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STUDYING THE EFFECT OF IRAQI STEEL SLAG ADDITION ON THE PHYSICAL AND MECHANICAL PROPERTIES OF CEMENT MORTAR

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Abstract: The need to produce high performance concrete led the researches to try to exploit the potentialities of natural or artificial materials in order to modify the performance of cement and concrete by adding steel slag to cement .Slag has been used as addition materials to cement in ratio (20%, 40%, 60%, 80%) of cement weight, since its main oxides are similar to those of cement. In this investigation, the effect of steel slag in physical and mechanical properties of mortar was studied including finesses, consistency, initial and final setting time as well as compressive strength of mortar in 7, 28 days and absorption in (28,7)days. Results demonstrated that the addition 40% slag of total weight of cement to mortar showed increase in compressive strength and superior performance at 40% slag adding to total weight of cement. Where the compressive strength after (90) days becomes (52MPa) and the reduction in water absorption in all case except at 80% of slag addition case becomes approximate equal to reference mortar.

Keywords*: steel slag, ordinary Portland cement, Compressive strength, Pozzloana.*

دراسة تاثير اضافة خبث الصلب العراقي على الخواص الفيزيائية والميكانيكية للمونة

الخلاصة: ان الحاجة الى انتاج خرسانة ذات اداء متميز أدت بالباحثين الى محاولة استغلال مواد طبيعية او صناعية. لتحسين اداء المونة و الخرسانة من ناحية ,تم اضافة خبث الستيل بنسب وزنية مختلفة (20%,40%,60%,80%) من وزن السمنت ,واضيف الخبث للسمنت لكون اكاسيده الرئيسية مشابهة الى اكاسيد السمنت. تضمن هذا البحث دراسة تأثير اضافة خبث الستيل على الخواص الفزيائية والميكانيكية للمونة . حيث أجريت فحوصات النعومة و الليونة القياسية وزمن التماسك الابتدائي والنهائي ومقاومة الانضغاط في عمر (90,28,7) يوم وفحص الامتصاص في(28,7) يوم ، تبين من النتائج تحسن مقاومة الانضغاط للمونة الحاوية على الخبث بنسبة مختلفة وكانت افضل مقاومة عند نسبة) 40% (أدت الى تحسين خواص المونة بالمقارنة مع الخلطات الاخرى حيث اصبحت مقاومة الانضغاط لعمر (90) يوم (52) ميكاباسكال.بالاضافة الى انخفاض في الامتصاص في عندالنسب (20%,40%,60%) ومساواتها تقريبا للخلطة المرجعية عند النسبة 80(%) من اضافة خبث الستيل الى المونة.

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1. Introduction

In the mid-twentieth century, research and attention began to focus on energy conservation and the use of materials economically costly "in the steps of production, the concrete industry is one of these industries covered by this attention because of the fact that cement is the main constituent in the concrete industry. Most studies included the possibility of modification , reducing the cost of cement materials and the use of low cost materials as well as and have cement properties .therefor the pozzolainic materials (Pozzloana) (,silica fume and slag are used for this purpose.

This has led to reduce the cost of production of concrete, especially since most of these new materials are product as by-product materials in the dusters and Cause environmental pollution, as well as hinder the production process in the case of non-use [1]. In spite of that the first Types (slag –cement) produced in 1862, the use of slag as cement is added to the concrete separately may adopt in the middle of the last century. The quantity of slag cement used with about (20%) of the amount of cement produced in Europe. Differ Methods of production and processed are used depending on raw materials types. For example slag produce from high blast furnace in both Canada and Australia called blast furnace slag (B-F-S).the slag produce by electric arc furnaces called (steel slag).this methods is used in Iraq in which the raw materials are steel scrap. (Loriote) in 1974 is the first person who use slag with cement to produce mortar as the raw material [2].

The develop countries taken this study in seriously discuss and developed and treating to benefit of it and producing concrete With suitable economic cost addition to good engineering properties in resistance to Sulfur and chlorides salts. Locally the research on slag took its way in order to cover all the local properties of slag and benefit from it. Al Mullah (6) is the first person who began to search in the local slag [3]. The slag types can be listed by the flowing

1 . Slag from metal manufacturing processes
- o Iron and steel slag.
  - Blast furnace slag(granulated blast furnaces slag, air- cooled blast furnace slag)
  - Steel making slag(converter slag, electric arc furnace slag)
- o Non – ferrous metal slag
  - Ferro- nickel slag
  - Copper slag

2. Slag from molten waste materials (molten trash slag .sewage sludge slag etc.)

The Steel Making Slag is a by product from steel making processes in which the contains of pig iron and steel-scrap are modified in order to produce steel that is so highly valued for excellent toughness and workability. Steelmaking slag contain of converter slag that is produce by converter and electric arc furnace slag that is product during the electric arc furnace steelmaking process that uses steel-scrap as the raw material.

The Converter Slag By the similar way as air-cooled blast furnace slag, converter slag is cooled slowly by natural cooling and water spray in a cooling yard. It is then processed and used for different iron and steel slag (converter) applications. Approximately (110 kg) of slag is produce for each ton of converter steel.
The Electric arc furnace slag is produce when iron scrap is melted and refined. It contains of oxidizing slag that is produce during oxidation refining, and reducing slag that is generated during reduction refining. About (70) kg of electric arc furnace oxidizing slag and (40) kg of reducing slag are generated for each ton of electric arc furnace steel [4].

The iron and steel slag is used in many fields where its unique properties can be put to effective use. As a result of growing environmental awareness, iron and steel slag is highly regarded as a recycled material that can reduce impacts on the environment due to its resource-conservation and energy saving effects. The Steelmaking slag Because of its hydraulic characteristic and the large bearing capacity it can produce, steelmaking slag is used as a road base course material. With high density of particle and hardness, this slag has superior resistance of wear and for this reason is used as an aggregate for asphalt concrete. In addition, according its high angle of shearing resistance, high particle density, and large weight per unit volume, it is also used as civil engineering works materials and as a ground modification material (i.e., material for sand compaction piles) [5].

2. Aim of the Work

The main goal of this research is to study effect of addition steel slag to ordinary Portland cement and find useful field of using steel slag, as industrial solid waste, saving raw materials and modified the cement as well as produce another types of Iraq cement contain locale steel slag. The using of steel slag for modification of concrete mixtures was one of the methods used to change the slag from solid environmental pollutant to valuable material from economical-technical point of view.

3. Experimental Part

3.1. Materials Used In the Work

The materials used in this study to make the samples used in the test Consist of;
A- Ordinary Portland cement (almass cement) Conforming to IQS No.5 (6).
B- Standard sand qualified with American standard specification ASTMC778 (7).
C- Steel slag from al Sumoode Company – the general company for steel production - metal and industry ministry.
D- Drinking water (Tap water).

3.2. General Specification of Materials

1. Iraqi ordinary Portland cement was brought from local market in (50) kg

packed paper bag conforming to IQS No.5 (6).As in Table (1) and (2).

Table1.The chemical analysis of the composition of the cements

Compound Composition	Abbreviation	Ratio By Weight	Limits of IQS No.5
Silica	SiO_2	19.75	_____
Lime	CaO	63.23	_____
Alumina	Al_2O_3	2.857	_____
Iron oxide	Fe_2O_3	3.149	_____
Sulfate	SO_3	2.36	2.8% ≤
Magnesium	MgO	1.746	5%≤
Loss On Ignition (%)	L.O.I	3.04	4%≤
Lime Saturation Factor (%)	L.S.F	0.95	0.66-1.02
Insoluble Residue (%)	I.R	0.64	1.5 ≤

Table2. Physical Property cements

Physical Property	Test result	Limits of IQS No.5
Specific Surface Area (cm^2/g)	3914	230 (min)
Setting time		
Initial (mins)	144	Min: 45 mins.
Final (mins)	396	Max: 10 hr.
Compressive strength (MPa)		
3 days	17.6	15 (min)
7 days	26	23 (min)

2 . Iraq Standard sand conforming to American standard specification ASTMC778 were also provided from local market.

C - Steel slag was provided from Sumood Company of steel production in the form of relatively large masses.

3 . Drinking water was available in the laboratory.

At the beginning, the masses of steel slag (SS) was crushed by hammer to smaller size and then. Crushed by Jaw crusher to fineness near to that of sand but this not wanted fineness therefor the steel slag was milling by mill type (maschineen fabrik H. G HEZOG-HSM100).

And sieving by sieve 200(micrometer) to have fineness more than that of ordinary Portland cement. The finesse test by Blaine methods and its about 4100 cm^2/g according American standard specification ASTMC204 (8) and Iraqi Standard No.198/1990(9).

Prepared steel slag was used in the mortar Mixtures in (20%, 40%, 60%, and 80%) addition of total weight of cements as shown in Table (3).

Table3. Details of mortar mix with different steel slag addition percentage.

Symbol	Cement (g)	Sand (g)	Water mL	W/C by Wt.	S/C	Slag by wt. of cement %	Flow 115±5 mm
ref	500	1375	236	0.472	-	0	11.6
S.A.I*	250	1375	222	0.444	1	25	11.6
S20	500	1375	246	0.492	0.2	20	11.5
S40	500	1375	250	0.5	0.4	40	11.5
S60	500	1375	255	0.51	0.6	60	11.5
S80	500	1375	269	0.538	0.8	80	11.5

*(S.A.I) this term meaning the slag activity index regard with ASTEM C989-05[10].

3.3. Chemical Composition of Steel Slag Used and Cement

Chemical composition of steel slag used in this work was analyzed in (S.C. of Geological Survey and Mining, Baghdad University). The composition depends on charge materials and melting process. The result was given in table (4) which taken by x-ray diffraction path. X-ray powder diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. The analyzed material is finely ground, homogenized, and average bulk composition is determined. X-ray powder diffraction is most widely used for the identification of unknown crystalline materials (e.g. minerals, inorganic compounds (11).

Table 4.X -Ray diffraction path analysis for steel slag

Symbol	Element	Norm. Int.	Concentration	Abs. Error
MgO	Magnesium	122.6973	3.606 %	0.028 %
Al2O3	Aluminum	2101.1839	14.62 %	0.02 %
SiO2	Silicon	12136.3219	35.34 %	0.03 %
P2O5	Phosphorus	359.9685	0.5376 %	0.0018 %
SO3	Sulfur	208.3830	0.1346 %	0.0006 %
Cl	Chlorine	310.5135	0.03659 %	0.00013 %
K2O	Potassium	69.0107	0.3149 %	0.0034 %
CaO	Calcium	3783.0742	14.75 %	0.02 %
TiO2	Titanium	894.1786	2.776 %	0.008 %
V2O5	Vanadium	54.9052	0.1133 %	0.0035 %
Cr2O3	Chromium	8242.5883	6.687 %	0.007 %
MnO	Manganese	8398.2332	5.162 %	0.006 %
Fe2O3	Iron	9350.8448	4.886 %	0.005 %
CoO	Cobalt	1.2397	< 0.00039 %	(0.0) %
NiO	Nickel	49.4333	0.01194 %	0.00016 %
CuO	Copper	73.4400	0.01367 %	0.00017 %
ZnO	Zinc	161.9469	0.02249 %	0.00015 %
Ga	Gallium	5.0842	0.00045 %	0.00006 %
Ge	Germanium	0.0000	< 0.00005 %	(0.0) %
As2O3	Arsenic	0.0000	< 0.00007 %	(0.0) %
Se	Selenium	0.0000	< 0.00005 %	(0.0) %
Br	Bromine	0.0000	< 0.00005 %	(0.0) %
Rb2O	Rubidium	45.5832	0.00125 %	0.00002 %
SrO	Strontium	1264.2564	0.03380 %	0.00008 %
Y	Yttrium	74.8981	0.00164 %	0.00003 %
ZrO2	Zirconium	148.3803	0.06773 %	0.00044 %
Nb2O5	Niobium	32.1535	0.01197 %	0.00016 %
Mo	Molybdenum	14.4673	0.00407 %	0.00012 %
Ag	Silver	0.0000	< 0.00020 %	(0.0) %
Cd	Cadmium	0.6309	< 0.00020 %	(0.0) %
SnO2	Tin	7.7931	0.00171 %	0.00012 %
Sb2O5	Antimony	5.2151	0.00134 %	0.00014 %
Te	Tellurium	6.0088	0.00034 %	0.00003 %
I	Iodine	0.0000	< 0.00030 %	(0.0) %
Cs	Cesium	0.0000	< 0.00040 %	(0.0) %
Ba	Barium	38.7340	0.03405 %	0.00095 %
La	Lanthanum	0.0000	< 0.00020 %	(0.0) %
Ce	Cerium	3.4209	0.00141 %	0.00045 %
Hf	Hafnium	2.5995	< 0.00018 %	(0.00004) %
Ta2O5	Tantalum	25.9399	0.00953 %	0.00035 %
WO3	Tungsten	6.3839	0.00152 %	0.00012 %
Hg	Mercury	0.0000	< 0.00010 %	(0.0) %
Tl	Thallium	0.0000	< 0.00010 %	(0.0) %
PbO	Lead	31.9798	0.00321 %	0.00006 %
Bi	Bismuth	0.0000	< 0.00010 %	(0.0) %
Th	Thorium	6.3403	0.00042 %	0.00004 %
U	Uranium	6.1109	< 0.00010 %	(0.0) %

3.4. Preparation of Mortar Mixtures Samples

In order to mix the samples required in this study, the following steps were done:
1. Metallic molds in which the samples were formed cubes (50*50*50) mm shapes were prepared and made clean, tighten and lubricate.
2. Mortar mixtures were prepared as showed in Table (3), were made respectively and cast in the prepared molds.
3. To prepare mortar mixtures, water was added to mix the solids materials, water quantity compute by flow table test to a constant workability of mortar about (115mm) According to ASTMC1437(12) and mix the mortar mixtures according to ASTMC305(13), uniform mixture was poured in the molds to form the samples, according to ASTMC109/C109M(14).
4. Point the numbers and the date of the casting samples.
5. Formed samples were left inside the mold for (24 hours), and then opened to have the samples prepared.
6. Samples for water permeability were put in oven to dry at (110^{o}C) for (24 hours). After drying, weight of samples was determined, samples were immersed in water bath for (7, 28 days), and then the weight of samples was rechecked. The difference in weight is the water Absorbed.
7. The remaining samples for compressive strength test were immersed in water For 7, 28 and 90 days. The results of the tests in (MPa) according to American standard specification ASTMC109/C109M after 7, 28 and 90 days were given in Table (7).

3.5. Testing of Prepared Samples

3.5.1. Testing of Physical Properties

1. Test of Standard consistency: this test include determined the standard consistency of all samples in the first case cement without steel slag and other cases include adding steel slag to total weight of cement in a percentage(20%,40%,60%,80%) as in Table(5).which determined according to IQS No.5.

Table5. Mixtures of cement and steel slag use for consistency and setting time (vicat) test.

Symbol	Cement (g)	Water mL	W/C	S/C	Slag % by the W.t	Setting time (mins)	
						initial	final
Ref	650	185.3	0.472	-	0	144	396
S20	650	218.4	0.492	0.2	20	169	374
S40	650	236.6	0.5	0.4	40	218	328
S60	650	265.2	0.51	0.6	60	200	314
S80	650	301	0.538	0.8	80	180	333

2. Testing of setting time: the setting time is determined for all mixes of cement and steel slag. The first mix of cement without steel slag and other mixes include adding

steel slag by weight of cement in a percentage (20%, 40%, 60%, 80%) as shown in Table (5).test methods were conforming to IQS No.5.

3 .Density calculation: the specimens were dried on laboratory oven at 110^0 C for 24 hours to insure completely dryness of the specimens. Then drying samples were weighed. Density had been calculated by dividing the drying weight of each specimen to the volume of it, as shown in Table (6).

4 . Water absorption Test: This test was carried out with regard to ASTM C642 (15).The Test has been achieved by using the weight of dried samples as a base. Then given samples were soaked completely in tap water basin for (7, 28) days and weighed again. The difference between the first and second weight was the weight of absorbed water. The percentage of absorbed water was calculated by dividing the absorbed water weight by the dry weight of each sample by (100) to get the value (wt. % value). The results were shown in Table (6), for each specimen.

Table 6. The absorption of samples in the case of addition steel slag.

No.	samples	Slag % by w.t	Mass of Dry Samples (g)	Calculated Density (gm/cm3)	Mass of Moist Samples(g)		Absorbed Water Percent Relative To Dry Mass (%)	
					7days	28 days	7days	28 days
1	ref	0	273.6	2.189	290.53	291.27	6.2	6.46
2	S20	20	284.7	2.278	297.19	298.37	4.4	4.81
3	S40	40	284.91	2.2793	298.93	299	4.9	4.95
4	S60	60	280.02	2.2402	293.3	294.1	4.7	5.03
5	S80	80	275.3	2.202	292.33	293.36	6.2	6.6

3.5.2. Testing of Compressive Strength

This test can be achieved by using the standard compression tester. The test was carried out after 7, 28 and (90) days for cubic samples. The results of tests were given in Table (7), for each case.

Table7. Results of compressive test and density in the case of addition slag to cement.

NO.	Symbol	Slag % by w.t	Density gm/cm^3	S/C	Flow 110±5mm	Compressive strength (MPa)		
						7 days	28days	90 days
1	ref	0	2.19	-	11.5	26	32	36
2	S.A.I	25	-	1	11.5	12.74	19.8	27.2
3	S20	20	2.278	0.2	11.4	26.86	29.6	46
4	S40	40	2.279	0.4	11.4	32.9	40.6	52
5	S60	60	2.24	0.6	11.4	28.6	22.92	43.2
6	S80	80	2.20	0.8	11.4	28.66	32.6	44

4. Results and discussion

1. Chemical analysis of slag: When comparing the local Iraqi slag with types of global slag and steel slag in England, Russia, Germany and France (Table 8). The Iraqi slag contains a proportion (14.62%) of AL_2 O_3which is low if compared with other centuries. As well as low content of CaO in Iraqi slag about 14.75%. High content of Fe_3O_2 about 4,886% a result of the high proportion of iron slag and dark color paste if compared its paste with normal Cement or global slag which is have conqueror color. the effectiveness of the global slag increasing by use of coke in electric arc furnaces which turn into a silica by firing .High increasing in silica lead to increase of effectiveness of the slag which it was few in Iraqi slag . As well as percentage of glass phase is low due to slow cooling method which was used to cool slag [16].

2. the initial setting time for all samples was increased .this behaver means that the steel slag was worked as retarder in low percentage .this will delay the process of hydration of cement due to low activity of steel slag if it was compared with high activity of cement .the final setting time would be lower than the final setting time of control mortar mix.

3 . The density of mortar increased by adding steel slag. The maximum density at 40% steel slag addition ratio of cement weight about 2.279 gm/cm^3 compared with density of samples without slag (2.16 gm/cm^3). Relatively high density concrete could be obtained by addition of 40% SS of cement weight. This increase in density of mortar specimens were due to more interference of small slag particles and high specific gravity of steel slag, so that final density would be higher and increased by Increasing steel slag content in mortar specimens . as shown in table (7).

4. Water absorption ratio was decreased by increasing slag addition ratio to cement. Except at 80% SS addition ratio, the Water absorption ratio was equal to that of reference which was about (6.2%) at 7 days and more than that of reference samples at 28 days about (6.6%). This drop in Water absorption ratio was due to smaller empty interspaces found which was within mortar structure if compared with that of samples without slag, so that the ability of water absorption by mortar would be less as shown in table (6).

5. The maximum compressive strength of the samples were at 40% SS addition ratio after 90 days as in Table (7).The compressive strength was increase with increase steel slag addition percentage until reached (60%, 80%) ,and then it will be decreased but remain higher than it for control mortar mix.

This increasing in compressive strength because of increase in a density due to high specific surface area of slag compared with specific surface area of cement therefore its fill the small pores which the cement cannot be filling it as well as reduce the free water. More over the slag increases size and quantity of hydration product of slag cement mix which have the direct effect in increase compressive strength.

6.the use of steel slag as addition material by weight percentage reduces flow ability. This reduction according to increase solid materials in the contents of mix and still water cement ratio was constant as well as specific surface area of slag was high. The addition of fine slag particles were made to compensate the loss of fine materials in cement and fine aggregate, but the fine aggregate which were used in this study not have loss in fine materials therefor any addition of fine slag will case reduction in workability.

Table 8.The composition of slag in different countries (17).

source	CaO%	SiO_2%	Al_2O_3%	MgO %	Fe_2O_3%
Iraq	14.75	35.34	14.62	3.606	4,886%
South Africa	39-28	38-28	22-10	21-7	3-0.4
Russia	48-29	35-34	23-5	18-0	2.4-0.3
France	48-40	36-29	19-13	8-2	3.8-0.5
German	46-38	35-29	16-10	12-4	1-0.2
British	43-36	36-28	22-12	11-4	0.7-0.3

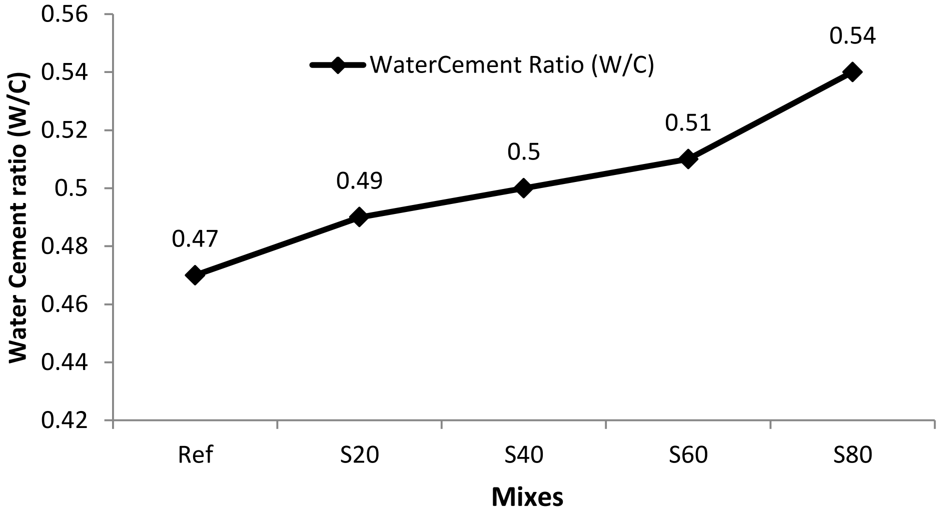

Fig (1) The relation shapes between steel slag % and water cement ratio (w/c).

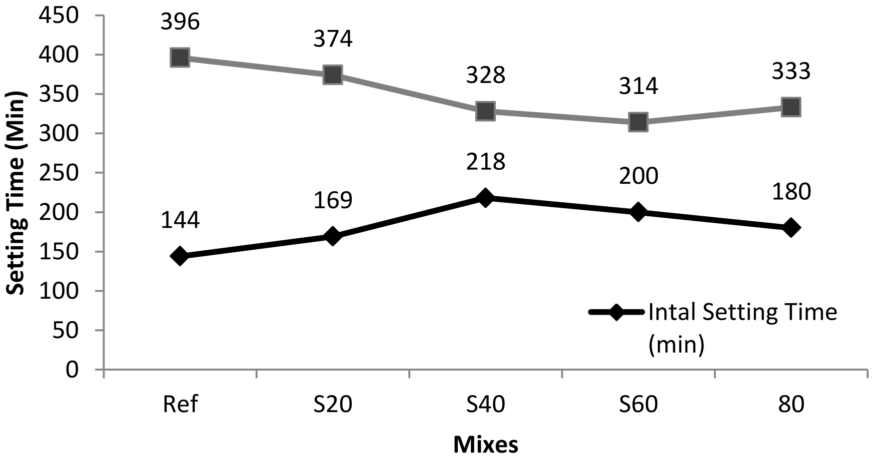

Fig .2 The initial and final setting time for cement and addition steel slag mixes.

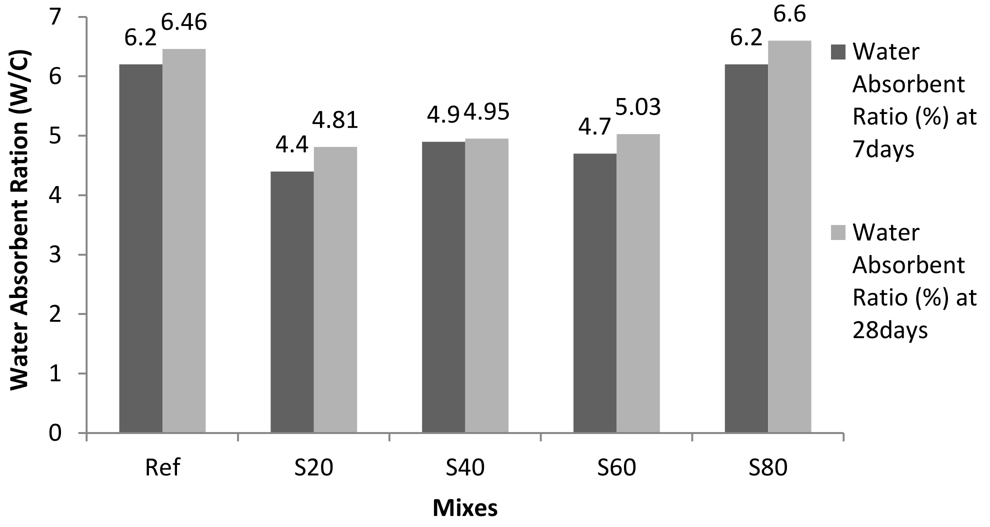

Fig 3.The relation between steel slag addition ratio and water absorption% at (7, 28) .

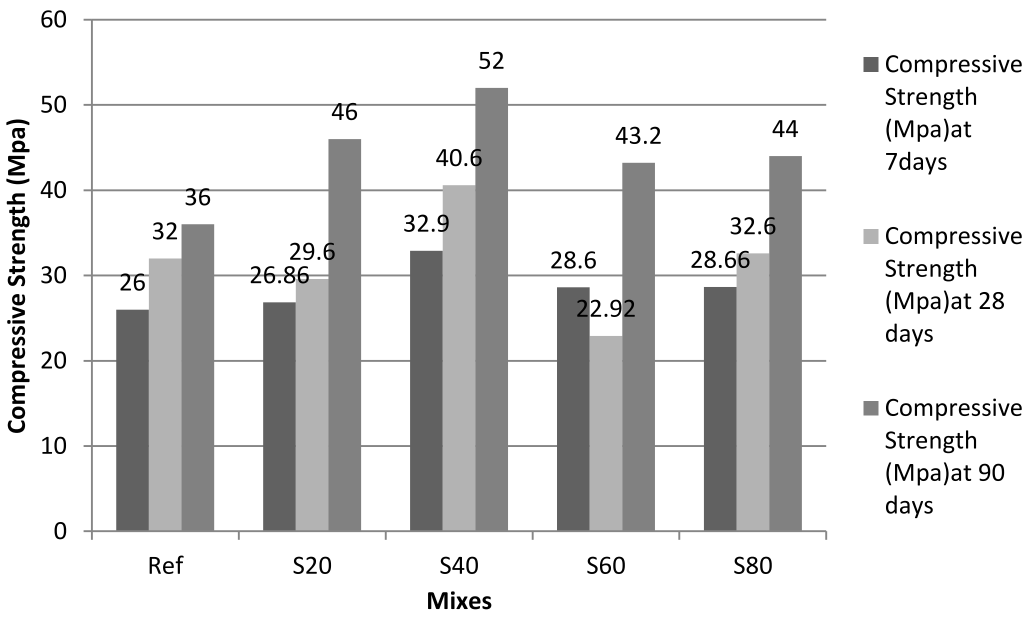

Fig 3.The relation between the steel slag addition ratio and compressive strength at (7, 28, 90) days.

5. Conclusion

1- Chemical analysis of slag: the local Iraqi slag showed that the low percentage of AL_2O_3 and CaO were about 14.62%, 14.75%.addition to above it had High content of Fe_3O_2 which was about 4,886% .This high content of Fe_3O_2 makes its paste has dark color as comparing with other types of global slag. The proportion of glass phase in the Iraqi slag is low because of left the slag cools slowly and not blowing out quickly.

2- The addition of steel slag to mortar mix was working as retarder for setting time when it was adding in low percentage.
3- The density of mortar specimens were increased by increase the slag addition percentage.
4- Water absorption ratio was reduced by adding steel slag but it was not affected when the addition ratio of steel slag reaches 80% by cement weight.
5- The workability of mortar mixes was reduced by adding of Steel slag because the steel slag has high specific surface area.
6- The compressive strength of mortar mixes was increased by Add steel slag to cement. The maximum compressive strength of mortar specimens was obtained at 40% SS addition ratio at 90 days.
7- Use of slag in cement production and as additives to concrete would reduce the solid waste and save the raw materials for cement production. As well as making modification its physical and mechanical properties.

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