Research Journal of Applied Sciences, Engineering and Technology 12(9): 955-963, 2016
DOI:10.19026/rjaset.12.2813
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: September 11, 2015 Accepted: December 8, 2015 Published: May 05, 2016

Research Article

Assessment of Bahariya Hematite-barite Ore as a Heavy Weight Concrete Mix for Subsea Pipeline Cladding

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Abstract: This study deals with a substitute of high density aggregates used for offshore pipeline coating, the hematite-barite ore mined and produced by Steel Manufacture Company and not used in steel manufacture due to containing barite ore and low iron content. Heavy aggregates of iron ore were imported by petroleum companies in Egypt, for utilization as a major constituent of concrete mix used for coating of offshore petroleum pipelines as a heavy coat for pipeline stability on sea bed and mechanical protection against anchor damages. The hematite-barite heavy aggregates form the main constituents 75% of the concrete mix, with sea water cements and specific water-cement ratio desired to achieve required compressive strength, water absorption and dry density. The laboratory and field tests conducted for the hematite-barite aggregate to ensure that the physical, chemical and mechanical properties complying with coating specification and standards. The hematite-barite heavy aggregate have 3.9-4.2 g/cm^3 specific gravity, well graded hematite-barite aggregate, chemically free from detrimental matter. Heavy concrete mix composed from hematite-barite aggregate, sea water cement and fresh water mixed together to produces a concrete mix of 180-185 pcf (2880-2964 kg/m^3), minimum dry density and compressive strength varying from 40-47 N/mm^2 (400-470 kg/cm^2), which satisfied the standard specification of submarine pipeline coating.

Keywords: Baharyia oasis, compressive strength, concrete cladding, concrete mix, heavy aggregate, hematite

INTRODUCTION

Steel Manufacture Company at Baharyia Oasis have a large quantity about 3 million tons of hematite ore mixed with a small ration of barite not useful in Steel Manufacture Company looking for using these ore as coating heavy aggregate or drilling fluids materials.

Natural mineral aggregates of high density include aggregates that contain or consist predominately of materials such as barite, magnetite, hematite, ilmenite, and serpentine (ASTM-C 637, 1998; ASTM-C 638, 1997). Hematite and Barite has been used as aggregate for heavy weight concrete which is particularly useful in weighting submerged oil and gas pipelines, which would be required to perform the same submerged function. The large pipelines for the Canadian North and Alaska were used a considerable tonnage of Muncho Lake barite for weighting purposes. It is estimated that the total tonnage of weights were 1,000,000 tons costing in the order of $100 per ton (Hlavay and Eng, 1970).

The main target of this study is to find an appropriate local substitute of magnetite and Ilmenite ores, which is used as the main constituent of the concrete mix for concrete cladding of sub-marine pipelines which specifically demanded in offshore oil and gas fields for transportation of petroleum materials. These heavy aggregates are imported by petroleum companies in Egypt and recently they use the local ilmenite ore instead of imported magnetite and hematite. Laboratory and field application tests disclosed the presence of unexploited hematite-barite deposit in Bahariya Oases mines can be utilized as a heavy aggregate.

The heavy aggregate ores usually occupies about 75% of the total volume of concrete mix, its properties have a definite influence on behavior of hardened and concrete strength; its properties also greatly affect durability (resistance to deterioration under freeze-thaw cycles). The crushing and grading of hematite-barite aggregate shall be conducted as per International standard to achieve the optimum percentages of both fine and coarse aggregates forming the concrete mix and achieving the required strength and density (Gaber, 2013; Singh and Ramana, 2014).

Heavy concrete coating provides is necessary to perform the negative buoyancy for subsea pipelines, mechanical protection during handling, transportation and laying operations (Fig. 1) (El-Bokle, 1994).

Hematite-barite occurrence in Bahariya Oasis: Bahariya iron ore deposits are located in several areas,

Fig. 1: Concrete Weight Coating (CWC) for offshore pipeline

e.g., El Harra, El Heiz, Ghorabi, El Gedida (Fig. 2 and 3) and Nasser. The iron ore of El Harra belongs to El Harra member of El Haffuf Formation; whereas El Gedida iron ore belongs to Naqb Formation. The area is covered by Bahariya Formation (unfossiliferous varicolored sandstone of Cenomanian age) followed by El Heiz Formation (brownish limestone and sandy clay beds), and El Haffuf Formation of sandstone, sandy clay, and ferruginous beds, which are partly taken by the iron ore deposit, Khuman Formation (chalky limestone) and Naqb Formation of thick limestone beds with few marl and clay associations. The iron content in the ironstone deposits ranges from 30 to 58% Fe, and the manganese content ranges from 0.7 to 7.66% Mn.

The stratigraphic position of Naqb Formation is partly taken by iron ore deposits at El Gedida, El Harra, and Ghorabi; where El Gedida iron ore member belongs to iron deposits of Lower Middle Eocene (Naqb Formation) and the upper Eocene (Abu Maharik

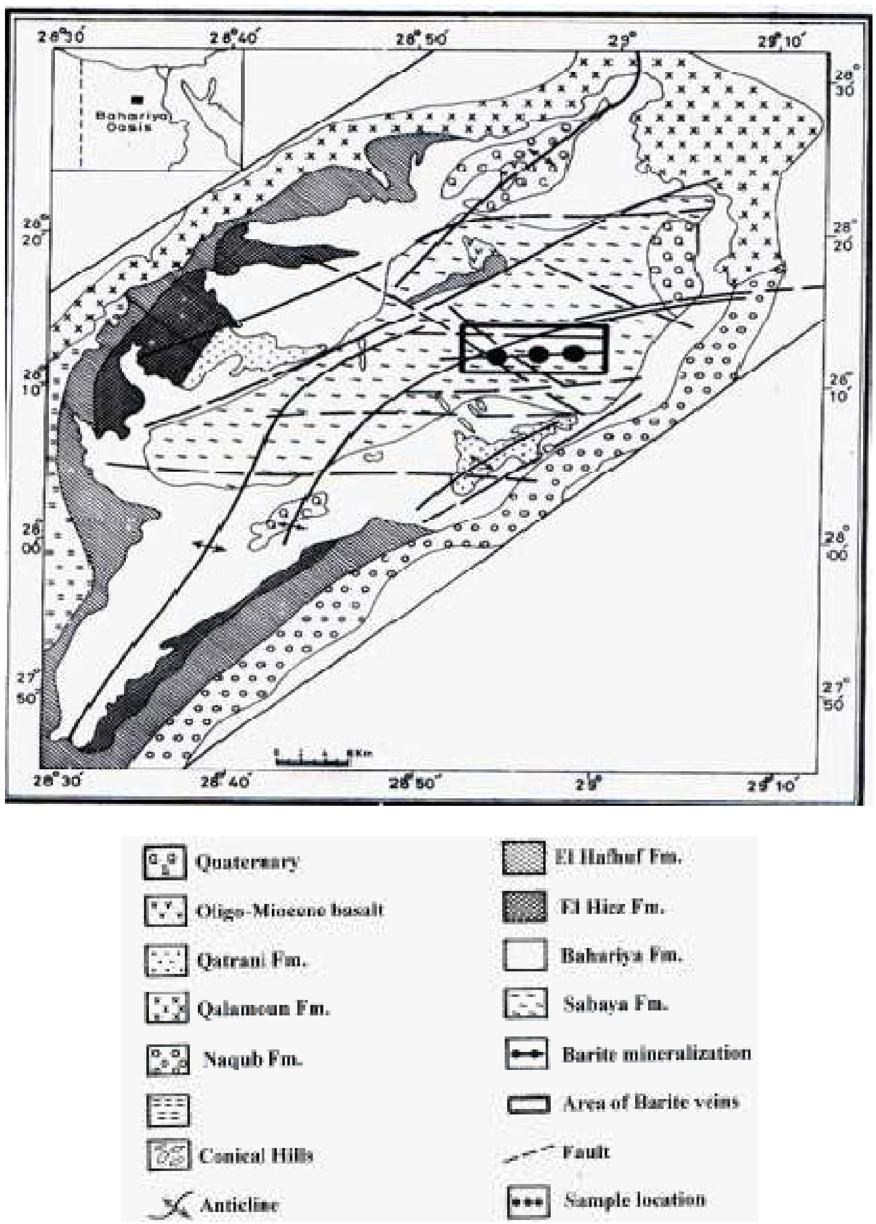


Fig. 2: Location map of Baharia Oasis showing barite ore, after Morsy (1987)

(a) Bahariya Oasis (El Gededda mine)

(b) 3 Million tons of hematite-barite ore

Fig. 3: El Geddedda mine at Baharyia oasis and reserve quantities of hematite-barite ore

Formation). The ore is localized in the crest of anticline (Abouzeid and Khalid, 2011).

The El Bahariya Oasis is an oval shaped depression (Fig. 2) trending in a NE-SW direction. Within the depression, the Cretaceous rocks outcrop at its base as well as at the base of the conical hills and the scarp. The Cretaceous rock succession (Sabaya, Bahariya, El Heiz and El Hafhuf Formations) comprises fluvialite to fluviomarine clastics of sandstone, claystone and shale. The Sabaya Formation of Lower Cenomanian age (Morsy, 1987) is coverd by Bahariya Formation which also belongs to the Lower Cenomanian (Soliman and El Badry, 1980). The Bahariya Formation is unconformably overlain by the Upper Cenomanian fluviomarine marly shale, sandy dolomitic limestone and calcareous sandstone of El Heiz Formation as well as by the Campanian cherty cavernous dolostone, crossbedded sandstone and phosphatic limestone of El Haufhuf Formation.

The barite veins are restricted to the fractures that are parallel to the main E-W or NW-SE striking faults in the Sabaya Formation (Fig. 2). These veins occur sub parallel sets with more than 7 m length and ranging in width between 0.5 to 4 m. They dip 50° towards N, S or NE directions. The barite veins are hard, massive, siliceous and white to gray in color. These veins are numerous and distributed in association with tectonically formed fractures and fissures (Haroun and Raslan, 2010).

MATERIALS AND METHODS

The aims of present work to study the physical, chemical analysis, mechanical properties and

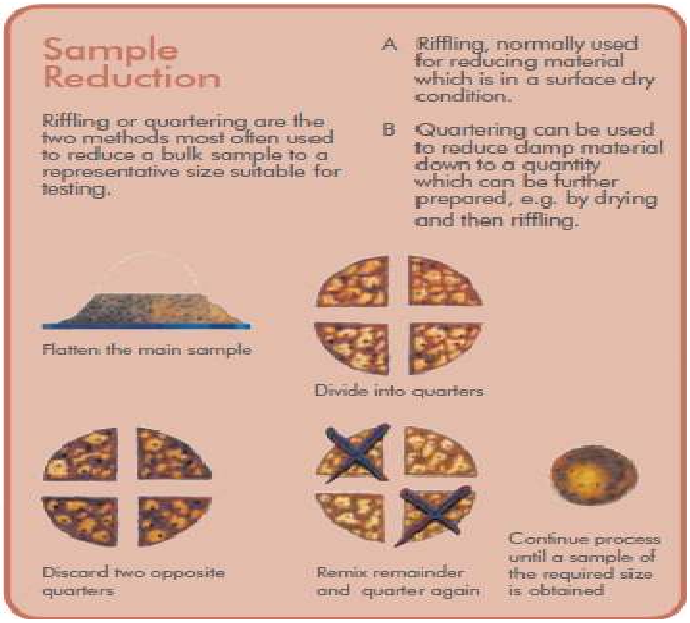


Fig. 4: Ore sample quartering for sieve analysis test

engineering field testing for high density hematite-barite ore aggregate to be utilized in concrete mix for offshore petroleum pipeline cladding.

Grading test: Grading test was carried out for 10 samples to ensure that the grading is comply with coating specification of Petroleum companies (ASTM-C-33, 1986; ASTM C-136, 1984). The following diagram (Fig. 4), showing the preparation procedure of aggregate samples (AASHTO T 248, 2011).

Aggregate particle shape: Aggregate particle shape and texture affect workability of fresh concrete mix and final production. The ideal aggregate would be spherical and smooth allowing good mixing and decreasing interaction between particles. Shape and texture of coarse aggregates affects the strength of the concrete mix. Increased surface area provides more opportunity for bonding and increases strength. However, excessive surface area in an aggregate can lead to internal stress concentrations and potential bond failure (University of Memphis, 2009).

Specific gravity: Is completed for 10 samples. This method covers the determination of apparent specific gravity which pertains to the relative density of solid material making up the constituent particles not including the pore space within the particles that's accessible to water (ASTM-C 128, 1979).

Chemical analysis: The XRF analysis was performed for 5 samples of hematite-barite ore taken from Steel Manufacture Company reserve. The standard properties of heavy ores indicated in Table 1.

Table 1: Typical physical properties of some heavy weight aggregates

Material	Chemical composition	Relative density	Granular Bulk density (kg/m^3)
Geothite	$Fe_2O_3.H_2O$	3.5-3.7	2100-2250
Limonite	Impure Fe_2O_3	3.4-4.0	2100-2400
Barytes	$BaSO_4$	4.0-4.6	2300-2550
Illmenite	$FeTiO_3$	4.3-4.8	2550-2700
Magnetite	Fe_3O_4	4.2-5.2	2400-3050
Hematite	Fe_2O_3	4.9-5.3	2900-3200
Ferro phosphorus	$Fe_2O_3.P_2O_3$	5.8-6.8	3200-4150
Steel	Fe (scrap iron, steel punchings)	7.8	3700-4650

Durability (soundness) of aggregates: Aggregates makeup the largest part of concrete mixes and are responsible for the durability of the mix. Durability is a measure of how well concrete will handle freezing and thawing, wetting and drying and physical wear. Chemical reactions also can contribute to problems with durability.

Unsound particles: Soft particles such as clay lumps, wood, and coal will cause pitting and scaling at the surface. Organic compounds can be released which interfere with setting and hardening. Weak material of low density which has low wear resistance should also be avoided.

This test is accomplished by repeated immersion in saturated solutions of magnesium sulphate followed by oven drying to partially or completely dehydrate the salt precipitated in permeable pore spaces (ASTM-C88, 1983; ASTM C-40, 1984).

Water absorption of final concrete mix (cubes): The absorption values are used to calculate the change in the weight of an aggregate due to water absorbed in the pore spaces within the constituent particles compared to the dry condition and the value shall be 5% maximum (ASTM C-642, 1982) and (ADMA-OPCO SP-1024, 1993) and (Agip Specification, 1998).

$$\text{Water absorption} = \frac{\text{saturated wt} - \text{Dry wt}}{\text{dry wt}} \times 100$$

Dry density of concrete mix: This test is designed to measure the prepared concrete mix that can produce the suitable dry density necessary for pipeline coating.

Compressive strength test: The main purpose of this test is to ensure that the concrete mix is capable of resist the external forces and shocks that may occur during and after the transportation and laying of the pipe-line undersea water (BS 1881-108, 1983; ASTM C-192, 1988; ASTM D-698, 1978).

RESULTS AND DISCUSSION

Grading (Sieve analysis) test: Sieve analysis conducted using the equipments (Fig. 5), to determine the gradation or distribution of hematite aggregate particle sizes within a standard range and the obtained results are listed in Table 2. The grading analysis results indicates that the hematite sample grading plotted within the coating specification range to achieve the required compaction, compressive strength, minimum water absorption and dry density of final concrete mix.

(a) Splitter for hematite ore sample preparation for sieve analysis

(b) Sieve analysis set

Fig. 5: Grading test tools for coarse aggregates

Table 2: Grading analysis of crushed hematite-barite iron ore

Sieve (mm)	Percentage of passing						
	1	2	3	4	5	6	Standard
9.5	100	100	100	100	100	100	100
4.75	98	97	97	96	97	97	95-100
2.36	90	84	85	84	84	85	80-100
1.18	70	67	68	68	67	69	50-85
0.6	45	42	43	43	41	44	25-60
0.3	24	22	23	22	21	23	10-30
0.15	7	5	6	6	5	7	2-10

Aggregate particle shape: The studied hematite-barite aggregate were crushed and graded to rounded sub angular particle shape (Fig. 6). Particles surface texture is smooth or rough based on visual judgment, and depends on: Rock hardness, grain size, porosity, they affect to workability, paste demand, and initial strength of final concrete mix (Nemati, 2015).

Specific gravity test: Specific gravity tests (Fig. 7), show that the results of selected hematite-barite samples ore grains ranges from 3.9-4.2 which achieve 180-185 pcf, dry density concrete mix as per listed in Table 3.

Fig. 6: Particle shape of hematite ore

Fig. 7: Specific gravity testing

Table 3: Specific gravity of hematite-barite aggregate

Sample No	Specific gravity/cm^3
1	4.1
2	4.0
3	3.9
4	4.0
5	3.9
6	4.1
7	4.0
8	3.9
9	4.2
10	3.9
Average	4.0

The following procedure was applied to calculate the ore specific gravity as follows:

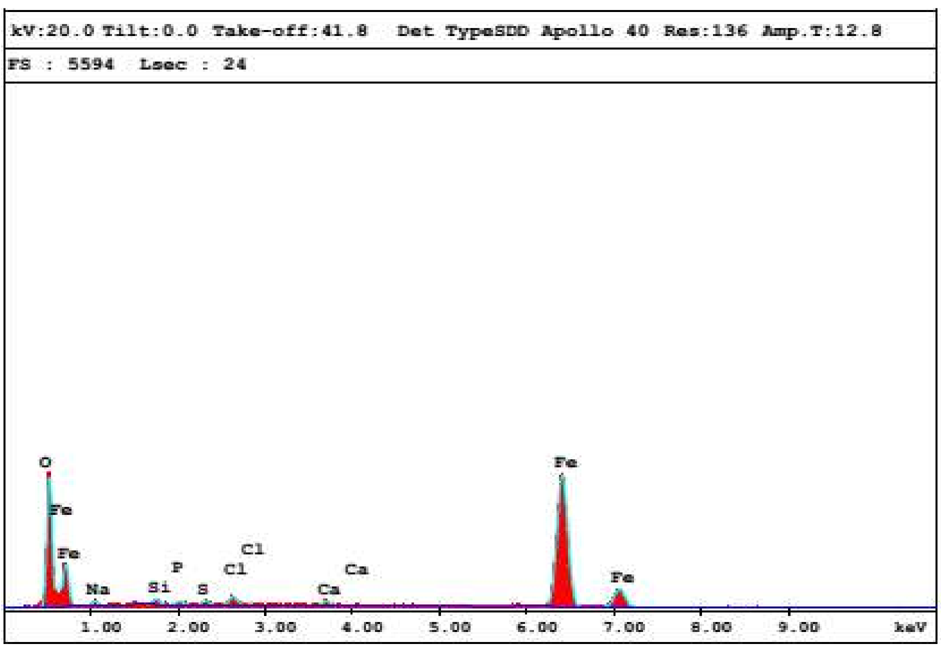
- Density of Liquid (DL) = $\frac{D-A}{V}$
- Density of mineral grains = $\frac{B-A}{(D-A)(C-B)}$ g/cm^3
- Specific gravity of the ore aggregate = *Density of ore grain x density of liquid*

where,
A = Weight of empty pycnometer
B = Weight of pycnometer+mineral grain
C = Weight of pycnometer+mineral gain+liquid
D = Weight of pycnometer+liquid
V = Volume of pycnometer

Table 4: Chemical analysis of hematite-barite ore

Constituents	Percentage
SiO2	4.42
TiO2	0.18
Al2O3	0.01
Fe2O3	33.35
MnO	0.74
MgO	0.66
CaO	2.47
Na2O	0.43
K2O	0.16
P2O5	0.46
Cl	0.50
SO3	19.00
BaO	34.47
LOI	2.73

Chemical analysis: The chemical analysis includes XRF and EDAX analysis of hematite-barite collected sample was conducted at The Egyptian resources Authority and the results illustrated in (Table 4) and (Fig. 8), which indicate that the material is mainly composed of Fe2O3 with 31.35%, BaO 34.47%, SO3 21.48%, SiO2 3.94 and CaO 2.47%.



Element	Wt %	At %	K-Ratio	Z	A	F
O K	21.67	47.51	0.1095	1.1162	0.4513	1.0029
NaK	1.61	2.46	0.0032	1.0440	0.1898	1.0001
SiK	0.94	1.17	0.0052	1.0681	0.5220	1.0019
P K	0.52	0.59	0.0034	1.0385	0.6363	1.0033
S K	0.68	0.74	0.0054	1.0670	0.7347	1.0055
ClK	1.37	1.35	0.0114	1.0186	0.8104	1.0084
CaK	0.86	0.76	0.0088	1.0435	0.9397	1.0412
FeK	72.35	45.43	0.6905	0.9525	1.0020	1.0000
Total	100.00	100.00				

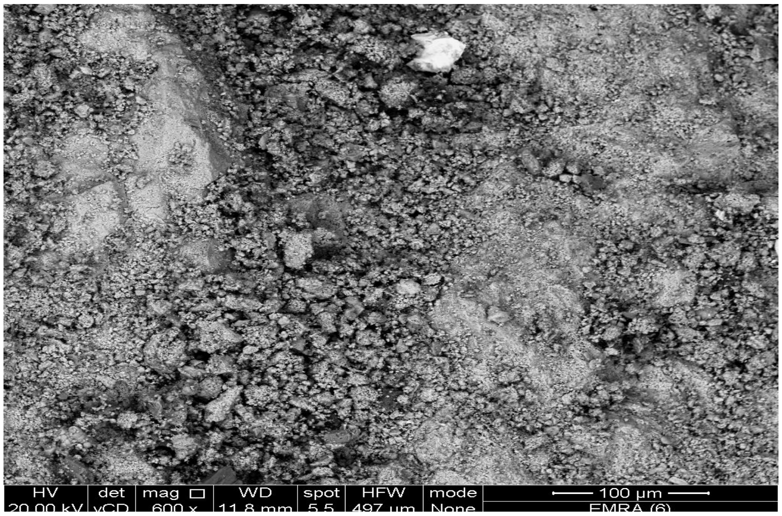


Fig. 8: EDX analysis for hematite-barite sample

EDX ANALYSIS

Soundness test of hematite-barite aggregate: The hematite-barite ore aggregate were subjected to five cycles of titration by using magnesium sulphate to determine the detrimental matter. The difference between the weight of samples before and after the test is the loss % and should be less than 15% (ASTM-C-88, 1983). The obtained results in Table 5 indicate that the ore is sound enough and loss % less than the standard.

Water absorption of concrete mix cubes: The water absorption was calculated to 10 samples and the ratio is less than 4%.

Dry density of cubes: The results show that the dry density of cubes ranging from 188 pcf to 195 pcf (3008 3120 kg/m³), meanwhile the dry density of coupon sample shall be representative approximately 96% relative compaction of cube results obtained for local hematite-barite concrete mix, accordingly the expected coupon dry density shall be ranging from 180 pcf to 187 pcf, which complying with offshore concrete coating requirement.

Compressive strength test: There are 20 cubes with dimensions of 15×15×15 cm were prepared using hematite-barite concrete mix (Fig. 9), with the following proportion of (75% ore, 25% cement, 8% water) and the results are listed in (Table 6) and

Table 5: Results of soundness test

Sieve siz (mm)	Wt. of sample before test	Wt. of sample after test	Percentage of loss
4.700	100	92	8
2.360	100	91	9
1.180	100	90	10
0.630	100	90	10

(a) Preparation concrete mix (hematite-barite ore, sea water cement and water)

(b) Prepare cube and compaction of concrete mix

(c) Complete the compaction of cubes for compressive strength test

(d) Compressive strength machine testing

Fig. 9: Concrete mix of hematite-barite ore aggregate, Sea water cement and fresh water (15×15×15 cm)

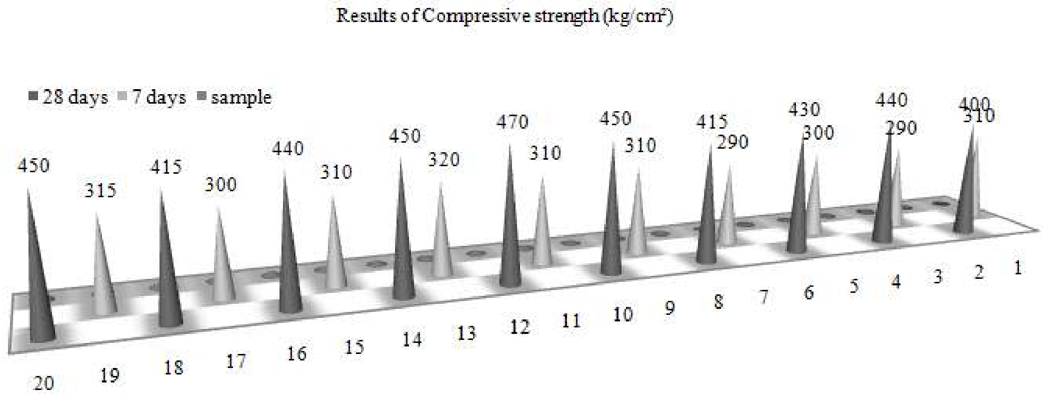


Fig. 10: Compressive strength of cubes after curing 7 and 28 days

Table 6: Compressive strength results after 7 and 28 days water curing

Cube No.	7 days curing (kg/cm²)	28 days curing (kg/cm²)
1& 2	310	400
3 & 4	290	440
5 & 6	300	430
7 & 8	290	415
9 & 10	310	450
11 & 12	310	470
13 & 14	320	450
15 & 16	310	440
17 & 18	300	415
19 & 20	315	450

(Fig. 10), which achieved the required compressive strength can resist the handling and barge laying forces and complying with coating specification approved by Petroleum companies.

CONCLUSION

Based on the laboratory tests and field application have been performed to investigate the possibility of applying the Baharyia hematite-barite ore as a heavy weight aggregate forming concrete mix utilized for coating of subsea pipeline, the following conclusions may be drawn.

- The Egyptian hematite iron ore possesses a specific gravity ranging from 3.9 to 4.3.
- The ore produce a concrete dry density ranging from 180-185 pcf (2884-2964 kg/m^3).
- The water absorption ration was obtained is below the maximum standard mentioned in coating specification 5 or 8%.
- The compressive strength necessary for pipeline cladding was achieved 40-48 N/MM² (400-480 kg/cm²).
- The ore is a new discovery of high density aggregate for concrete coating purpose of petroleum pipeline.
- The practical coating trial for 3 pipes is required for measuring negative bouncy and coupon density of actual coated sample.

ACKNOWLEDGMENT

The authors would like to express their gratitude to Steel Manufacture Company team at Baharyia Oasis for help to collect the representative samples, also his thanks to PETROJET, Coating plants team for arrangement and help during filed tests.

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