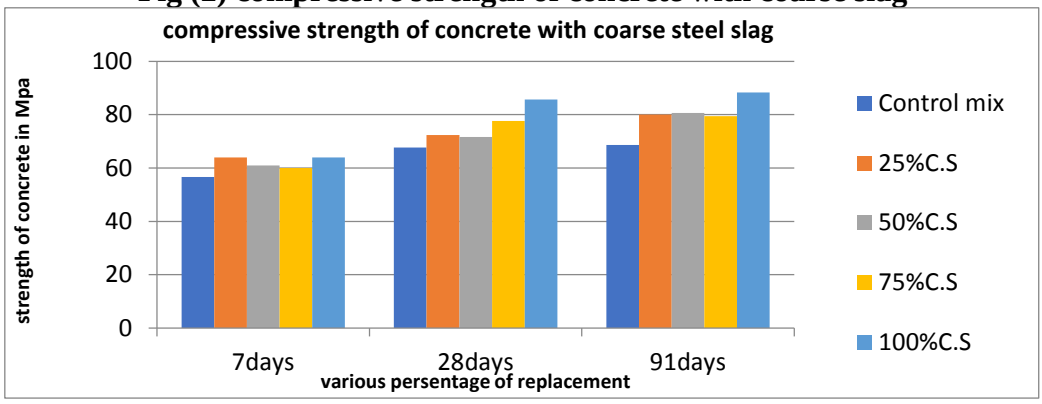
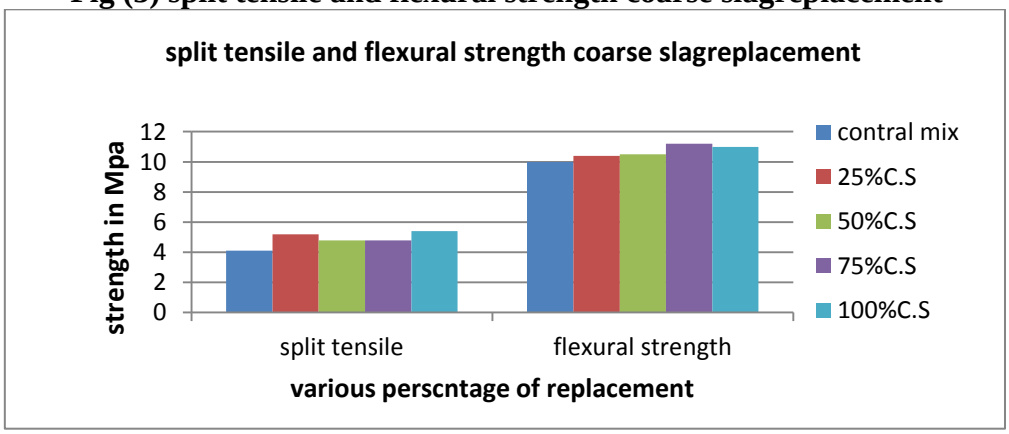


Fig (3) split tensile and flexural strength coarse slagreplacement



Replaced 25% of fine aggregate with fine steel slag improved compressive strength by 14.7% and 17.4% at 28 and 91 days, 25% fine slag replacement increased compression of concrete but more increased in proportion of replacement caused decrease in compression strength because fine steel slag have high absorption ratio and with constant of water to cement ratio 30%, then fine steel slag absorbed more water and caused decrease in cement hydration.

Fig (4) compression strength of concrete with fine slag replacement

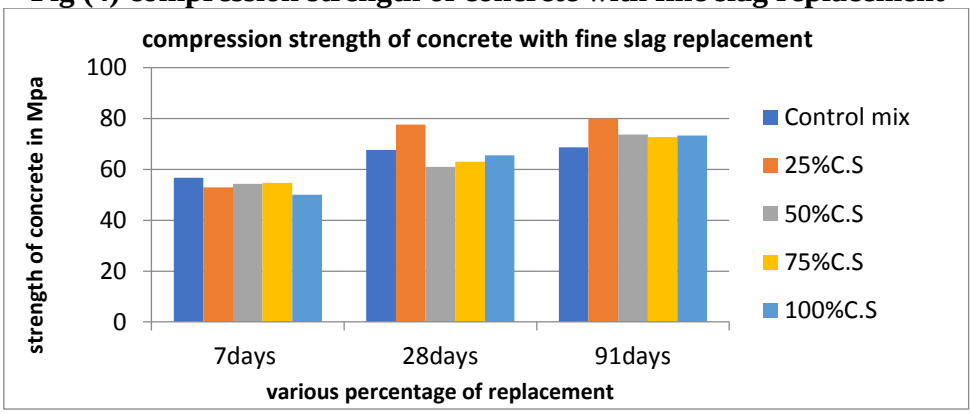
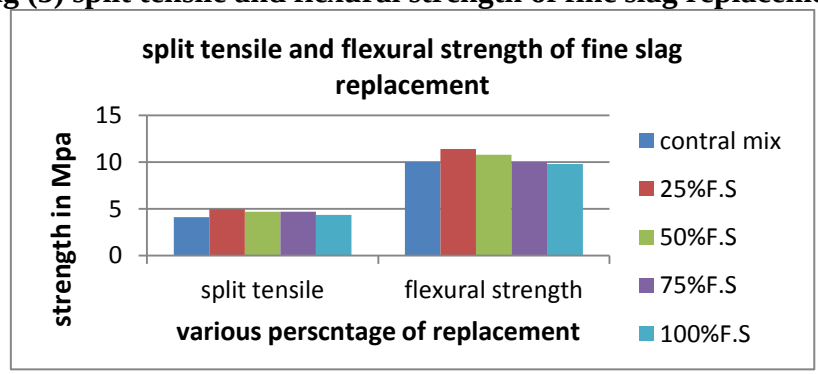
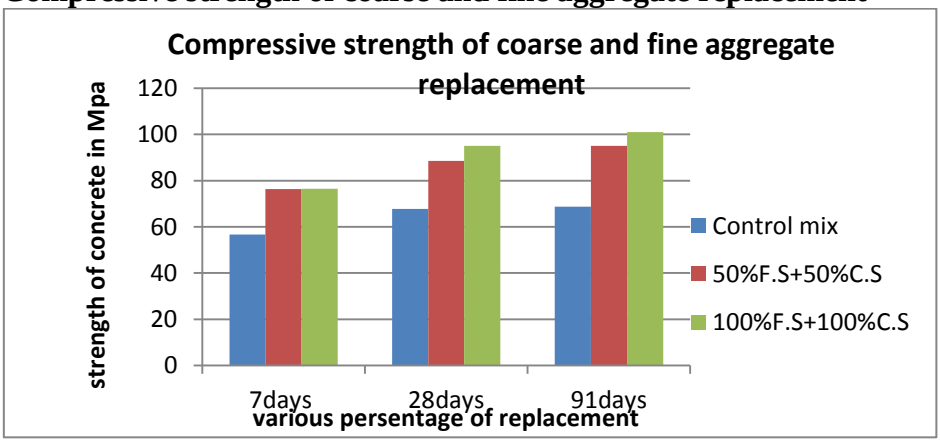


Fig (5) split tensile and flexural strength of fine slag replacement



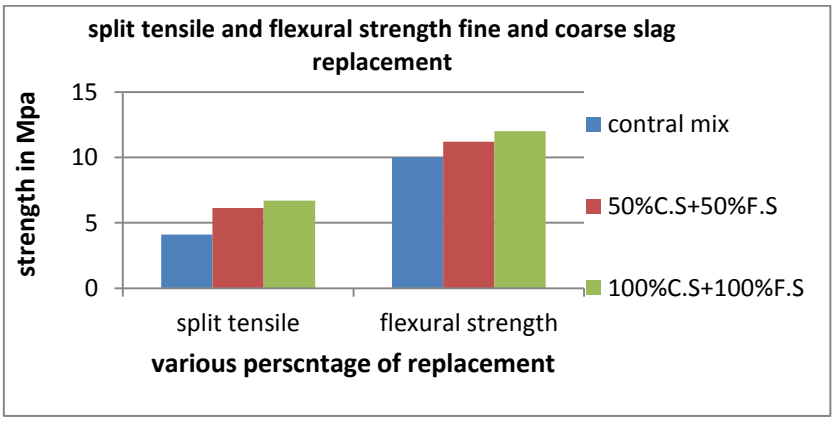
Result indicate that the strength of compression improved with increase proportion of EAFS as coarse and fine aggregate to gather, mix of 50% replacement improved the strength of concrete by (30.7% at 28 days) and (38.9% at 91 days) but the mix of 100% replacement improved strength of concrete by (40% at 28 days) and (47% at 91 days).

Fig (6) Compressive strength of coarse and fine aggregate replacement



Because of good properties of steel slag as aggregate which have very good stiffness, low water absorption and porous surface, increase the stiffness of aggregate which occupies 70% of concrete composition caused increased in stiffness of concrete and because of porous surface of steel slag that increased cohesion force between concrete paste and aggregate, and fine steel slag made increased the interaction between coarse and fine aggregate then the improvement in compressive strength became more than mix which contained coarse steel slag with normal fine aggregate.

Fig (7) split tensile and flexural strength fine and coarse slag replacement



Flexural strength and splitting strength increased because the compressive strength of these mixes was improved because the splitting strength and flexural strength is a ratio from compressive strength of concrete.

5. Conclusions:

In this paper to investigate the possibility of replacing normal aggregate with electrical arc furnace slag the compressive strength, split tensile, flexural strength, durability and gamma penetration was studied, According to the results presented in this research work the following conclusions can be drawn:

1-the optimum percentage of replacement for fine aggregate is 25% with fine electrical arc furnace slag, optimum percentage of replacement for coarse aggregate is 100% with coarse steel slag and optimum percentage of replacement for fine and coarse slag together is 100% fine slag +100% coarse slag.

2-workability of concrete improved with increase replacement proportion of coarse steel slag and decrease with increase replacement proportion of fine steel slag.

3- Optimum mix of replaced fine aggregate with fine steel slag was mix which contained 25% fine steel slag had best improvement in mechanical properties.
4- Optimum mix of replaced coarse steel slag was mix which contained 100% coarse steel slag, which had best improvement of mechanical properties.

5- Optimum mix of all mixes was the mix which contained 100% fine and coarse steel slag, had best results of compressive strength and splitting strength and flexural strength.

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