ASIAN JOURNAL OF CIVIL ENGINEERING (BUILDING AND HOUSING) VOL. 12, NO. 5 (2011)
PAGES 563-578

DURABILITY STUDIES ON COPPER SLAG ADMIXED CONCRETE

D. Brindha* and S. Nagan
Department of Civil Engineering, Thiagarajar College of Engineering, Madurai-625015.
Tamil Nadu, India

Received: 29 December 2010, **Accepted:** 10 March 2011

ABSTRACT

Utilization of industrial soil waste or secondary materials has encouraged in construction field for the production of cement and concrete because it contribute to reducing the consumption of natural resources. Copper slag is one of the materials that is considered as a waste which could have a promising future in construction Industry as partial or full substitute of either cement or aggregates. Many researchers have already found it possible to use copper slag as a concrete aggregate. But not much research has been carried out in India concerning durability and corrosion studies of copper slag admixed concrete. This paper presents the results of an experimental study on various corrosion and durability tests on concrete containing copper slag as partial replacement of sand and cement. For this research work, M20 grade concrete was used and tests were conducted for various proportions of copper slag replacement with sand of 0 to 60%, cement of 0 to 20% in concrete. The obtained results were compared with those of control concrete made with ordinary Portland cement and sand.

Keywords: Copper Slag; hydrated lime; accelerated corrosion test; RCPT test; ultrasonic pulse velocity test; compressive strength; split tensile strength; acid attack etc

1. INTRODUCTION

The government of India has targeted the year 2010 for providing housing for all. Such large scale housing construction activities require huge amount of money out of the total cost of house construction, building materials contribute to about 70 percent cost in developing countries like India. Therefore the need of hour is replacement of costly and scarce conventional building materials by innovative, cost effective and environment friend by alternate building materials.

Utilization of industrial soil waste or secondary materials has encouraged in construction

* E-mail address of the corresponding author: dbrindha@yahoo.co.in (D. Brindha)

field for the production of cement and concrete because it contribute to reducing the consumption of natural resources. For many years, by-products such as fly ash, silica fume and slag were considered as waste materials. They have been successfully used in the construction industry for partially or fully replacement for fine and coarse aggregates. Akihiko Y, Takashi Y & Ayano Toshiki et al. [1] suggested that copper slag can be used as a replacement for fine aggregates in order to obtain a concrete with good strength and durability requirements. Ayano Toshiki, Kuramoto Osamu, Sakata Kenji [2] has clarified the strength, setting time and durability of concrete with copper slag.

Recent research papers of Bipra gorai et al. [4], Caijun Shi et al [10], and Christian Meyer, Ali Behnood [8] reviewed the potential use of copper slag as a partial substitute of cement and aggregates in concrete and asphalt mixtures. The effect of copper slag on the hydration of cement based materials was investigated by Mobasher et al [5] and Tixier et al [6]. The Pozzolanic activity of copper slag has been investigated by O.Pavez, F.Rojas et al [7].

Durability is a major concern for concrete structures exposed to aggressive environments. Many environmental phenomena like acid rain, polluted water etc significantly influence the durability of concrete structures. When Reinforced concrete structures are exposed to harsh environments, deterioration of concrete will occur due to many reasons like chloride and sulphate attack, acid attack and corrosion failure etc. it is now recognized that strength of concrete alone is not sufficient, the degree of harshness of the environmental condition to which concrete is exposed over its entire life is equally important.

Since copper slag contains more than 55% of ferrous content, corrosion and durability factors are necessary to find out, when it replaced with sand and cement in concrete. Although there are many studies that have been reported by investigators on the use of copper slag in cement concrete, not much research has been carried out in India and other countries concerning the incorporation of durability effect of copper slag in concrete. Therefore, to generate specific experimental data on durability properties of copper slag as sand and cement replacement in concrete, this research was performed.

2. EXPERIMENTAL PROGRAM

2.0 Materials

2.1 Cement

Ordinary Portland cement from Ramco Cement Company was used for this study. This cement is the most widely used one in the construction industry in India.

2.2 Coarse and fine aggregates

Coarse aggregates of 20mm size and fine aggregates of Zone II were procured from Melur area of Tamil Nadu.

2.3 Copper slag

Copper slag from Sterlite Industries India Limited (SIIL), Tuticorin, Tamil Nadu, India was made use of.

2.4 Physical properties of copper slag

The slag is a black glassy and granular in nature and has a similar particle size range like sand. The specific gravity of slag lies between 3.4 and 3.98. The bulk density of granulated copper slag is varying between 1.9 to 2.15 kg/ m^3 which is almost similar to the bulk density of conventional fine aggregate. The hardness of the slag lies between 6 and 7 in MoH scale. This is almost equal to the hardness of gypsum. The pH of aqueous solution of aqueous extract as per IS 11127 varies from 6.6 to 7.2. The free moisture content present in slag was found to be less than 0.5%. Gradation test was conducted on copper slag and sand showed that both copper slag and sand had comparable particle size distribution. However, it seems that sand has higher fines content than copper slag.

Tests to determine specific gravity and water absorption for copper slag and sand were carried out in accordance with ASTM C128. The results presented in Table.1 shows that copper slag has a specific gravity of 3.91 which is higher than that for sand (2.57) and OPC (3.12) which may results in production of HPC with higher density when used as sand substitution. Also**,** Table.2 shows that the measured water absorption for copper slag was 0.16% compared with 1.25% for sand. This suggests that copper slag would demand less water than that required by sand in the concrete mix. Therefore it is expected that the free water content in concrete matrix will increase as the copper slag content increases which consequently will lead to increase in the workability of the concrete.

Table 1: Physical Properties of copper slag

Physical Properties	**Sand**	**Copper slag**
Particle shape	Irregular	Irregular
Appearance	Brownish yellow	Black & glassy
Type	River sand	Air cooled
Specific gravity	2.57	3.91
Percentage of voids %	33	43
Bulk density g/cc	1.71	2.08
Fineness modulus of copper slag	2.73	3.47
Angle of internal friction	45°	51° 20’
Ultimate shear stress kg/cm^2	0.299	0.4106
Water absorption %	1.25	0.15 to 0.20
Moisture content %	0.5	0.1
Fineness of copper slag m^2 /kg (after grinding)	---	125

The presence of silica in slag is about 26% which is desirable since it is one of the constituents of the natural fine aggregate used to normal concreting operations. The fineness of copper slag was calculated as 125 m^2/kg. The following Table.2 shows physical properties of copper slag.

2.2 Chemical analysis of Copper Slag and Portland cement

Chemical analysis of Copper Slag and Portland cement are presented in Table 2. Ordinary Portland cement has a lime content of 63%, whereas copper slag has a very low lime content of <1%. Generally, the free lime content of Copper slag is very low. This indicates that Copper slag is not highly chemically reactive materials in order to be used as cementitious materials. Copper slag must have a sufficient quantity of lime to reach the required rate of hydration and to achieve the required early age strength. Therefore, in this case, in order to increase its Pozzolanic reaction, hydrated lime was added up to 2.0% to the weight of cement.

Copper slag has high concentrations of SiO_2 and Fe_2O_3 compared with OPC. In comparison with the chemical composition of natural pozzolans of ASTM C 618-99, the summation of the three oxides (silica, alumina and iron oxide) in copper slag is nearly 95%, (National council for cement and building materials, Ballabgarh)[9]which exceeds the 70% Percentile requirement for Class N raw and calcined natural pozzolans. Therefore, copper slag is expected to have good potential to produce high quality pozzolans.

Table 2: Chemical compositions of copper slag

S. No	Chemical component	% Of Chemical component
1.	SiO_2	25.84
2.	Fe_2O_3	68.29
3.	Al_2O_3	0.22
4.	CaO	0.15
5.	Na_2O	0.58
7.	K_2O	0.23
8.	LoI	6.59
9.	Mn_2O_3	0.22
10.	TiO_2	0.41
11.	SO_3	0.11
12.	CuO	1.20
13.	Sulphide sulphur	0.25
14.	Insoluble residue	14.88
15.	Chloride	0.018

2.3 Leaching of heavy elements in copper slag

Leaching of heavy metals in copper slag samples was conducted by National council for cement and building materials, New Delhi India as per method given in ASTM D-5233-1995d which involves sample treatment under aggressive conditions. The results presented in Table 3 indicate that the leaching of heavy metals was well below the toxicity limits even under aggressive conditions.

Table 3: Leaching of heavy elements in copper slag

Sample No	**Constituents determined**	**Leaching (ppm)**
1.	As	0.923
2.	Ba	0.258
3.	Cd	Nil
4.	Co	Nil
5.	Cr	Nil
6.	Cu	11.64
7.	Mn	0.048
8.	Mo	Nil
9.	Ni	0.097
10.	Pb	Nil
11.	Se	Nil
12.	Sr	0.046
13.	Zn	0.991

3. LABORATORY TESTING PROGRAM

3.1 Mix design and sample preparation

The mix proportion chosen for this study is **1 : 1.66 : 3.76 with 0.45 water/cement ratio.** Concrete mixtures with different proportions of copper slag ranging from 0% (for the control mix) to 60% for sand replacement and 0 to 20 % for cement replacement were considered. One set of cubes was prepared as a combination specimen which contains 40% of copper slag as fine aggregate and 15% of copper slag as cement These eight concrete mixtures were prepared with different proportions of copper slag as shown in Table 4. The materials were mixed in a rotating pan in accordance with ASTM C192-98 [8]. The mixes were compacted using vibrating table. The slump of the fresh concrete was determined to ensure that it would be within the design value and to study the effect of copper slag replacement on the workability of concrete. The specimens were demoulded after 24 hr, cured in water and then tested at room temperature.

Table 4: Concrete Mixtures with Different Proportions of copper slag with cement

Mix materials	CC kg/m^3	S20 kg/m^3	S40 kg/m^3	S60 kg/m^3	C05 kg/m^3	C15 kg/m^3	C20 kg/m^3	CMB kg/m^3
Cement	340	340	340	340	323	289	272	306
Copper slag	0	113.4	226.8	340.2	17	51	68	294.8
Water	153	153	153	153	153	153	153	153
F.A	567	453.6	340.2	226.8	567	567	567	340.2
C.A	1278	1278	1278	1278	1278	1278	1278	1278
Hydrated lime	0	0	0	0	1.7	5.1	6.8	3.4

4. TEST RESULTS AND DISCUSSIONS

4.1 Compressive Strength of Cubes

Concrete cubes of size 150 mm×150mm×150mm were cast with and without copper slag. The maximum load at failure reading was taken and the average compressive strength is calculated using the equation.

$$\textbf{Compressive strength}\,(\mathbf{N/mm^2}) = \frac{\textbf{Ultimate load in N}}{\textbf{Area of cross section}\,(\mathbf{mm^2})}$$

Here 0 to 60% (S20, S40& S60) of copper slag was replaced with sand and 0 to 20% (C05, C15& C20) of copper slag replaced with cement. Since optimum percentage of replacement was obtained at 40% replacement of copper slag with sand and 15% replacement with cement, one combination specimen (40% copper slag + 60%sand & 15% copper slag + 85% cement + 1.5% hydrated lime) was also cast for determining strength properties. For control concrete the compressive strength was found to be 35.11 N/mm^2. On the other hand, for slag admixed concrete the compressive strength obtained was 43.4N/mm^2 for S20 concrete, 46.67 N/mm^2 for S40 concrete and 39.7 N/mm^2 for S60 concrete after 28 days of curing. The compressive strength of the copper slag admixed concrete showed higher strength values than corresponding control concrete. The maximum percentage of increase in strength is found to be 32.93% at S40.

Similarly for cement replacement, to increase the pozzolanic reaction of copper slag concrete, hydrated lime (S Type) was added as an admixture in concrete specimens. After the addition of hydrated lime in concrete, the compressive strength of slag admixed concrete specimens showed higher strength values than that of the corresponding control specimens. The optimum percentage of strength was obtained at 15% replacement of cement with copper slag mixed with 1.5% of hydrated lime. The percentage increase in strength for 15% replacement is found to be 10.14%. After that the compressive strength of concrete decreased gradually. The combination specimens gave 8.87% increase in strength when hydrated lime was added as an activator. Table 5 shows the percentage increase in compressive strength for various percentage replacement of copper slag with sand and cement.

Table 5: Compressive Strength of cube specimens at 28 days

Sample No	% of replacement with copper slag	Ultimate load (kN)	Avg load (kN)	Compressive strength N/mm^2 at 28 days	Increase in compressive strength (%)
1	CC	770 820 780	790.00	35.11	–
2	S20	960 980 990	976.6	43.4	23.61
3	S40	1120 1020 1010	1050	46.67	32.93
4	S60	940 860 880	893.3	39.70	13.07
5	C05	800 830 840	823.33	36.67	4.44
6	C15	880 860 870	870	38.67	10.14
7	C20	750 670 650	690	30.67	–12.64
8	CMB	900 820 860	860	38.22	8.87

4.2 Split tensile strength test

Concrete cylinders of size 150 mm diameters and 300mm height were cast using 1:1.67:3.76 mix with a W/C ratio of 0.45 with and without copper slag. The maximum load at failure reading was taken and the average split tensile strength is calculated using the equation.

$$\textbf{Split tensile strength (N/mm}^2\textbf{)} = \frac{\mathbf{2P}}{\Pi\,\mathbf{L\,D}}$$

Where, P=Ultimate load at failure (N),
L=Length of specimen (mm),
D=Diameter of cylindrical specimen (mm).

Table 6: Split Tensile Strength test on cylinder specimens at 28 days

Sample No.	% of replacement with copper slag	Ultimate load (kN)	Average ultimate load in kN	Tensile strength N/mm^2 at 28 days	Increase in split tensile strength (%)
1	CC	250 240 220	236.66	3.354	-
2	S20	240 280 320	280.00	3.961	18.20
3	S40	310 320 340	323.33	4.576	36.45
4	S60	300 270 260	276.70	3.924	17
5	C05	250 240 260	250.00	3.536	5.4
6	C15	260 280 280	273.33	3.866	15.2
7	C20	220 190 200	203.33	2.878	-14.19
8	CMB	250 280 260	263.33	3.727	11.12

Table 6 shows the split tensile strength of cylindrical specimens for various replacement percentages of sand and cement with copper slag. Here for cement replacement hydrated lime (S type) was added as an activator. The optimum value was obtained at 40% replacement of sand with copper slag. When copper slag had been replaced with Ordinary Portland Cement, the Copper slag admixed concrete showed higher split tensile strength values than corresponding control concrete. The percentage increase in strength was found to be 15.2% at 15% replacement of cement and 36.45% at 40% replacement of sand. The combination specimens also give 11.12% higher split tensile strength than that of control concrete. Therefore it was observed that the addition of copper slag increased the split tensile strength of concrete admixed concrete up to 40% addition in sand and 15% addition in cement.

4.3 Ultrasonic pulse velocity measurement:

The ultrasonic pulse velocity of concrete is mainly related to its density and modulus of elasticity. This in turn, depends upon the materials and mix proportions used in making concrete as well as the method of placing, compaction and curing of concrete.

The quality of concrete was assessed using the guidelines given in Table 2 of IS 13311 (Part 1):1992.

Table 7: Results for Ultrsonic Pulse wave Velocity test

Sample No.	**Replacement % of copper slag in concrete**	**Distance (mm)**	**Transit time (µ Sec)**	**Pulse wave veloity (km/sec)**	**Average pulse velocity km/sec**	**Quality of concrete**
1	CC	150	33.30	4.504	4.546	Excellent
		150	32.20	4.615		
		150	32.80	4.520		
2	S20	150	32.30	4.644	4.753	Excellent
		150	30.80	4.870		
		150	31.60	4.747		
3	S40	150	30.50	4.918	5.038	Excellent
		150	30.00	4.988		
		150	29.80	5.208		
4	S60	150	31.30	4.792	4.689	Excellent
		150	32.60	4.601		
		150	32.10	4.673		
5	C05	150	31.00	4.839	4.807	Excellent
		150	31.30	4.792		
		150	31.40	4.777		
6	C15	150	30.70	4.886	4.833	Excellent
		150	31.30	4.792		
		150	31.10	4.823		
7	C20	150	33.40	4.491	4.470	Excellent
		150	34.10	4.399		
		150	32.80	4.520		
8	CMB	150	30.70	4.886	4.897	Excellent
		150	30.10	4.983		
		150	31.10	4.823		

UPV test results conducted for eight concrete mixes are shown in Table 7. The travel time of ultrasonic waves in concrete is slightly greater and hence pulse velocity in control mix is relatively less when compared to copper slag incorporated mixes. As the average pulse velocity is above 5 km/sec for the 40% copper slag replacement, it is understood that for 40% replacement, the density of the mix is high and free from pores. Also it could be seen that with 15% cement replaced mixes also gives higher pulse velocity. Therefore the quality of concrete is excellent for all mixes, especially for copper slag mixes, it is superficially excellent.

4.4 Accelerated corrosion process: Galvano static weight loss method

Since copper slag contains more than 50% of ferrous content, it is necessary to find corrosion properties of copper slag admixed concrete. To do so, the weighed TMT steel specimens were embedded in concrete cylinder of size 150mm diameter and 300 mm height. The concrete samples were subjected to alternate wetting and drying exposure in 3.5% NaCl solution. Regular D.C power supply of 12V is supplied continuously throughout the corrosion period of 15 days. Positive terminal of voltmeter is connected with soldered wires and negative terminal is connected with copper plate (cathode). After the process of accelerated corrosion was over, all the specimens were disconnected and removed from tank. After the corrosion period, the rod was taken out and weighed. The loss in weight was calculated. Corrosion test was conducted for coated and uncoated rebar. From the weight loss values, (ASTM G-1) the corrosion rates were obtained from the relationship:

$$\textbf{Corrosion Rate} = \frac{\mathbf{(K \times W)}}{\mathbf{(A \times T \times D)}}\,\textbf{(mm/yr)}$$

Where K is a constant, K = 87.6 in case of expressing corrosion rate in mm/yr

T is the exposure time expressed in hours,

A is the surface area in cm^2, W is the mass loss in milli gram, and

D is the density of the corroding metal (7.85g/cm^3)

From Table 8, it was observed that the slag admixed concrete showed higher corrosion rates than control concrete in all replacements. The corrosion rate of slag admixed concrete is maximum for 60% replacement of copper slag of sand. The combination specimens also showed 10 times greater rate of corrosion than control cylindrical specimens. Therefore the corrosion rate of slag admixed specimens are higher than the control concrete. To control the corrosion rate in concrete the rebar in cylindrical specimens was coated with zinc phosphate paint and tested for accelerated corrosion. After 15 days the coated specimens showed 0% corrosion for all replacements. Therefore it is recommended that if the slag admixed concrete is to be used in corroded environment, the reinforcement should be coated with some protective coating.

Table 8: Results for accelerated corrosion process (uncoated and coated rebar)

Mix	Weight of rod(gm)		% loss in weight of rod	Corrosion rate (uncoated rebar) mm/yr	Corrosion rate (coated rebar) mm/yr
	Before corrosion	After corrosion			
CC	320	318.5	0.468	0.30	Nil
S20	320	315.3	1.469	0.966	Nil
S40	320	313.3	2.093	1.38	Nil
S60	320	296.2	7.437	4.89	Nil
C05	320	317.6	0.750	0.489	Nil
C15	320	313.2	2.125	1.40	Nil
CMB	320	308.2	3.687	3.08	Nil

4.5 Rapid chloride permeability test

Corrosion is mainly caused by the ingress of chloride ion into concrete annulling the original passivity present. Rapid chloride permeability test (RCPT) has been developed as a quick test able to measure the rate of transport of Chloride ions in concrete. Concrete disc specimens of size 100mm dia and 50mm thick were cast using, with and without copper slag. After 24 hours, the disc specimens were removed from the mould and subjected to curing for 90 days in chloride free distilled water. After curing, the specimens were tested for chloride permeability. All the specimens were dried free of moisture before testing. The test set up is called rapid chloride penetration test (RCPT) assembly. This is a two-component cell assembly checked for air and watertight. The cathode compartment is filled with 3%NaCl solution and anode compartment is filled with 0.3 NaOH solutions. Then the concrete specimens were subjected to RCPT by impressing a 60V from a DC power source between the anode and cathode. Current is monitored up to 6 hours at an interval of 30 minutes. From the current values, the chloride permeability is calculated in terms of coulombs at the end of 6 hours by using the formula.

$$Q= 900\ (I_0 + 2I_{30} + 2I_{60} + 2I_{90} + \ldots\ldots\ldots\ldots + 2I_{300} + 2I_{330} + 2I_{360})$$

Where,

Q = Charge passed (Coulombs)

I_0 = Current (amperes) immediately after voltage is applied

I_t = Current (amperes) at t min. after voltage is applied

The relationship between chloride penetrating rate and the charge passed by coulombs is given in Table 9.

Table 9: Rapid Chloride Ion Penetrating Test

S. No	Mix	Charge passed in Coulombs	As per ASTM C1202: Chloride penetrating rate
1	CC	406.18	Very low
2	S20	341.37	Very low
3	S40	522.03	Very low
4	S60	810.05	Very low
5	C05	533.65	Very low
6	C15	602.91	Very low
7	CMB	487.64	Very low

For control concrete, the average charge passed was found to be 406.18 and for slag admixture concrete the maximum charge passed was 810.05 after 90 days of curing. The charge passed for copper slag admixed concrete has shown slightly higher values than control concrete but within the limits. As per ASTM C1202, the value obtained for slag admixed concrete is graded under the category “very low”. As such, it is indicating lesser permeability of slag admixture concrete.The important observation is that addition of slag definitely reduces the pores of concrete and makes the concrete impermeable.

4.6 Acid resistance test

A total number of 60 cubes of size 150mm×150mm cast and stored in a place at a temperature of 27°C for 24 hours and then the demould specimens were water cured for 28 days. After 28 days curing, the specimens are taken out and allowed to dry for one day. Initial weights of the cubes were taken. For acid attack, 5% dilute sulphuric acid (H_2So_4) by volume of the water with ph value of about 2 was used. After that cubes were immersed in the above said acid water for a period of 30 & 60 days. The test was repeated for 30 cycles and the concentration of the solution was maintained throughout this period by changing the solution periodically. The specimens were taken out from the Acid solution at 30& 60 days. The surface of the cubes were cleaned, weighed and then tested in the compression testing machine and the test results are presented in the Table 10 and 11. Figure 1 shows the reduction of compressive strength of concrete cubes due to acid attack.

Table 10: Effect of acid on compressive strength of M20 Grade of concrete at 30 days

S.No	% of replacement with copper slag	Weight of cubes(kg) Before immersion	Weight of cubes(kg) After immersion	% Loss in wt.	Ultimate load (kN)	Avg (kN)	Compressive strength N/mm^2 at 30 days
1	CC	8.6	8.46	1.627	740	790	33.18
		8.66	8.52	1.616	720		
		8.64	8.52	1.388	780		
2	S20	8.96	8.36	6.696	700	740	32.8
		9.02	8.56	5.099	750		
		8.98	8.24	8.240	770		
3	S40	9.06	8.48	6.401	640	620	27.5
		9.04	8.38	7.3	630		
		9.02	8.34	7.528	650		
4	S60	9.06	8.28	8.609	580	570	25.2
		9.48	8.8	7.172	490		
		9.25	8.6	7.027	640		
5	C05	8.36	8.04	3.827	490	485	21.6
		8.28	7.5	9.420	510		
		8.32	7.77	6.610	455		
6	C15	9.04	7.86	13.052	580	570	25.37
		9.08	8.38	7.709	590		
		9.05	7.88	12.928	570		
7	CMB	8.88	8.16	8.108	440	450	19.88
		8.94	8.2	8.277	420		
		8.96	8.22	8.258	490		

Table 11: Effect of acid on compressive strength of M20 Grade of concrete at 60 days

S. No.	% of replacement with copper slag	Weight of cubes(kg)		% Loss in wt.	Ultimate load (kN)	Avg (kN)	Compressive strength N/mm^2 at 60 days
		Before immersion	After immersion				
1	CC	8.6	8.36	2.790	680	670	29.7
		8.66	8.42	2.771	700		
		8.64	8.32	3.703	630		
2	S20	8.96	8.16	8.928	500	510	22.66
		9.02	8.36	7.317	560		
		8.98	8.04	10.467	470		
3	S40	9.06	8.28	8.609	450	480	21.33
		9.04	8.18	9.513	510		
		9.02	8.14	9.756	480		
4	S60	9.06	8.08	10.816	360	400	17.77
		9.48	8.68	8.438	410		
		9.25	8.48	8.324	430		
5	C05	8.36	7.88	5.740	350	350	15.55
		8.28	7.35	11.321	380		
		8.32	7.57	9.014	320		
6	C15	9.04	7.56	16.371	400	380	16.88
		9.08	8.18	9.911	410		
		9.05	7.58	16.241	330		

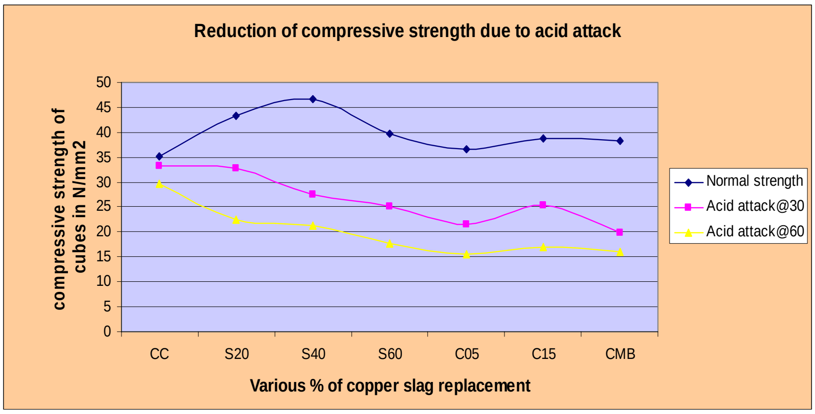

Figure 1. Reduction of compressive strength of cubes after acid attack

The results revealed that the copper slag replaced concrete specimens showed lesser resistance to acid attack, when compare to control concrete. The dimension of cube specimens were reduced 3mm for all sides at 30days. From the test results, the concrete containing copper slag was found to be slightly decrease resistant to the H_2So_4 solution than the control concrete.

5. CONCLUSIONS

The following conclusions were drawn from this study

- The utilization of copper slag in cement and concrete provides additional environmental as well as technical benefits for all related industries.
- Replacement of copper slag in both fine aggregates and cement replacement reduces the cost of making concrete.
- When copper slag replaced with cement, use of hydrated lime by 1.5% to the weight of cement gives improvement in rate of strength gain.
- Replacement of copper slag increases the self weight of concrete specimens to the maximum of 15 to 20%.
- For higher replacement of copper slag in cement (greater than 20%) and sand (greater than 50%) the compressive and split tensile strength decreases due to an increase of free water content in the mix.
- The results of compressive, split tensile strength test have indicated that the strength of concrete increases with respect to the percentage of slag added by weight of fine aggregate up to 40% of additions and 15% of cement.
- As per ASTM C1202, the chloride penetrating value obtained for copper slag admixed concrete is graded under the category "very low". As such, it is indicating lesser permeability of slag admixture concrete .The important observation is that addition of slag definitely reduces the pores of concrete and makes the concrete impermeable.
- From acid resistance test, it was observed that the concrete containing copper slag was found to be slightly low resistant to the H_2So_4 solution than the control concrete.
- Accelerated corrosion test reveals that the corrosion rate of copper slag admixed uncoated rebar is some what higher when compared to controlled specimens. But when the rebar is coated with zinc phosphate paint the corrosion rate had became zero.
- Since copper slag concrete exhibits good durability characteristics, it can be used as an alternate to fine aggregate and also be utilized in cement as a raw material for making blended cements.

Acknowledgement: The authors wish to acknowledge Thiagarajar College of Engineering, Madurai and Sterlite Industries (India) Ltd., Tuticorin, India for providing all the facilities for carrying out this work.

REFERENCES

1. Akihiko Y, Takashi Y. Study of utilization of copper slag as fine aggregate for concrete. *Ashikaya Kogyo Daigaku Kenkyu Shuroku*, **23**(1996)79-85.
2. Ayano Toshiki, Kuramoto Osamu, Sakata Kenji, Concrete with copper slag fine

aggregate. *Society of Materials Science*, No. 10, **49**(2000) 1097-102.

3. Al-Jabri K, Taha R, Al-Ghassani M. Use of copper slag and cement by-pass dust as cementitious materials. *Cement Concrete Aggregates*, No. 1, **24**(2002)7-12.
4. Bipra gorai, R.K. Jana, Premchand, Characteristics and utilisation of copper slag - a review. *Resources, Conservation and Recycling*, **39**(2003) 299-313.
5. Mobasher B, Devaguptapu R, Arino AM. Effect of copper slag on the hydration of blended cemetitious mixtures. In: Chong K, editor. *Proceedings of the ASCE Materials Engineering Conference, Materials for the New Millennium*; 1996. pp. 1677-1686.
6. Tixier R, Arino-Moreno A, Mobasher B. Properties of cementitious mixture modified by copper slag. Symposium: HH, Structure-Property Relationships in Hardened Cement Paste and Composites. Tucson, Arizona, USA: Minerals Research and Recovery; 1996.
7. Pavez O, Rojas F, Palacios J, Nazer A. Pozzolanic activity of copper slag. *Proceedings of the VI National Conference on Clean Technologies for the Mining Industry*, Chile 2002.
8. Shi C, Meyer C, Behnood A. Utilization of copper slag in cement and concrete Resources, Conservation and Recycling, **52**(2008) 1115–20.
9. Khalifa S. Al-Jabri, Makoto Hisada, Salem K. Al-Oraimi, Abdullah H. Al-Saidy. Copper slag as sand replacement for high performance concrete, *Cement & Concrete Composites*, No. 7, **31**(2009) 483–8.
10. Caijun Shi, Jueshi Qian, High performance cementing materials from industrial slags - a review, *Resources, Conservation and Recycling* **29**(2000)195–207.
11. Report on Utilization of copper slag as performance improver in ordinary Portland cement for M/s Sterlite Industries (India) Ltd., Tuticorin, Tamil Nadu, submitted by National Council for cement and building materials, New Delhi, Jan 2009.
12. Collins R, Ciesielski SK. Recycling and use of waste materials and by-products in highway construction. In: National cooperative highway research program synthesis of highway practice no. 199. Washington (DC): Transportation Research Board; 1994.
13. Deja J, Malolepszy J. Resistance of alkali activated slag mortars to chloride solution. In: Proceedings of the third international conference on the use of fly ash, silica fume, slag, and natural pozzolans in concrete. *ACI* SP-114, **2**(1989) 1677–95.
14. Washington Almeida Moura Jardel Pereira Gonc¸ alves Monica Batista Leite Lima, Copper slag waste as a supplementary cementing material to concrete, *Journal of Material Scienc*, **42**(2007) 2226–30.
15. Zong L. The replacement of granulated copper slag for sand concrete. *Journal of Qingdao Institute of Architecture and Engineering*, No. 2, **24**(2003)20–2.
16. Hwang CL, Laiw JC. Properties of concrete using copper slag as a substitute for fine Aggregate. In: *Proceedings of the 3rd international conference on fly ash, silica fume, slag, and natural pozzolans in concrete*, SP-114, **82**(1989) 1677–95.
17. Khalifa S. Al-Jabri, Makoto Hisada, Abdullah H. Al-Saidy, and S.K. Al-Oraimi. Performance of high strength concrete made with copper slag as a fine aggregate. *Construction and Building Materials* **23**(2009) 2132–40.
18. IS: 383-1970. Specifications for Coarse and Fine Aggregates from Natural Sources for Concrete. Bureau of Indian Standards, New Delhi.
19. IS: 456-2000. Plain and Reinforced Concrete. Code of Practice. Bureau of Indian Standards, New Delhi.