

Characteristics of M30 Grade Concrete using Copper Slag as Partial Replacement for River Sand as Fine Aggregate

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ABSTRACT

Concrete is the preferred construction material for a wide range of buildings, bridges and any other civil engineering structures. It is the second most widely consumed substance on earth after water. Aggregates are considered as one of the main constituents of concrete since they occupy 70-80% of the volume of concrete. In many countries, there is a scarcity of natural aggregates. To reduce dependence on natural aggregates as the main source of aggregate in concrete, artificially manufactured aggregates generated from industrial wastes provide an alternative for the construction industry. Copper slag is one such industrial waste that can be implemented as an alternative for natural aggregate. Copper slag is an excellent by-product or waste material that retains its original properties. Due to its chemical composition which includes high iron, silica and aluminum oxide content, it can be used as a partial replacement for sand in concrete mixes. This paper emphasizes on COPPER SLAG CONCRETE which is a new evolution in the field of concrete design. Copper slag upon using as a partial replacement for river sand as fine aggregate can avoid the voids in the concrete and may increase the durability and strength of structure. In this study M30 grade concrete mixes of 30%, 40% and 50% replacement of river sand with copper slag are tested for compressive, split tensile and flexural strengths for the ages of 1, 3, 7, 28, 56 and 91 days of curing.

Key Words: Copper slag, Copper slag concrete, Fine Aggregate, M30 Grade Concrete.

1. INTRODUCTION

Concrete is the man made material widely used for construction purposes. It is a popular building material in the world for past 170 years and more. The usual ingredients in concrete are cement, fine aggregate, coarse aggregate, and water. Although worldwide used concrete has disadvantages such as scarcity in availability of natural aggregates like river sand which is used as fine aggregate in concrete, consumption of aggregates in construction industry globally are still projected at an increase of more than 51 billion metric tons by 2021. Such large consumption of natural aggregates will cause destruction to the environment. To overcome this issue, industrial wastes should be used as an alternative to naturally available aggregates. The beneficial use of industrial by-products in concrete is well known for many years with regard to the use of materials such as coal ash, fly ash, pulverized fuel ash, bottom ash, blast furnace slag and silica fume as partial replacement for Portland cement or as fine aggregate.

Natural resources are depleting worldwide while at the same time the generated wastes from the industry are increasing substantially. The sustainable development for construction involves the use of non-conventional and innovative materials. This can be achieved by recycling of waste materials in order to compensate the lack of natural resources and to find alternative ways for conserving the environment.

1.1 Copper Slag

Copper slag is produced as a by-product of metallurgical operations in reverberator furnaces. For every ton of copper production, about 2.2 tons of copper slag is generated. Earlier copper slag was used as an abrasive material for removing rust and marine deposits from ships through sand blasting. After repetitive recycling and reuse, the copper slag lost its original abrasive property and with no good use thereafter, it was disposed in landfills. Industries found a novel way of encapsulating this waste into concrete, thereby not only removing the environmental concern but also finding a value-added and meaningful substitute for natural sand.

Copper slag is totally inert material and its physical properties are similar to natural sand. Copper slag when grounded fine can be used as a replacement for sand in concrete which provides potential, environmental as well as economic benefits for all related industries. The major constituent of a smelting charge are sulphides and oxides of iron and copper. The charge also contains oxides such as SiO₂, Al₂O₃, CaO and MgO which are either present in original concentrate or added as flux. It is Iron, Copper, Sulphur, Oxygen and their oxides which largely control the chemistry and physical constitution of smelting system.

Copper slag concrete historically has been utilized in a variety of ways. Though most copper processing facilities currently recycle or dispose of their slag, there are numerous opportunities for utilization. The application that could potentially use the largest quantities of copper slag is using it as a highway construction aggregate. Copper slag has also been utilized for construction purposes in the past, but all facilities currently generating dispose of them.

2 OBJECTIVE OF STUDY

The objective of the present study is to determine and compare the properties of copper slag concrete with that of conventional concrete in terms of workability, compressive strength, split tensile strength and flexural strength.

3 SCOPE OF STUDY

The scope of the present investigation is to study and evaluate the effect of replacement of river sand with copper slag in concrete and to evaluate the strength characteristics of copper slag concrete in terms of compressive, split tensile and flexural strengths, a total of 4 mixes were cast with different proportions of copper slag as a replacement of fine aggregate (0%, 30%, 40%, 50%) and optimum dosage is found out. Later for this optimum dosage, compressive strength, split tensile strength and flexural strength tests were carried out. In all mixes, the same type of aggregate i.e. crushed granite aggregate, river sand and the same proportion of fine aggregate to total aggregate are used. The relative proportions of cement, coarse aggregate, sand and water are obtained by IS - Code method. M30 grade of concrete is considered as a reference mix. Cubes of standard size 150 mm x 150 mm x 150 mm (length x breadth x height) were cast and tested for 1, 3, 7 and 28 days compressive strength. Standard cylinders of size 150 mm x 300 mm (length x breadth) were cast and tested for 1, 3, 7, 28, 56 and 91 days split tensile strength. Standard beams of size 500 mm x 100 mm x 100 mm (length x breadth x height) were cast and were tested for 1, 3, 7, 28, 56 and 91 days flexural strength.

4. EXPERIMENTAL DETAILS

In the present investigation, the following materials were used

- Ordinary Portland Cement of 53 Grade cement conforming to IS: 169-1989.
- River sand of zone-II is used as fine aggregate conforming to IS: 2386-1963.
- Crushed granite material with 60% passing 20mm and retained on 10mm sieve, 40% passing 10mm and retained on 4.75mm sieve is used as coarse aggregate.
- Copper slag.
- Potable fresh water free from concentration of acid or organic substances was used for mixing the concrete.

4.1 Cement

Ordinary Portland cement (OPC) is the commonly used cement in general uses throughout the world as a prime ingredient of concrete, mortar. Ordinary Portland Cement of 53 Grade of brand name Ultratech, available in the local market was used for the investigation. The physical properties of the cement are listed in Table 1

Table.1 Physical properties of cement

S.no.	Property	Value
1.	Specific Gravity	3.01
2.	Fineness of cement (By sieving)	2.75%
3.	Standard Consistency	31%
4.	Setting Time	
	i) Initial setting time	115 minutes
	ii) Final setting time	253 minutes

4.2 Fine Aggregate

Natural River sand is used as fine aggregate. The physical properties of sand are listed in Table 2.

Table 2. Physical properties of sand

S.no.	Property	Value
1.	Grading of Sand	Zone II as per IS 383
2.	Specific Gravity	2.61
3.	Fineness Modulus	2.66

4.3 Coarse Aggregate

Aggregates typically make up about 60 to 80% of the volume of concrete mixture. The aggregates of size 10mm and 20mm of following physical properties are used in present investigation.

Table 3. Physical properties of coarse aggregates

S.no.	Property	Value
1.	Specific Gravity	2.74
2.	Fineness Modulus	6.76
3.	Water Absorption	1%

4.4 Copper slag

Copper slag is a by-product obtained during the matte smelting and refining of copper. Copper slag is also called as Ferro sand. Copper slag is a black glassy and granular in nature and has similar particle size range like sand. It is also found that the copper slag has less moisture content so it has less heat of hydration. The glass content of slag is suitable for blending with Portland cement typically varies between 90-100% and depends on the cooling method and the temperature at which cooling is initiated. The glass structure of the quenched glass largely depends on the proportions of network-forming elements such as Si and Al over network-modifiers such as Ca, Mg and to a lesser extent Al. The physical and chemical properties of copper slag are listed in Table 4 and Table 5 respectively.

Table 4. Physical properties of copper slag

S.no.	Physical properties	Suggested values by supplier
1.	Colour	Black
2.	Specific Gravity	3.77
3.	Fineness	3.44%

Table 5. Chemical properties of copper slag

S.no.	Chemical component	% of chemical component
1	SiO ₂	25.42
2	Fe ₂	68.79
3	Al ₂ O ₃	0.21
4	CaO	0.14
5	Na ₂ O	0.55
6	K ₂ O	0.22
7	MnO ₃	0.24
8	TiO ₂	0.39
9	SO ₃	14.38
10	CuO	6.53

4.5 Water

The water used for mixing and curing should be clean and free from hazardous impurities such as alkalis, acids, oils, salt, sugar, organic materials, vegetable growth and other substances that may be deleterious to bricks, stone, concrete or steel. Potable water is generally considered satisfactory for mixing. The **pH** value of water should not be less than 6.

4.6 Mix Proportions

In this study, mix design is carried out according to IS 10262 : 2009. M30 grade of concrete was designed. The control mix (Mix 0) has proportion (by weight) of 1(cement): 1.82(fine aggregate): 3.18(coarse aggregate) and water to cement ratio(w/c) is 0.45. In mixes Mix-1, Mix-2 and Mix-3, river sand(fine aggregate) is partially replaced with 30%, 40% and 50% copper slag respectively.

Table 6. Mix proportions of M30 concrete

Mix designation	Water (lt/m ³)	Cement (kg/m ³)	Fine aggregate (kg/m ³)	Coarse aggregate (kg/m ³)	Copper slag (kg/m ³)
Mix-0	171	380	694.95	1209.79	0
Mix-1	171	380	486.47	1209.79	208.49
Mix-2	171	380	416.97	1209.79	277.9
Mix-3	171	380	347.46	1209.79	347.46

4.6 Preliminary Investigations

In the preliminary investigation, so as to obtain the optimum percentage replacement of fine aggregate with copper slag, tests like workability and compressive strength were conducted on 30%, 40% and 50% replacement of fine aggregate with copper slag. Workability is conducted in terms of compacting factor test. The variation of compaction factor and compressive strength for respective percentages of fine aggregate replacement with copper slag are tabulated below

Table 7. Variation of compaction factor

Grade of Concrete	M30			
	Mix – 0 (0% CS)	Mix – 1 (30% CS)	Mix – 2 (40% CS)	Mix – 3 (50% CS)
Percentage Replacement of Copper slag concrete				
Compaction Factor	0.89	0.88	0.87	0.85

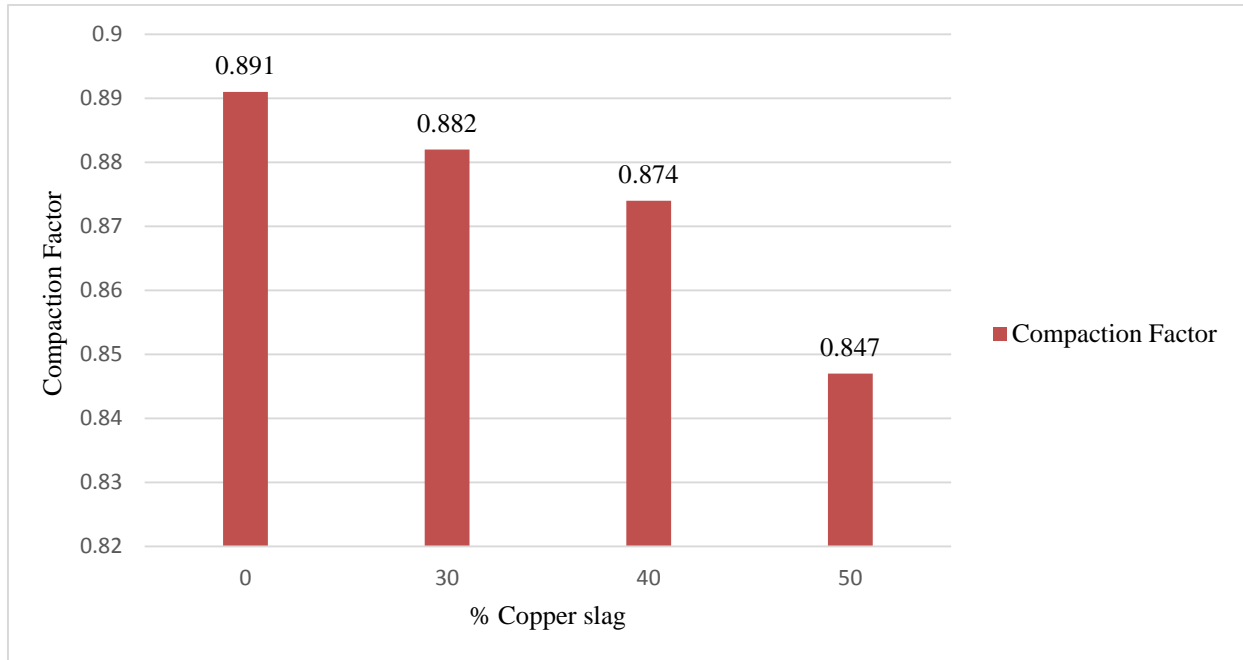


Figure1. Variation of workability (compaction factor)

Table 8. Variation of compressive strength for 7 and 28 days curing

Age(days)	Compressive strength(MPa)			
	Mix – 0 (0% CS)	Mix – 1 (30% CS)	Mix – 2 (40% CS)	Mix – 3 (50% CS)
7	28.29	27.81	42.51	24.88
28	42.03	30.57	53.48	32.79

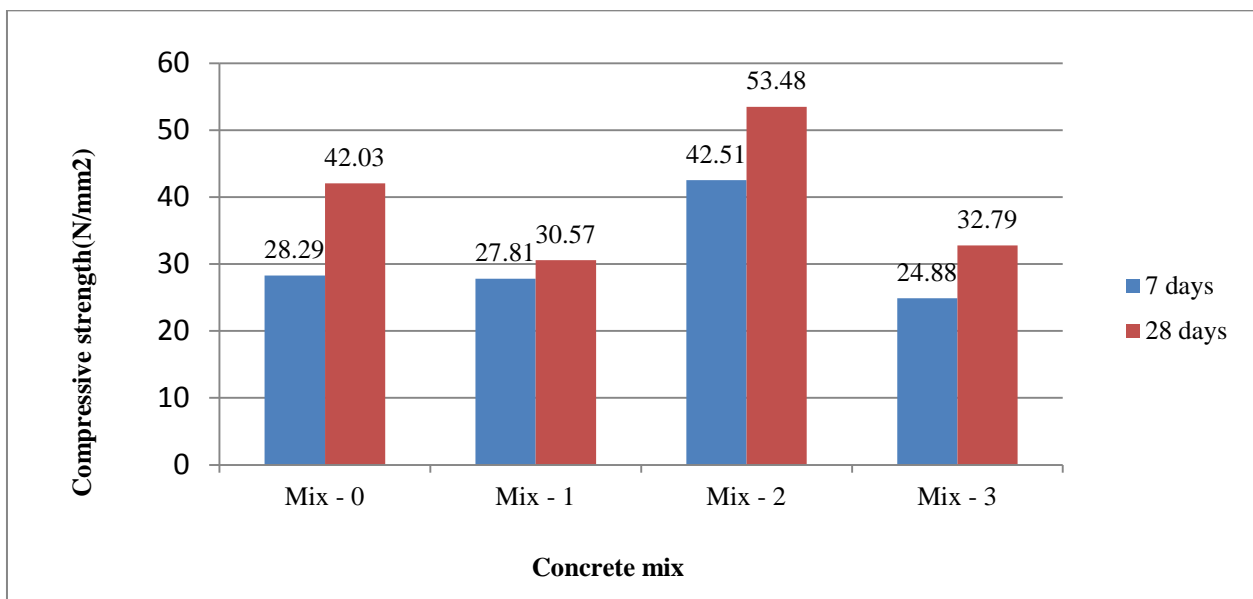


Figure 2. Variation of compressive strength for 7 and 28 days curing

It has been observed that 40% replacement of fine aggregate with copper slag (Mix-2) is giving better results when compared with other replacements. Hence, we can conclude 40% replacement of fine aggregate with copper slag as the optimum dosage.

5. RESULTS AND DISCUSSION

5.1. Workability in terms of Compaction Factor

The values of compaction factor obtained in the present investigation for various percentages of replacement of fine aggregate with Copper slag are shown in Table 7. It can be observed that as the percentage of the replacement of fine aggregate with Copper slag increases the compaction factor decreases. Hence it can be concluded that as the percentage of Copper slag increases the workability decreases.

5.2. Compressive strength of M30 grade Concrete

Compressive strength test has been conducted on cubes of standard size 150 mm x 150 mm x 150 mm for all mixes and resulting compressive strength obtained at the age of 1, 3, 7, 28, 56 and 91 days for M30 grade concrete were tabulated in the table 8, 9 and fig 3. It can be seen that the compressive strength of concrete with fine aggregate replaced by Copper slag is more than the conventional concrete mix at all ages.

Table.9 Compressive strength of M30 grade concrete with 40% replacement of fine aggregate by copper slag

Age (days)	Compressive strength (MPa)	
	0%CS	40%CS
1	19.91	27.84
3	26	35.7
7	28.29	42.51
28	42.03	53.48
56	45.7	53.72
91	46.6	53.86

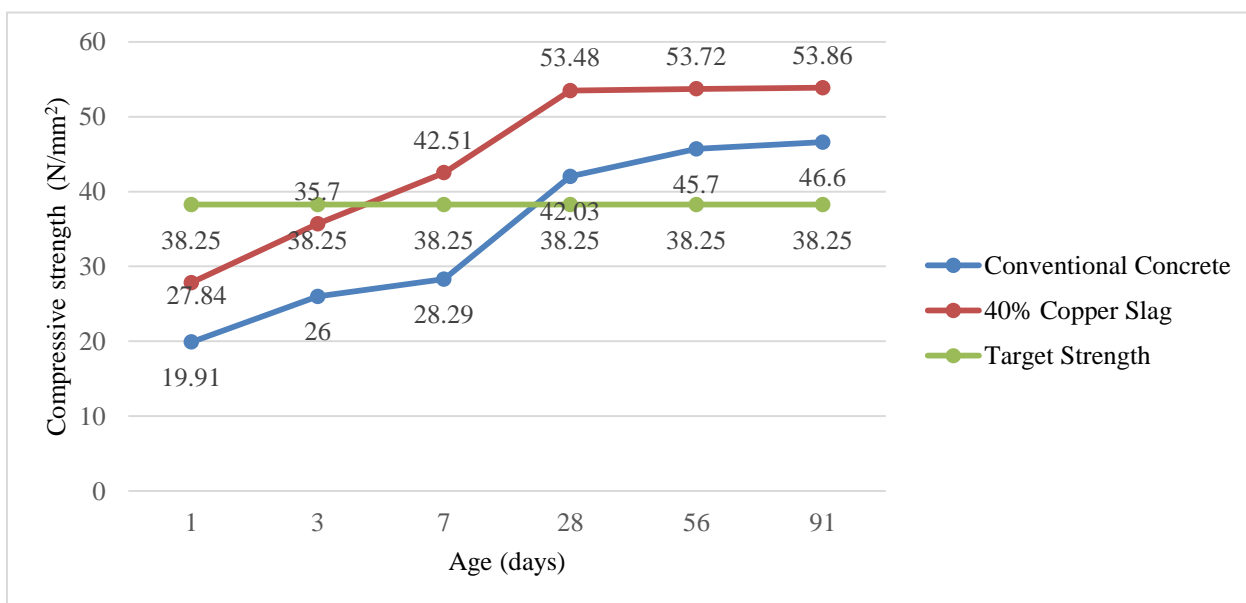


Figure 3. Variation of compressive strength with age for conventional concrete and 40% copper slag concrete

Observation: It is observed that 40% replacement of natural sand by Copper slag is giving better compressive strength for M30 grade concrete compared to other proportions of mixes for all ages.

5.3 Split Tensile strength test

Split tensile strength test has been conducted on cylinders of size 150mm x 300mm for all mixes and resulting split tensile strength obtained at the age of 1, 3, 7, 28, 56 and 91 days for M30 grade concrete were tabulated in the table 10 and fig.4. It can be seen that the split tensile strength of concrete with fine aggregate replaced by Copper slag is more than the conventional concrete mix at later ages.

Table: 10. Split tensile strength of M30 grade concrete with 40% replacement of fine aggregate by copper slag

Age (days)	Split Tensile strength (MPa)	
	0%CS	40%CS
1	1.59	1.93
3	1.88	2.19
7	2.49	2.68
28	2.87	2.89
56	3.25	3.49
91	3.34	3.72

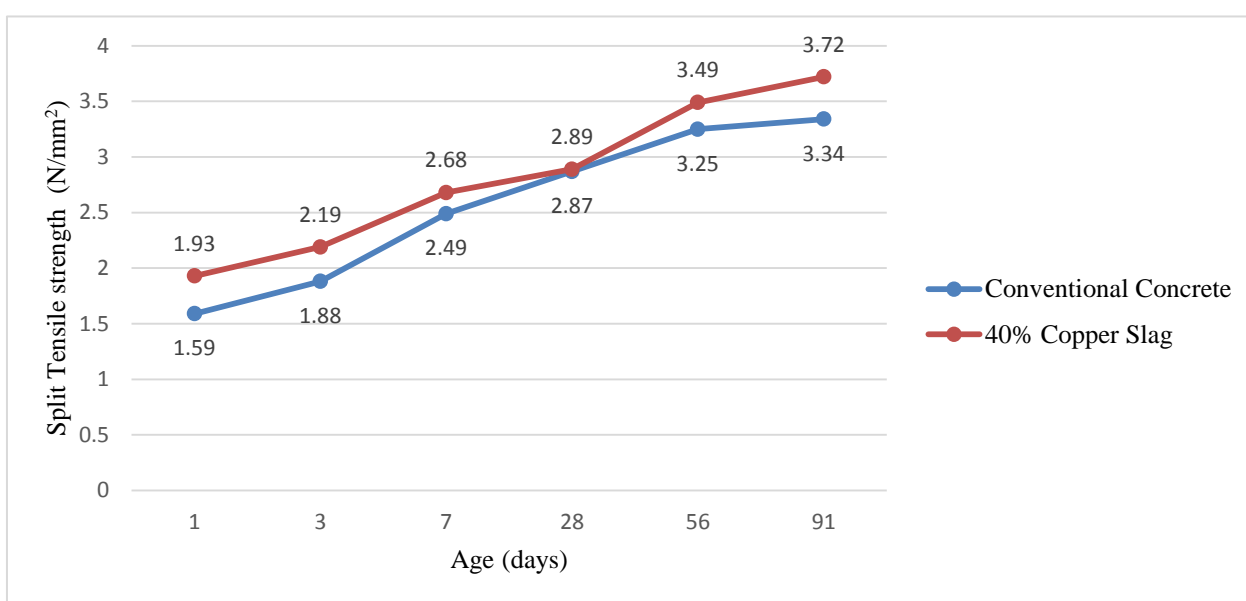


Figure 4. Variation of split tensile strength with age for conventional concrete and copper slag concrete

Observation: It is observed that 40% replacement of natural sand by Copper slag is giving better split tensile strength for M30 grade concrete compared to other proportions of mixes for later ages (28,56 and 91 days).

5.4 Flexural Strength test

Flexural strength test has been conducted on beams of size 500mm x 100mm x 100mm for all mixes and resulting flexural strength obtained at the age of 1, 3, 7, 28, 56 and 91 days for M30 grade of concrete were tabulated in the Table 11 and Fig.5. It can be seen that the flexural strength of concrete with fine aggregate replaced by Copper slag is more than the conventional concrete mix at later ages.

Table: 11. Flexural strength of M30 grade concrete with 40% replacement of fine aggregate by copper slag

Age (days)	Flexural strength (MPa)	
	0%CS	40%CS
1	3.71	3.21
3	4.57	4.49
7	5.69	4.86
28	5.85	5.96
56	6.19	6.32
91	6.28	7.34

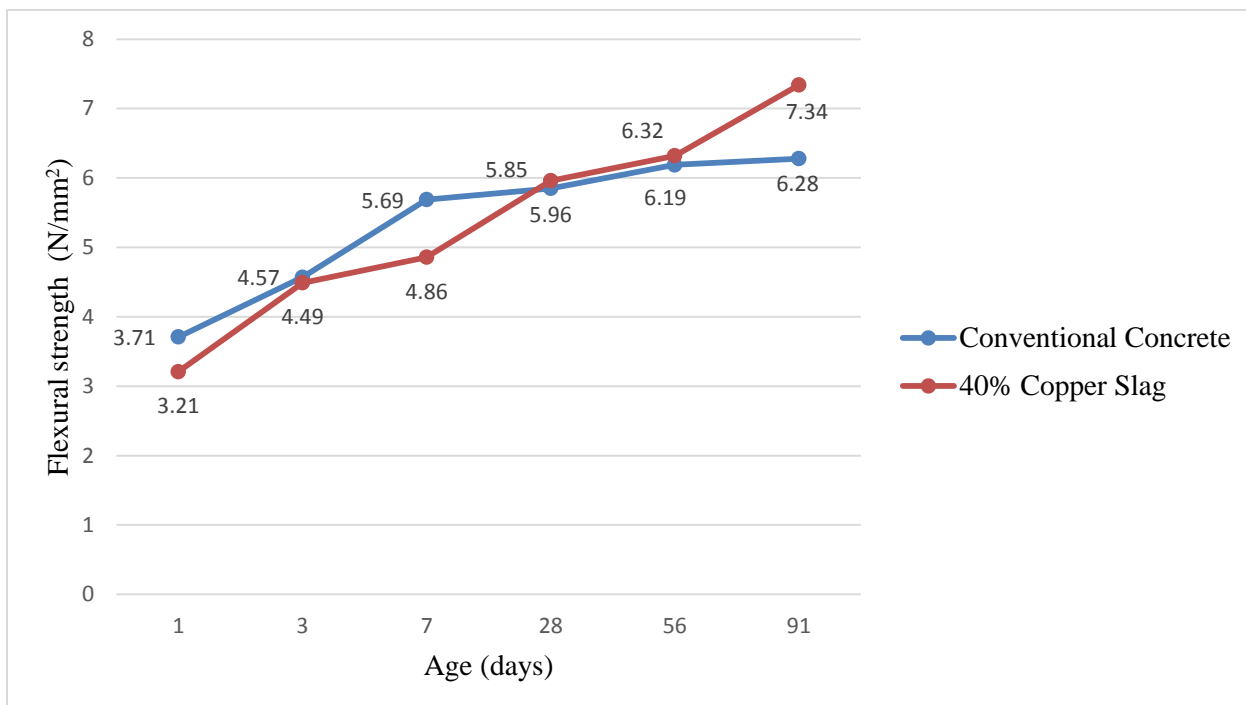


Figure 5. Variation of flexural strength with age for conventional concrete and copper slag concrete

Observation: It is observed that 40% replacement of natural sand by Copper slag is giving better flexural strength for M30 grade concrete compared to other proportions of mixes for later ages (28,56,91 days)

6. CONCLUSIONS

1. The compaction factor values of concrete with Copper slag are observed to be relatively less when compared to conventional concrete, as Copper slag has more water absorption capacity compared to the river sand. Therefore, workability of concrete decreases significantly with the increase of Copper slag percentage in concrete.
2. The Copper slag can be used as a best alternative material for partial replacement of natural sand and gives more compressive strength in order of 15% to 50% for M30 grade concrete than conventional concrete.
3. It is observed that 40% replacement of natural sand by Copper slag is giving better compressive strength when compared to other proportions (0%, 30% and 50%) of mixes for 7 and 28 days.
4. It is observed that 40% replacement of natural sand by Copper slag is giving better split tensile strength when compared to other proportions of mixes for later ages (28,56,91 days).
5. It is observed that 40% replacement of natural sand by Copper slag is giving better flexural strength, when compared to other proportions of mixes for later ages (28,56,91 days).
6. The compressive strength of copper slag concrete is of order 39.83%, 37.30%, 50.26%, 27.24%, 17.5%, 15.5% more for 1, 3, 7, 28, 56 and 91days respectively, when compared with conventional concrete.
7. The split tensile strength of copper slag concrete is of order 21.38%,16.48%,7.6%,0.69%,7.38%,11.37% more for 1, 3, 7, 28, 56 and 91days respectively, when compared with conventional concrete.
8. The flexural strength is of copper slag concrete is of order 13.4%, 1.75%, 14.58%, 1.88%, 2.10%, 16.87% more for 1, 3, 7, 28, 56, 91 days respectively, when compared with conventional concrete.

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