Effect of Jarosite Waste on Pavement Quality Concrete

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ABSTRACT

Jarosite is a waste material produced during the extraction of zinc ore concentrate by hydrometallurgy operation. Jarosite released from the zinc metal extraction process is hazardous and its worldwide disposal has become a major environmental concern. The annual production of Jarosite material is about 0.5 million tons from Hindustan Zinc Ltd., Chittorgarh, Rajasthan state, India. The unutilized accumulated material is about 1.5 million tons. This research was conducted to investigate the performance of fresh and hardened concrete containing Jarosite as a replacement for cement. Concrete performance was evaluated concerning compressive strength, flexural strength and shrinkage limit. Based on the results generated during the study, the following conclusions can be drawn. The study has revealed that Jarosite is a very fine material. Its higher fineness influences most of the properties of green and hardened concrete. It reduces the workability of concrete mix. In other words, the water demand of the mix is increased when jarosite is used in partial replacement of cement. Due to an increase in water demand, higher water content is required for achieving the desired workability. Jarosite can be advantageously blended with Ordinary Portland Cement (OPC) up to 10% (by weight of OPC) at the clinker grinding stage. Jarosite blending up to 10 per cent increases in compressive and flexural strength of concrete of M30 Grade Concrete.

Key Words: Jarosite, Compressive Strength, Flexural Strength, Ordinary Portland Cement, Workability.

1. INTRODUCTION

1.1 General

Concrete is a composite construction material composed of aggregate, cement and water. The aggregate is generally coarse gravel or crushed rocks such as limestone, or granite, along with a fine aggregate such as sand. The cement, commonly Portland cement, and other cementations materials such as fly ash and slag cement, serve as a binder for the aggregate. Concrete has relatively high compressive Strength, but much lower tensile strength for this reason it is usually reinforced with materials that are strong in tension (often steel). Concrete is widely used for making architectural structures, foundations, bridges, roads etc. Famous concrete structures include the Burj Khalifa, the Hoover dam etc.

During the 1970's and 1980's, environmental agencies began to pay increasing attention to industrial pollution, safety and waste management control. As a result, the Jarosite has been revaluating standard practices with regard to the disposal of their use in cement and soil.

Jarosite is a by-product material produced during extraction of zinc ore concentrate by hydrometallurgy operation. Jarosite can be used as mineral admixture in cement concrete and soil application. Reusing Jarosite has a positive impact on the environment in a number of areas, reducing in greenhouse gas emission and particulate matter emission.

This study investigates the potential use of Jarosite in pavement quality concrete (PQC) (M30 Grade Concrete) as a partial replacement of cement. Different percentage of Jarosite has been used in PQC and various properties of green and hardened concrete have been evaluated.

1.2 Jarosite

Jarosite is a waste material obtained from zinc smelting industry. In the process of zinc manufacturing, a lot of residue becomes available which need to disposed-off properly. The residue available from the zinc refining process is referred to as jarosite. The raw jarosite needs certain physical processing to be done before it can be used. Jarosite is obtained in slurry form which is kept to dry in atmosphere, after drying jarosite is converted to dry powder which is used as mineral admixture in cement concrete mixes (Photo 1). The particulate Jarosite is in very fine powder form, much finer than OPC. It can therefore, looked as a mineral fill-in void of OPC particles.

Basic Properties of Jarosite

Jarsoite must possess certain attributes so as to get homogenized with the basic material it is blended with. Jarosite, like other mineral admixtures, is not a binding material (cement) in itself. It is an inert material with small percentages of minerals in the form of oxides of Iron, silica, alumina and zinc. It also has, like most other wastes, traces of heavy metals. Due to presence of iron, aluminium, zinc, and silica, the free-lime available from OPC undergoes pozzlanic reaction over a period of time which finally results in slightly higher compressive strength. Photo 1shows the view of Jarosite.

2. PAVEMENT QUALITY

Concrete (m30) mix design

D-1 Stipulation for proportioning

a) Grade designation — M40
b) Type of Cement — OPC 43 grade conforming to IS: 8112
c) Maximum nominal size of Aggregate — 20mm
d) Minimum cement content — 325 Kg/m^3
e) Maximum water-cement Ratio — 0.5
f) Workability — 20 ± 5 mm (slump)
g) Degree of supervision — Good
h) Type of Aggregate — Crushed angular aggregate
i) Maximum cement content — 425 Kg/m^3
j) Chemical admixture type — Super Plasticizer

D-2 Test data for materials

a) Cement used — OPC 43 grade conforming to IS:8112
b) Specific Gravity
   I. Cement — 3.15
   II. Coarse Aggregate
      1) 20mm — 2.70
      2) 10mm — 2.72
   III. Fine Aggregate — 2.62
c) Water Absorption
   I. Coarse Aggregate
      1) 20mm — 0.70%
      2) 10mm — 0.53%
   II. Fine Aggregate — 0.21%
d) Free (Surface) Moisture
   I. Coarse Aggregate — Nil (Absorbed Moisture also nil)
   II. Fine Aggregate — Nil
e) Sieve Analysis
   I. Coarse Aggregate

IS sieve sizes (mm)	Analysis of Coarse aggregate fraction, % Passing		Percentage Passing of Different Fractions			Percentage Passing for Graded Aggregate as Per Table 1, IRC: 44
	I 20 to 10 mm	I 10 mm down	I 60 per cent	I 40 per cent	Combined 100 percent	
20	100	100	60	40	100	95-100
10	2.8	78.3	1.68	31.3	32.98	25-55
4.75	Nil	8.7	-	3.48	3.48	0-10

II. Fine Aggregate:- Conforming to grading Zone III of Table 2, IRC: 44.

D-3 Design compressive strength for mix proportioning

f'_{ck} = f_{ck}+1.65×s
= 30 + 1.65×5.0
= 38.25 N/mm^2

Where,
f'_{ck} = target average compressive strength, N/mm^2 at 28 days.
f_{ck} = characteristic compressive strength, N/mm^2 at 28 days.
s = standard deviation, N/mm^2
From Table 3, IRC: 44; Standard deviation= 5.0 N/mm^2
Therefore, design compressive strength = 40+1.65×5.0= 48.25 N/mm^2
Design flexural strength using IS: 456 relationships = 4.32N/mm^2

D-4 Selection of water-cement ratio

From Table 4, IRC: 44; preliminary water-cement ratio = 0.45
0.45<0.50, hence O.K.

D-5 Selection of water content

From Table 5, IRC: 44; water content for 20mm aggregate = 186 Kg/m^3 at W/C=0.5As super plasticizer is proposed to be used, the water content can be reduced maximum up to 30% (vide Para 7.2 for details). For the purpose of present trail exercise, a reduction of water content of 15% has been assumed by adjusting suitably the doses of the super plasticizer. The design can use this reduction as peer his requirement of the availability of the grade of cement and the quality of super plasticizer. With 15% reduction in water content ratio of 0.38, the reduced water content equals to 186×0.85=158.1 kg, say 158 kg.

So, 186×0.85=158.1kg say 158kg

D-6 Calculation of cement content

Water-cement ratio = 0.45
Water content = 158 Kg/m^3
Cement content = 158/0.45 = 351.11 Kg/m3, say 352 Kg/m^3

Check for minimum and maximum cement content as per IRC: 15
Minimum cement content as per IRC: 15, 325 kg/m^3< 352 kg/m^3

Hence, O.K.
Maximum cement content as per IRC: 15, 425 kg/m^3> 352 kg/m^3
Hence, O.K.

D-7 Proportion of volume of coarse aggregate and fine aggregate

From table 6, IRC: 44; volume of coarse aggregate corresponding to 20mm size aggregate and fine aggregate grading zone III = 0.64 per unit volume of total aggregate. This is valid for water-cement ratio of 0.50. As water-cement ratio is actually 0.45, the ratio as 0.65 to reduce sand content (as per Note 3 of Table 6).

Volume of fine aggregate content = 1-0.65
= 0.35 per volume of total aggregate

D-8 Mix calculation

a) Volume of Concrete = 1 m^3
b) Volume of Cement = (Mass of Cement/ Sp. Gravity of Cement)×(1/1000)
= (352/3.15) × (1/1000)
= 0.1117 m^3
c) Volume of Water = (Mass of Water/ Sp. Gravity of Water)×(1/1000)
= (158/1) × (1/1000)
= 0.158 m^3
d) Volume of Chemical (Admixture) (Super plasticizer) {@ 1% by mass of Cementitious Material} = (Mass of Chemical Admixture/ Specific Gravity of Chemical Admixture) × (1/1000)
= (3.52/1.2) × (1/1000)
= 0.0027 m^3
(i.e. 1% of 352= 3.52)
e) Volume of all in Aggregate = {a-(b+c+d)}
= {1-(0.1117+0.158+0.0027)}
= 0.728 m^3
f) Mass of Coarse Aggregate
(20 mm) = (e) ×0.39×2.72×1000
(60% of 0.65= 0.39)
= 0.728×0.39×2.72×1000
(2.72 = Sp. Gravity of 20mm Aggregate)
= 772.26 Kg/m^3
(10 mm) = (e) ×0.26×2.70×1000
(40% of 0.65= 0.39)
= 0.728×0.26×2.70×1000
(2.70 = Sp. Gravity of 10mm aggregate)
= 675.22 Kg/m^3

D-9 Mix proportion for trial number 1 based on aggregate in ssd condition

a) Cement = 352 Kg/m^3
b) Water = 158 Kg/m^3
c) Finer Aggregate = 675.22 Kg/m^3
d) Coarse Aggregate
   I. 20mm = 772.26 Kg/m^3
   II. 10mm = 511.05 Kg/m^3
e) Chemical Admixture = 3.25 Kg/m^3
f) Water-Cement Ratio = 0.45

D-10 Mix proportion for trial number 1 based on aggregate in dry condition

a) Cement = 352 Kg/m^3
b) Water = 158+1.42+4.09+3.58 Kg/m^3
= 167.09 Kg/m^3
c) Finer Aggregate = 673.80 Kg/m^3
d) Coarse Aggregate
  I. 20mm = 768.16 Kg/m^3
  II. 10mm = 507.47 Kg/m^3
e) Chemical Admixture = 3.25 Kg/m^3
f) Water-Cement Ratio = 0.45

- Concrete samples to be made in the lab:-
  A. 6 Cube = size 10 cm
  Volume of 1 cube = $(10)^{-3}$ m^3
  Volume of 6 cubes = 6×10^{-3} m^3
  Density of concrete = 2400 kg/m^3
  Weight of concrete = $2400 \times 6 \times 10^{-3}$ = 14.4 kg

  B. 6 Beams = size 10 × 10 × 50 cm
  Volume of 1 cube = $5 \times (10)^{-3}$ m^3
  Volume of 6 beams = 30×10^{-3} m^3
  Density of concrete = 2400 kg/m^3
  Weight of concrete = $2400 \times 30 \times 10^{-3}$ = 72 kg
  C. 2 Dry Shrinkage Moulds = size 8 × 8 × 30cm
  Volume of 1 cube = $192 \times (10)^{-5}$ m^3
  Volume of 2 moulds = 384×10^{-5} m^3
  Density of concrete = 2400 kg/m^3
  Weight of concrete = $2400 \times 384 \times 10^{-5}$ = 9.216kg
  D. Abrasion Resistance Sample(slab)=1
  Size = 50 × 40 × 10 cm
  Volume of 1 slab = $2 \times (10)^{-2}$ m^3
  Density of concrete = 2400 kg/m^3
  Weight of concrete = $2400 \times 2 \times 10^{-2}$= 48 kg

Let us make a concrete mix of 160 Kg
Total weight of adjusted mix proportion= 2469
Therefore, amount of water in 160 Kg of mix
= (167.09 × 160) ÷ 2469 = 10.83Kg
Amount of cement in 160 kg of mix
= (351.98 × 160) ÷ 2469= 22.81Kg
Amount of 20 mm aggregate
= (768.16 × 160) ÷ 2469 = 49.78 Kg
Amount of 10 mm aggregate
= (507.47 × 160) ÷ 2469 = 32.89 Kg
Amount of sand
= (673.80 × 160) ÷ 2469 = 43.66 Kg

3. LABORATORY MIX PREPARATION

- Mix 1(control Mix)
  Water = 10.83 Kg
  Cement= 22.81 Kg
  Sand = 43.66 Kg
  Coarse aggregate (10mm) = 32.89 Kg
  (20mm) = 49.78 Kg
  Observations:-
  Compacting factor = 0.93
  Slump =45 mm

- Mix 2 (5% Replacement)
  Water = 10.83 Kg
  Cement = 21.67 Kg
  Sand = 43.66 Kg
  Coarse aggregate (10mm) = 32.89 Kg
  (20mm) = 49.78 Kg
  Jarosite = 1.09 Kg
  Observations:-
  Compacting factor = 0.9
  Slump = 42 mm

- Mix 3 (10% Replacement)
  Water = 10.83 Kg
  Cement= 20.50 Kg
  Sand = 43.66Kg
  Coarse aggregate (10mm) = 32.89 Kg
  (20mm) = 49.78 Kg
  Jarosite = 2.38 Kg
  Observations:-
  Compacting factor = 0.89
  Slump = 35 mm

- Mix 4 (15% Replacement)
  Water = 10.83 Kg
  Cement = 19.39 Kg
  Sand = 43.66 Kg
  Coarse aggregate (10mm) = 32.89 Kg
  (20mm) = 49.78 Kg
  Jarosite = 3.26 Kg
  Observations:-
  Compacting factor = 0.87
  Slump = 32 mm

- Mix 5 (20% Replacement)
  Water = 10.83 Kg
  Cement = 18.25 Kg
  Sand = 43.66 Kg
  Coarse aggregate (10mm) = 32.89 Kg
  (20mm) = 49.78 Kg
  Jarosite = 4.34 Kg
  Observations:-
  Compacting factor = 0.86
  Slump =28mm

- Mix 6 (25% Replacement)
  Water = 10.83 Kg
  Cement = 17.11 Kg
  Sand = 43.66 Kg
  Coarse aggregate (10mm) = 32.89 Kg
  (20mm) = 49.78 Kg
  Jarosite = 5.43 Kg
  Observations:-
  Compacting factor = 0.84
  Slump = 17 mm

- Mix 7 (30% Replacement)
  Water = 10.83 Kg
  Cement = 15.95 Kg
  Sand = 43.66 Kg
  Coarse aggregate (10mm) = 32.89 Kg
  (20mm) = 49.78 Kg
  Jarosite = 6.52 Kg
  Observations:-
  Compacting factor = 0.82
  Slump = 10 mm

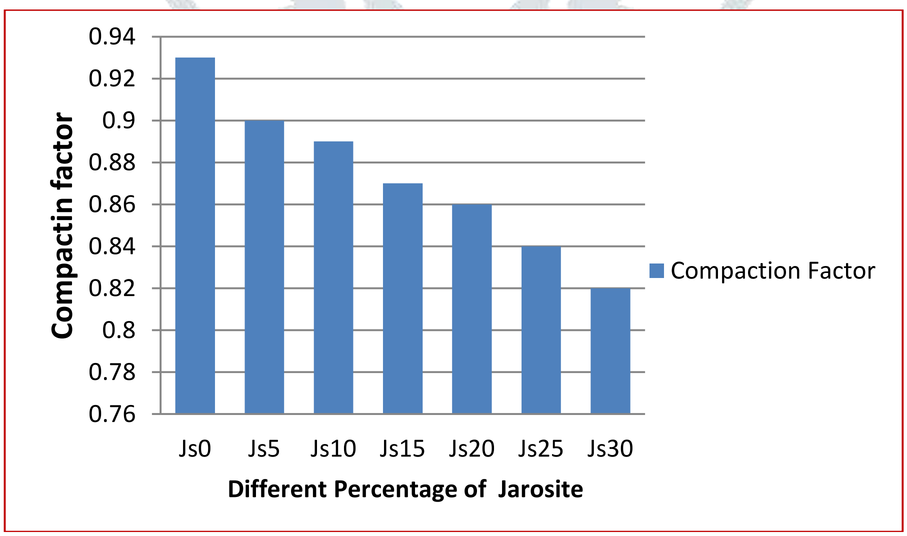
Procedure for sample preparation

- Fill concrete into the mould in layers approx. 5 cm deep by moving the scoop around the top edge of the mould as the concrete slides from it, in order to ensure a symmetrical distribution of the concrete within the mould.
- Compaction: - if compaction is done by hand, tamp the concrete with the standard rod. For 10 cm cube, the number of strokes should not be less than 25 per layer. If compaction is done by vibration, then each layer is compacted by means of suitable vibrating hammer or vibrator or vibrating table.
- Curing: - storing the specimen in a place at temp. 27 C ± 2 C for 24 hour from the time of addition of water to dry ingredients. Remove the specimen from the mould and keep it immediately submerged in clean, fresh water an keep there until taken out just prior to test. Water in which specimen is submerged shall be renewed every seven days.

4. RESULTS AND DISCUSSION

Workability

The workability of all the mixes was measured in terms of both compaction factor and slump. Figure 2 shows the variation of compaction factor of the mix with the addition of different percentage of Jarosite. It can be seen that the compaction factor and therefore the workability of the mix reduces with the increase in the amount of Jarosite. Its value is 0.93 for the control mix containing which is reduced to 0.82 for the mix containing 30% Jarosite. The reduction in workability is because of the greater fineness of Jarosite, which increases the water demand of the mix to achieve the same workability. Though, on the basis of flow table studies, water content was increased incrementally with the increasing amount of Jarosite, but it could not prevent the reduction of workability completely.



Variation in Compaction Factor with different % of Jarosite

Compressive Strength

Compressive strength is the capacity of a material or structure to withstand axially directed pushing forces. It provides data (or a plot) of force vs. deformation for the conditions of the test method. When the limit of compressive strength is reached, brittle materials are crushed. Concrete can be made to have high compressive strength, e.g. many concrete structures have compressive strengths in excess of 50 MPa, whereas a material such as soft sandstone may have a compressive strength as low as 5 or 10 MPa. By contrast, a small plastic container might have a compressive strength of less than 250 N.

Concrete is primarily strong in compression and in actual construction, the concrete is used in compression. Concrete strong in compression is also good in other qualities. Higher the compressive strength better is the durability. Bond strength also improves with the increase in compressive strength. Bond strength is important in R.C.C. compressive strength also indicates extent of control exercised during construction. Resistance to abrasion and volume stability improves with the compressive strength. Test for compressive strength is, therefore very important in quality control of concrete. Cube specimens of 10 cm were prepared for testing compressive strength of the mixes.

Compressive strength test procedure

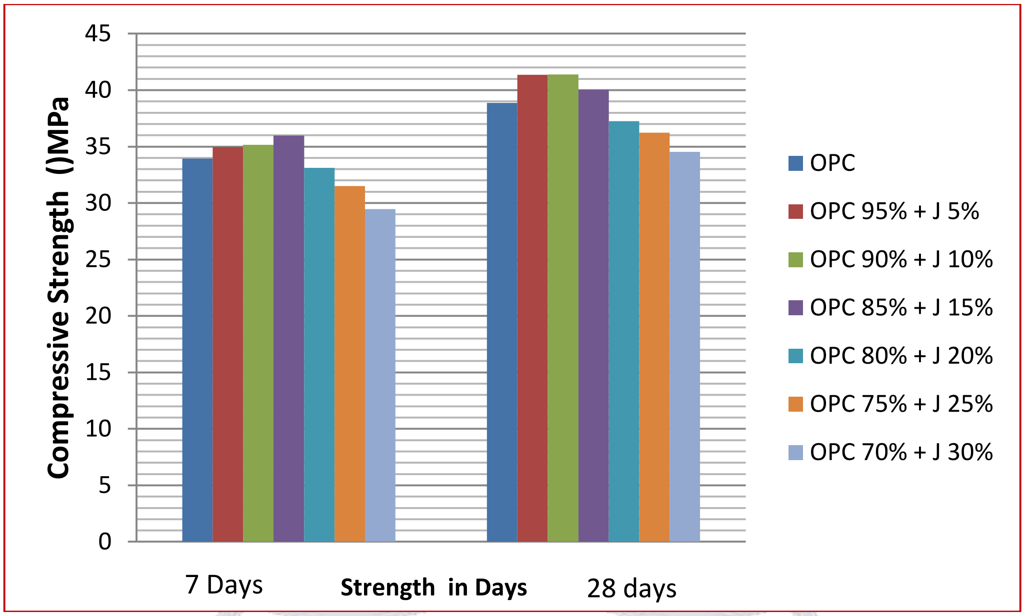
- Age of test: - usually testing is done after 7 days and 28 days, the days being measured from the time the water is added to the dry ingredients.
- Test at least three specimens at a time
- Note the dimensions of the specimens and also note down their weight
- Place the specimen in such a manner that the load shall be applied to opposite sides of the cube as cast
- Align carefully the center of thrust of the spherically seated platen
- Apply load slowly and at the rate of 140 $kg/cm^2/min$ till the cube breaks.
- Note down the maximum load and appearance of the concrete failure i.e. whether aggregate has broken or cement paste has separated from the aggregate etc.

Photo 15 shows the concrete cube specimens used for compressive strength tests. Photo 16 shows the testing of cubes in a compression testing machine. Table 14 gives the compressive strength test results for 7 days and 28 days. Figure 3 shows the variation of compressive strength at 7 and 28 days with Jarosite content.

Compressive Strength Development of Jarosite Blended OPC Concrete

Sr. No	Description	Compressive Strength in MPa	
		7 Days	28 days
1	OPC	33.93	38.86
2	OPC 95% + J 5%	34.95	41.35
3	OPC 90% + J 10%	35.15	41.4
4	OPC 85% + J 15%	35.97	40.03
5	OPC 80% + J 20%	33.12	37.24
6	OPC 75% + J 25%	31.5	36.22
7	OPC 70% + J 30%	29.46	34.54

Results show that the compressive strength of concrete both at 7 and 28 days first it starts to increase up to 10% and after that it goes on decreasing with the increasing amount of Jarosite in the mix. The seven days compressive strength decreases from 33.93 MPa to 29.46 MPa as the Jarosite content is increased from 0% to 30%. Similarly, 28 days strength decreases from 38.86MPa to 34.54MPa. In the seven days compressive strength we concluded that the strength of mix increases up to 15% and then it starts decreasing, but in twenty-eight days compressive strength we found that the strength increases only up to 10% and after that is starts decreasing. The decrease in strength is because of additional water, which requires to be added into the mix to meet the increasing water demand of the mix when finer Jarosite replaces cement.



Compressive Strength Development of Jarosite Blended OPC Concrete

Flexural Strength

Flexural strength, also known as modulus of rupture, bend strength, or fracture strength, a mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load. The transverse bending test is most frequently employed, in which a rod specimen having either a circular or rectangular cross-section is bent until fracture using a three point flexural test technique. The flexural strength represents the highest stress experienced within the material at its moment of rupture. The knowledge of tensile strength in concrete is of value in estimating the load under which cracking will develop. The absence of cracking is of considerable importance in maintaining the continuity of a concrete structure and preventing corrosion of reinforcement. Maximum tensile stress reached in the bottom fiber of the test beam is known as "modulus of rupture". For measuring the flexural strength beam specimen of size 10 cm x 10 cm x 50 cm were prepared.

Flexural strength test procedure

- Method of filling the mould, curing and measuring the dimensions is the same as is done for the compressive strength test.
- Place the specimen in the testing machine such that the load shall be applied to the upper most surface as cast in mould. Along two lines spaced 20 cm or 13.3 cm apart.
- Apply load carefully without shock and at a rate of 400kg/min for 15.0 cm specimen and at the rate of 180 kg/min for 10 cm specimen.
- If 'a' equals the distance between the line of fracture and the nearer support in cm, then modulus of rupture,

$$\boldsymbol{Fb = p \times l/b \times d2}$$

When 'a' is greater than 13.3cm for 10 cm specimen,

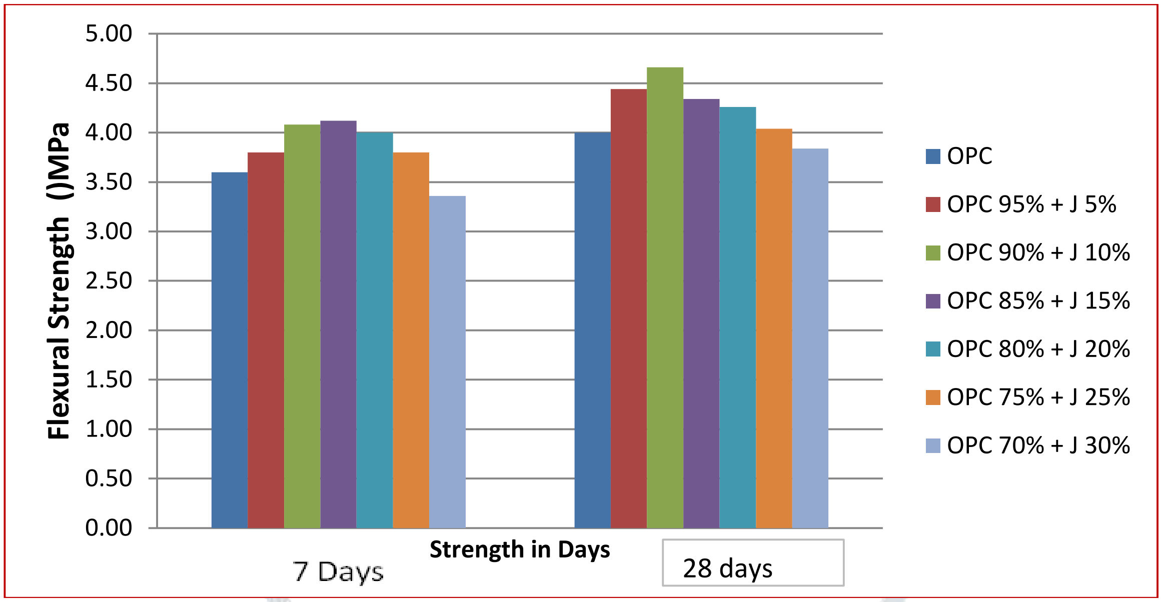
- $\boldsymbol{Fb = 3p \times a/b \times d2}$, when 'a' is less than 13.3 cm but greater than 11.0 cm for 10 cm specimen, where p is maximum load in Kg. 'b' and 'd' are width and depth of beam and 'i' is span of the beam(all in cm)
- If 'a' is less than 11cm for 10cm specimen, the results of the tests are to be discarded

Photo 17 shows the flexural strength test under third point loading. Photo 18 shows the beam specimen cracked into two pieces during the test. Table 15 gives the flexural strength test results for all the mixes tested at 28 days. Figure 4 shows the variation of flexural strength with the content of Jarosite.

Flexural Strength Development of Jarosite Blended OPC Concrete

Sr. No	Description	Flexural Strength MPa	
		7 Days	28 days
1	OPC	3.60	4.00
2	OPC 95% + J 5%	3.80	4.44
3	OPC 90% + J 10%	4.08	4.66
4	OPC 85% + J 15%	4.12	4.34

5	OPC 80% + J 20%	4.00	4.26
6	OPC 75% + J 25%	3.80	4.04
7	OPC 70% + J 30%	3.36	3.84



Flexural Strength Development of Jarosite Blended OPC Concrete

Flexural strength of concrete also decreases with the increase in the amount of Jarosite in the mix. From the fig.3 it can be seen that the Flexural strength at 7 days increases upto addition of 15% jarosite to the mix after that there is the decrease in the flexural strength of concrete. Same thing happens in twenty-eight days strength but this time it increases till 10% only, and after that it decreases. This is also because of the requirement of increasing water-cement ratio of the mixes as explained above.

5. CONCLUSION

On the basis of the results generated during the study, following conclusions can be drawn.

- Jarosite is a very fine material. Its higher fineness influences most of the properties of green and hardened concrete.
- Jarosite reduces the workability of concrete mix. In other words, water demand of the mix is increased when Jarosite is used in partial replacement of cement (O.P.C.).
- Due to increase in water demand, higher water content is required for achieving the desired workability. But, it increases the water-cement ratio of the mix which reduces both compressive and flexural strength of concrete.
- Jarosite can be used in cement concrete only in small amount of 10 percent of cement for Pavement Quality Concrete (M30 Grade)

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