

Experimental Study on MEPS Concrete and Brick using Nano Materials

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ABSTRACT: Modified Expanded Polystyrene [MEPS] aggregates are the artificial aggregates developed from non-biodegradable Expanded Polystyrene waste [EPS] based on Heat Treatment Method [HTM]. In HTM, EPS waste is placed in closed hot air oven at 130⁰ C for 15 minutes. EPS waste become hardened & forms as MEPS aggregates. MEPS aggregates are used as MEPS Coarse Aggregate [MEPS CA] & MEPS Fine Aggregate [MEPS FA] by sieving based on their sizes. The present investigation directed towards the development and performance evaluation of the MEPS aggregate concrete containing MEPS CA, MEPS FA, Water, Super Plasticizer and OPC partially replaced by pozzolonic materials like GGBS, Silica Fume, Fly Ash, nano TiO₂, nano Fe₂O₃ and nano MgO at different levels. The final optimal mixture of MEPS aggregate concrete was selected among experiments under consideration to manufacture the light weight bricks. The compressive strength is inversely proportional to workability were compared with similar concrete composites as reported earlier.

KEYWORDS: LWC, ULWC, Artificial aggregates, MEPS Concrete, MEPS Bricks.

I. INTRODUCTION

It is clear that with the improvement of human civilization, concrete will continue to be a governing construction material in the future. Concrete is only second to water as the most profoundly consumed substance with about six billion tons being produced every year. The civil construction is growing rapidly, increased the demand of natural aggregates [NA] which is reducing the natural sources and on the other hand industrial by-products, soil wastes such as expanded polystyrene or thermocol, styrofoam, plastic, rubber, glass, iron, steel fibres, wood, brick-bats, thermal waste etc. are creating a huge loss to environment. For this reason, the Civil and Environmental Engineers have been challenged to convert the above waste materials to useful construction material. Hence, we require new artificial aggregates [AA] with equal NA properties. Modification to the above waste can result in new constructions material which can replace NA requirements. Hence, it is essential to advancing the new technologies which can result in new construction materials. This will create comfort to the environment pollution and facilitate the natural balance of life.

Recently, with the rapid development of high rise buildings, floating marine platforms, larger-sized and long-span concrete structures, lightweight concrete [LWC] has been a promising modern construction material. In comparison with ordinary concrete, LWC shows some excellent characteristics such as lower density, higher specific strength, better thermal insulation and greater energy absorption which can be obtained by replacing standard aggregate totally or partially by lightweight aggregate [LWA]. Lightweight aggregate are broadly classified into two types: natural [pumice, diatomite, volcanic cinders, etc.] and artificial [perlite, clay, sintered fly ash, expanded shale, etc.]. Expanded polystyrene [EPS] is a type of artificial lightweight aggregate with the density of only 10–30 kg/m³. Due to the ultra-lightweight density of EPS, the lightweight aggregate concrete is prone to segregation during casting. Many researchers have studied to overcome this drawback. Babu DS and Babu KG added ultra fine silica fume to improve the bonding between EPS beads and cement paste. Roy et al. utilized superplasticizer to avoid the segregation of EPS

International Journal of Innovative Research in Science, Engineering and Technology

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spheres. Chen and Liu applied styrene-butadiene rubber [SBR] latex to improve the strength of concrete.

Expanded Polystyrene [EPS] used as equipments production tools to absorb vibration during handling and transportation process. After this process, the EPS serves as disposal waste. Disposal is difficult as EPS is non-biodegradable and due to its light weight characteristics, it has the capacity to serve as aggregates in concrete by modifying it by Heat Treatment. As it is not eco-friendly, this waste EPS can be used in preparation of concrete. The EPS waste was kept in a closed hot air oven at 130⁰ C for 15 minutes & resulted in Modified EPS aggregates [MEPS]. MEPS aggregate concrete consists of larger & finer MEPS aggregates, pozzolonic materials, water and superplasticizer. Natural aggregates are completely absent in MEPS aggregate concrete. Here, few special investigations of the MEPS lightweight concrete and bricks made by MEPS lightweight aggregate concrete and the mechanical properties of MEPS brick masonry have been reported. The brick is produced through extrusion moulding technique which can avoid the segregation of MEPS aggregates. The production of MEPS lightweight concrete bricks with low thermal conductivity can also provide an alternative solution for the utilization and development of MEPS lightweight aggregate concrete in engineering considering the economic and practical factors. During cement the production of cement, CO₂ is released & causes global warming. Hence, the main objective of this paper is to reduce cement content & provide some basic information about the relationship between the elementary composition and the properties of MEPS concrete. The density and compressive strength were tested and discussed. Then, the optimal mixture proportioning of MEPS lightweight aggregate concrete was seeking to manufacture the lightweight bricks based on the requirements on density, strength, cost, and thermal conductivity. The properties of the brick masonry under compressive and shear loadings were studied. To make MEPS concrete economical with high quality, acid & weather resistance with durability properties, the pozzolonic materials such as Fly Ash, GGBS, Silica Fume, nano Mgo, nano TiO₂ and nano Fe₂O₃ are replaced to weight of cement at different levels.

II. MATERIALS AND THEIR PROPERTIES

The materials used in the present investigation are as follows;

1. MEPS Coarse Aggregates
2. MEPS Fine Aggregates
3. Water
4. Super Plasticizer
5. Cement
6. Fly Ash
7. Ground granulated blast slag [GGBS]
8. Silica Fume
9. Nano Titanium dioxide [TiO₂]
10. Nano Magnesium oxide [Mgo]
11. Nano Iron oxide [Fe₂O₃]

The modified EPS aggregates are divided with respect to their sizes as per IS 383:1970 and because of nominal size selected is 20 mm, the max. & min. sizes of MEPS coarse aggregates is 20 mm & 4.75 mm. with specific gravity factor 0.24 and lesser to 4.75 mm aggregates as MEPS fine aggregate with specific gravity factor 0.34. These specific gravity factor values are not a true specific gravity, because its value incorporates compensation for absorption of free water by the MEPS aggregates and it can be used in exactly the same way to calculate the aggregate volume relationship. MEPS aggregates consists of density less than 300 kg/m³ and compressive strength is up to 9 MPa. MEPS are hydrophobic aggregates and they do not absorb water because it consist of about million closed cellular and the inside voids filled with melted matter, but the MEPS Aggregates catches the water included to the voids on the surface thickness caused due to heat treatment process.



Figure 1: 20 mm, 12.5 mm, 10 mm MEPS coarse aggregate and MEPS fine aggregates

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Website: www.ijirset.com

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Water is an important constituent of concrete, it should receive due attention in preparation and for quality control of concrete. Water used for mixing and curing is pure domestic water, conforming to IS: 3025 – 1964 part 22, part 23 and IS: 456 – 2000. Super plasticizers, also known as high range water reducers, are chemical admixtures used where well-dispersed particle suspension is required. These polymers are used as dispersants to avoid particle segregation [coarse and fine aggregates], and to improve the flow characteristics of suspensions such as in concrete applications. Their addition to concrete or mortar allows the reduction of the water to cement ratio, not affecting the workability of the mixture, and enables the production of self-consolidating concrete and high performance concrete. This effect drastically improves the performance of the hardening fresh paste. The strength of concrete increases when the water to cement ratio decreases. However, their working mechanisms lack a full understanding, revealing in certain cases cement-super plasticizer incompatibilities. The addition of super plasticizer in the truck during transit is a fairly new development within the industry. Admixtures added in transit through automated slump management systems allows concrete producers to maintain slump until discharge without reducing concrete quality. Since w/c ratio should be less so high range water reducer is used. To increase strength, water content should be reduced. Master Glenium sky 8233 formerly B-233 which is poly-carboxylic ether based superplasticizer is used. It is brought from BASF India Ltd construction chemicals –Chennai. It is a Light brown colour liquid whose pH & specific gravity is 6 & 1.08, comply with ASTM C494 Type F.

In this present investigation, JSW GGBS powder conforming to 12089:1987, Sigma Nano TiO₂ powder of particle size 5 to 10 nm, Astra silica fume powder conforming to ASTM C1240 & IS 15388:2003, Kirti Adhia nano Mgo of particle size 30-80 nm and nano wings nano Fe₂O₃ of particle size 30-50 nm are used to replace Chettinad cement of ordinary Portland cement [OPC] of 53 Grade was used which satisfies the requirements of IS: 12269-1987.

III. MIX PROPORTIONS

The selection of mix proportions is the process of choosing suitable ingredients of concrete and determining their relative quantities with the object of producing as economically as possible concrete of certain minimum properties. Here it is intended to investigate the potential influence that a range of ingredient parameters have on the mechanical properties and thermal performance of EPS lightweight concrete. In general, the coefficient of thermal conductivity is closely related with the density. The lower the density of concrete, the higher is its thermal insulation. But there is an inverse relation that low density results in a decrease in compressive strength. Hence this program was concentrated on reduction of OPC use in MEPS concrete. In the present study, the best possible levels of mix proportions are investigated to get maximum compressive strength. Therefore, the factors and levels to be considered for concrete are given in the below tables. The MEPS concretes were initially designed as per trails & previous experience and modified by incorporating the OPC at different volume percentages in the MEPS concrete with no grade of concrete. OPC is replaced by Fly ash mixes namely F1,F2,F3,F4, & F5; GGBS mixes namely G1,G2,G3,G4, & G5 at 10%, 20%, 30%, 40%, & 50%; ; Silica Fume[SF] mixes namely S1,S2,S3,S4, & S5 at 5%, 10%, 15%, 20%, 25%; nano Mgo mixes namely M1,M2,M3,M4, & M5; Nano TiO₂ mixes namely T1,T2,T3,T4, & T5; Nano Fe₂O₃ mixes namely i1,i2,i3,i4, & i5 a1%, 2%, 3%, 4% & 5% which are compared to M0.

Table 1: Mix Proportions of fly ash replaced MEPS Concrete

Mix No.	Replacement Details	Meps Ca [Kg/M ³]	Meps Fa [Kg/M ³]	Water [Kg/M ³]	Sp [Kg/M ³]	Cement [Kg/M ³]	Fly Ash [Kg/M ³]
M0	0% FLY ASH	107.85	80.11	139.98	6.07	437.50	0
F1	10% FLY ASH	107.85	80.11	139.98	6.07	393.75	43.75
F2	20% FLY ASH	107.85	80.11	139.98	6.07	350.00	87.50
F3	30% FLY ASH	107.85	80.11	139.98	6.07	306.25	131.25
F4	40% FLY ASH	107.85	80.11	139.98	6.07	262.50	175.00
F5	50% FLY ASH	107.85	80.11	139.98	6.07	218.75	218.75

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Table 2: Mix Proportions of GGBS replaced MEPS Concrete

Mix No.	Replacement Details	Meps Ca [Kg/M ³]	Meps Fa [Kg/M ³]	Water [Kg/M ³]	Sp [Kg/M ³]	Fly Ash [Kg/M ³]	Cement [Kg/M ³]	GGBS [Kg/M ³]
M0	0% GGBS	107.85	80.11	139.98	6.07	0	437.50	0
G1	10% GGBS	107.85	80.11	139.98	6.07	131.25	275.625	30.625
G2	20% GGBS	107.85	80.11	139.98	6.07	131.25	245.00	61.25
G3	30% GGBS	107.85	80.11	139.98	6.07	131.25	214.375	91.875
G4	40% GGBS	107.85	80.11	139.98	6.07	131.25	183.75	122.50
G5	50% GGBS	107.85	80.11	139.98	6.07	131.25	153.125	153.125

Table 3: Mix Proportions of Silica Fume replaced MEPS Concrete

Mix No.	Replacement Details	Meps Ca [Kg/M ³]	Meps Fa [Kg/M ³]	Water [Kg/M ³]	Sp [Kg/M ³]	Fly Ash [Kg/M ³]	GGBS [Kg/M ³]	Cement [Kg/M ³]	SF [Kg/M ³]
M0	0% SILICA FUME	107.85	80.11	139.98	6.07	0	0	437.50	0
S1	5% SILICA FUME	107.85	80.11	139.98	6.07	131.25	61.25	232.75	12.25
S2	10% SILICA FUME	107.85	80.11	139.98	6.07	131.25	61.25	220.50	24.50
S3	15% SILICA FUME	107.85	80.11	139.98	6.07	131.25	61.25	208.25	36.75
S4	20% SILICA FUME	107.85	80.11	139.98	6.07	131.25	61.25	196	49
S5	25% SILICA FUME	107.85	80.11	139.98	6.07	131.25	61.25	183.75	61.25

Table 4: Mix Proportions of Nano Mgo replaced MEPS Concrete

Mix No.	Replacement Details	Meps Ca [Kg/M ³]	Meps Fa [Kg/M ³]	Water [Kg/M ³]	Sp [Kg/M ³]	Fly Ash [Kg/M ³]	GGBS [Kg/M ³]	SF [Kg/M ³]	Cement [Kg/M ³]	Nano Mgo [Kg/M ³]
M0	0% NANO MGO	107.85	80.11	139.98	6.07	0	0	0	437.50	0
M1	1% NANO MGO	107.85	80.11	139.98	6.07	131.25	61.25	36.75	206.168	2.083
M2	2% NANO MGO	107.85	80.11	139.98	6.07	131.25	61.25	36.75	204.085	4.165
M3	3% NANO MGO	107.85	80.11	139.98	6.07	131.25	61.25	36.75	202.003	6.248
M4	4% NANO MGO	107.85	80.11	139.98	6.07	131.25	61.25	36.75	199.92	8.33
M5	5% NANO MGO	107.85	80.11	139.98	6.07	131.25	61.25	36.75	197.838	10.413

Table 5: Mix Proportions of Nano Tio₂ replaced MEPS Concrete

Mix No.	Replacement Details	Meps Ca [Kg/M ³]	Meps Fa [Kg/M ³]	Water [Kg/M ³]	Sp [Kg/M ³]	Fly Ash [Kg/M ³]	GGBS [Kg/M ³]	SF [Kg/M ³]	Nano Mgo [Kg/M ³]	Cement [Kg/M ³]	Nano Tio ₂ [Kg/M ³]
M0	0% NANO TIO ₂	107.85	80.11	139.98	6.07	0	0	0	0	437.50	0
T1	1% NANO TIO ₂	107.85	80.11	139.98	6.07	131.25	61.25	36.75	2.083	204.106	2.062
T2	2% NANO TIO ₂	107.85	80.11	139.98	6.07	131.25	61.25	36.75	2.083	202.045	4.124
T3	3% NANO TIO ₂	107.85	80.11	139.98	6.07	131.25	61.25	36.75	2.083	199.989	6.185
T4	4% NANO TIO ₂	107.85	80.11	139.98	6.07	131.25	61.25	36.75	2.083	197.93	8.25
T5	5% NANO TIO ₂	107.85	80.11	139.98	6.07	131.25	61.25	36.75	2.083	195.86	10.31

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Table 6: Mix Proportions of Nano Fe₂O₃ replaced MEPS Concrete

Mix No.	Replacement Details	MEPS Ca [Kg/M ³]	MEPS FA [Kg/M ³]	Water [Kg/M ³]	Sp [Kg/M ³]	Fly Ash [Kg/M ³]	GGBS [Kg/M ³]	SF [Kg/M ³]	Nano Mgo [Kg/M ³]	Nano TiO ₂ [Kg/M ³]	Cement [Kg/M ³]	Nano Fe ₂ O ₃ [Kg/M ³]
M0	0%Fe ₂ O ₃	107.85	80.11	139.98	6.07	0	0	0	0	0	437.50	0
i1	1%Fe ₂ O ₃	107.85	80.11	139.98	6.07	131.25	61.25	36.75	2.083	8.25	195.95	1.98
i2	2%Fe ₂ O ₃	107.85	80.11	139.98	6.07	131.25	61.25	36.75	2.083	8.25	193.97	3.96
i3	3%Fe ₂ O ₃	107.85	80.11	139.98	6.07	131.25	61.25	36.75	2.083	8.25	191.99	5.94
i4	4%Fe ₂ O ₃	107.85	80.11	139.98	6.07	131.25	61.25	36.75	2.083	8.25	190.01	7.92
i5	5%Fe ₂ O ₃	107.85	80.11	139.98	6.07	131.25	61.25	36.75	2.083	8.25	188.03	9.89

IV. EXPERIMENTAL PROCEDURE

The mixing of concrete is essential for the production of uniform concrete. The mixing should be making sure that the concrete becomes homogeneous, uniform and consistency. Mixing of concrete is done according to IS: 516-1959. Mixing of the concrete is done using a pan mixer of capacity 40kg. To avoid segregation only required hand compaction blows while casting are followed by continuous mixing at very low speed. 50% extra quantity of concrete are mixed to avoid volumetric loss. Ingredients such as powder material, MEPS FA, MEPS CA, 2/3 part of water and 1/3 water diluted with measured super plasticizer are introduced to the pan mixer. Initially dry powder materials and MEPS FA were mixed for about 3 min at low speed to which MEPS CA were added and thoroughly mixed for another 3-5 min. The water, super plasticizer added water is introduced to this mixture in three intervals. The mixture is allowed to mix until it forms a homogeneous mixture.



Figure 2: Pan Mixer

To proceed with the experimental programme, initially specimens of standard cubes [150 mm X 150 mm X 150 mm] were taken and these specimens were cleaned for dust particles and were brushed with oil on all the inner faces to facilitate easy removal of specimens for demoulding. The ingredients are weighed accurately using weighting machine as calculated. The weighed MEPS aggregates are placed in water for 24 hours before they are introduced to the mix. The completely saturated MEPS aggregates are allowed to air dry for a while so that it should become unsaturated. All the tools like the pan mixer, trowels, measuring jars, tamping rods, steel scale, head floats, gloves, masks, safety glasses and weighed ingredients are kept at a place and all precautions must be taken before commencing the mix. For each mix 3 cubes were casted. After the completion of workability tests, the concrete was placed in the

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standard metallic moulds in three layers and it was compacted each time by tamping rod. The concrete in the moulds was not vibrated but the tamping blows are enough helpful in finishing smoothly being compacted thoroughly with a tamping rod to avoid voids. The cube specimens were casted at an average temperature of 24⁰ C and the moulds are covered with wet gunny bags for 10 hours after casting to maintain ambient moisture content, de-moulded after 24 hours and were kept immersed in a clean water tank for curing. After 28 days of water curing, the specimens were tested for compressive strength and split tensile strength. The compressive strength is inversely proportional to workability were compared with similar concrete composites.

V. RESULTS AND DISCUSSIONS

Most of the MEPS concrete mixes displayed good workability but it was observed that with increase in replacements to OPC, there is gradual decrease in workability. Slump test had carried out to evaluate the workability and recorded slump were given in chart 1. There is increase in density in all MEPS concrete mixes except in fly ash mixes. A comparison of variation of compressive strengths with different volume percentages of cement replacement to Fly Ash, GGBS, Silica Fume, Nano Mgo, Nano Tio₂ and Nano Fe₂O₃ at 28-D curing age were given in chart 1 & 2. can be better understood and visualize. The optimum compressive strength in fly ash is 15.7 Mpa at 40% replacement to OPC which kept as constant in continuing mixes.

Nano material effects comprise inter-particle void filling, acceleration of cement hydration, formation of additional Calcium-Silicate-Hydrate [C-S-H] by pozzolanic reaction, higher compressive strength, improved frost resistance and lower permeability. Nano Mgo, Nano Tio₂ and Nano Fe₂O₃ do not only fill the voids left by large particles, but by being highly reactive they react with calcium hydroxide and additionally act as nucleation sites for the production of very fine C-S-H phase. Small quantity of nano material is enough to increase its mechanical properties. The optimum of compressive strength in Nano Mgo and Nano Tio₂ mixes at 1% and 4% replacement to OPC of the optimum cement in last mixes. The final optimal mixture of MEPS aggregate obtained at Mix No. i5 concrete at 30% Fly Ash, 20% GGBS, 15% Silica Fume, 1% Nano Mgo, 4% Nano Tio₂ and 5% Nano Fe₂O₃ replaced to OPC and Maximum compressive strength of 20.77 Mpa is achieved in i5 Mix.

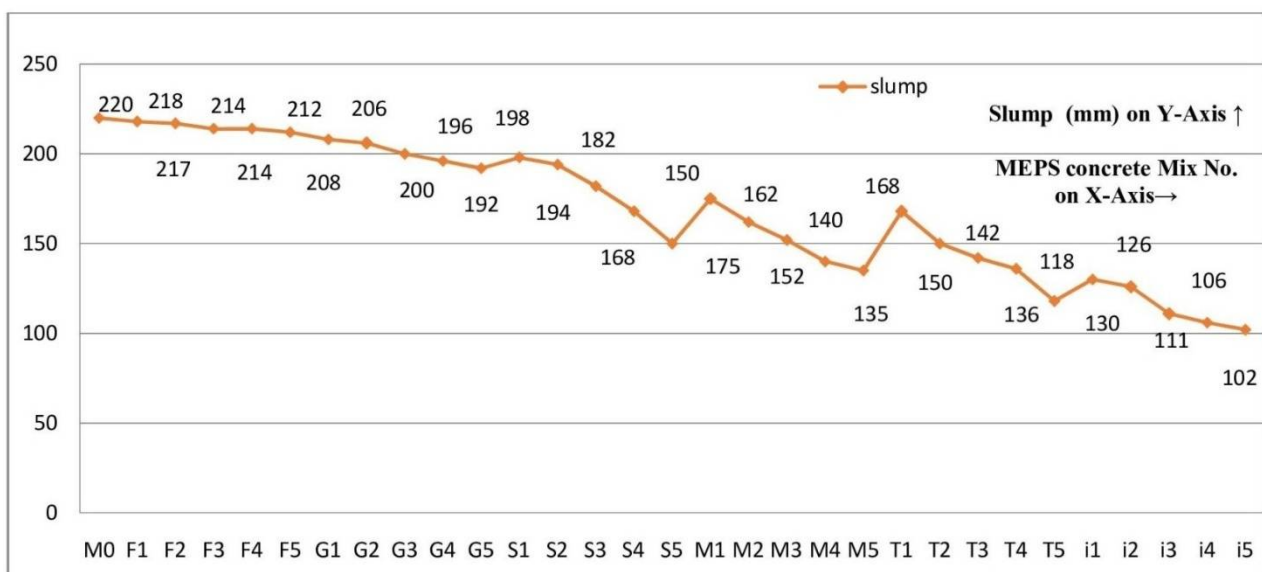


Chart No.1: Variation between slump and MEPS concretes.

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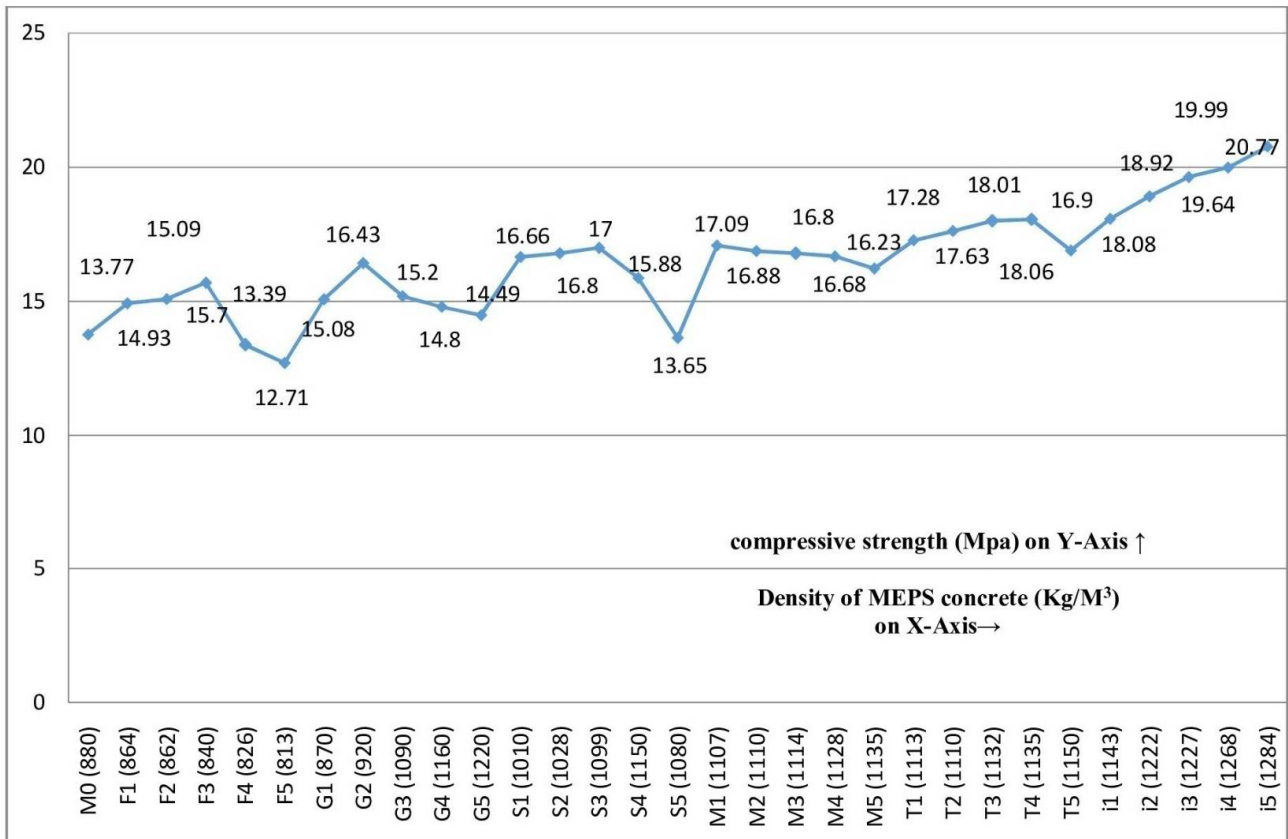


Chart No. 2: Relationship between compressive strength and Density of MEPS concretes.

VI. APPLICATION

The major purpose of this paper is to find out the optimum mix ratio of MEPS lightweight concrete to produce the bricks. From an economic and energy-saving conservation point of view, the MEPS lightweight bricks have obvious benefits of improving thermal insulation, absorbing sound characteristics as well as reducing the loads of building walls. There is a contradiction in the comparison of optimum mix proportions of maximization of compressive strength and minimization of density [i.e., low thermal conductivity]. Due to the cost effective concern and other practical consideration, a compromise composition based on the preliminary trial experiments was applied for utilization. In order to analyze the mechanical behaviour of MEPS lightweight brick masonry, three specimens of size 240 mm x 390 mm x 720 mm and six specimens of size 390 mm x 290 mm x 240 mm were prepared with Cement mortar [1:6], later transferred to a storage area for curing up to 28 days and tested for compressive strength and shear strength respectively.

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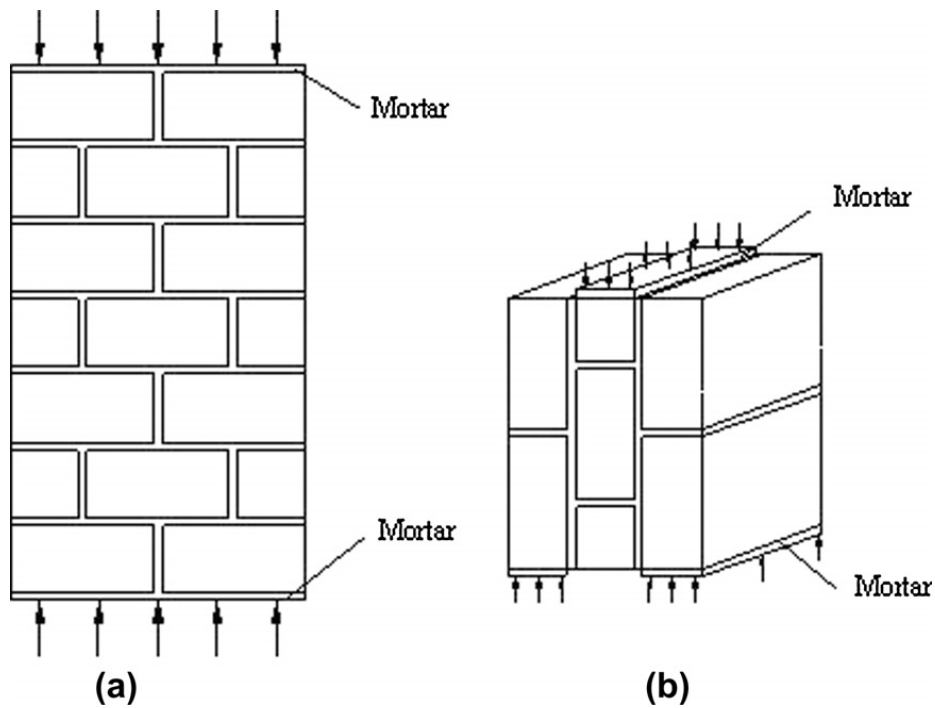


Figure 3: Geometrical configuration of masonry prism for [a] Compression Test and [b] Shear Test.



Figure 4: Cracking mode of masonry prism in compression and Failure mode of shear test

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The final optimal mixture of MEPS aggregate [i.e., Mix No. i5] concrete was selected among experiments under consideration to manufacture the light weight bricks. The tests were executed in conditions of applying the load at a uniform rate so that the maximum load was reached in 1–3 min. The masonry prisms were considered as extracted from a real masonry wall. The arrangements are shown in figure 3. It can be considered that the MEPS lightweight bricks were suitable for masonry walls. The cracking mode is illustrated in figure 4 and it appeared that the cracks along the head joints and crossed also the joined bricks. Then, horizontal deformation developed without relevant increasing of the compression stress and the masonry fractured with vertical cracks. The elasticity modulus has been considered as the secant modulus at 40% of the ultimate stress. The compressive strength of three masonry specimen were 3.2, 3.4 and 3.5 Mpa and the shear strength results of six masonry specimens were 0.16, 0.19, 0.17, 0.15, 0.14 and 0.18 MPa, respectively. The failure mode is presented in figure 4. The mortar cores had been formed by the filling of the brick cavities with fresh mortar, which could contribute to a resistance in shear of the masonry work.

VII. CONCLUSIONS

By using EPS waste for MEPS aggregate production not only solves the EPS disposal problems, but also helps to preserve natural resources. A new recycling technology to shrink waste EPS was developed by using Heat Treatment Method. By keeping EPS waste in a closed hot air oven at 130⁰ C for 15 minutes resulted in Modified EPS aggregates [MEPS]. The final optimal mixture of MEPS aggregate obtained at Mix No. i5 concrete at 30% Fly Ash, 20% GGBS, 15% Silica Fume, 1% Nano Mgo, 4% Nano TiO₂ and 5% Nano Fe₂O₃ replaced to OPC and Maximum compressive strength of 20.77 Mpa is achieved in i5 Mix. From the economic and practical concern, a compromise composition of MEPS concrete [i5 mix] was chosen to produce MEPS lightweight bricks. The compressive strength of three masonry specimen were 3.2, 3.4 and 3.5 Mpa and the shear strength results of six masonry specimens were 0.16, 0.19, 0.17, 0.15, 0.14 and 0.18 MPa, respectively. The compressive strength is inversely proportional to workability were compared with similar concrete composites. In Concrete construction, Self Weight represents a very large portion of the load on the Structure and use of MEPS aggregates in concrete can reduce the self weight up to 60% and are considerably advantages in reducing the cross-section dimensions of beams, columns & footing. This will have the double advantage of reduction in the cost of construction materials and also cost of waste disposal.

ACKNOWLEDGEMENT

The Author is thankful to the President, Ayaan Educational Society and authorities of the department of civil engineering, Ayaan College of Engineering & Technology, Hyderabad, India for the facilities and guidance to carry out this research work during January 2016 to June 2017.

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