Development of Foaming-Agent Floating Material composed of Inorganic Microsphere

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ABSTRACT

Floating materials, characterized as light weight, low density and high porosity ratio, are most commonly used in the harbor and river engineering such as floating dock, floating bridge. When applied to construction engineering, they are used for the purpose of heat insulation, sound insulation and lightweight. For the development of floating material applicable to the pontoon structure for flood-prone areas, this study attempts to adopt cement as binding material, microspheres as filled composite, combined with self-developed foaming agent. In this study, the developed floating material is characteristic of low density and non-connected pore structure; therefore, it has mid strength, low permeation, low thermal conduction and other properties but high surface water absorption.

1) INTRODUCTION

Due to the needs of crossing the waters, fishing and marine drilling, human beings developed various floating material to meet the need of loads, float and water resistance. In addition, in order to explore land resources in the process of urban development, the role of low-lying areas as well as the mechanism of its hydrology were varied, which caused the change of flood peak and decreased infiltration and weakened the flood resistance, even led to ground subsidence owing to excessive withdrawal of groundwater for coastal aquaculture fisheries. All of these factors related to the reasons that buildings in low-lying areas prone to flood during disasters, which easily caused victims of lives or properties. It also highlighted the importance of regional flood control. In recent years, due to extreme weather changes, overrun with wind and rain have become the norm. For the inevitable natural tendency, e.g. frequent floods caused by climate disasters, to construct floating structure by floating material within flood-prone areas may be one of the feasible solutions. Furthermore, since the features of the floating material with low density and high void ratio, it often can be used as the construction functional material for the need of heat insulation, sound insulation and structural lightweight materials.

Traditional floating material includes low density liquids for packing, foams, foamed glass, aluminum, lithium metal, wood and polyolefin materials and so on.

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However, the leakage of low density liquid for packing may result in contaminated waters. Though Lithium metal is able to meet the demand of its strength, it will react with water and its cost is expensive. Foam, foam glass, aluminum and wood are featured as low strength, unable to meet the project needs. Therefore, floating materials with polymer matrix composites are developed, such as foam, polyurethane foam and epoxy resins of unsaturated polyester composite materials. Due to the polymer material has a low density, insulation, and insulation, corrosion, cheap and easily made, the advantages and producing technical and engineering applications have been quite mature, but its long-term usage increases the brittleness, easiness to crack and lead to deterioration of aging. (Taherishargh,2014). In addition, application of floating polymer composite material on the primary structure often result in loss and other damage due to poor compatibility, its application in construction works shall consider compatibility issues with the reinforced concrete (Lim, 2006). In order to overcome the polymer-based floating material defect of concrete structure durability and compatibility, development of floating material with low density, mid-strength and excellent compatibility with cement concrete can be regarded as one of the key issues to explore the application of floating material and extend floating material in the engineering structures of construction. This study applied principles of material composition through design of experiments and statistical analysis, develop cement matrix floating material (abbrev. as CMFM) featured as light weight, mid strength and compatible with concrete.

At present, the common floating materials mainly developed with polymer matrix composites, characteristics of low density, low cost, corrosion-resistant and easy manufacture. But for the utilization in river engineering and construction project, there are the following main limitations (Videla and Lopez, 2000):

- **poor durability and weatherability**: polymer-based materials due to its bonds weak vulnerable to ultraviolet radiation, accelerated deterioration, brittleness and lead to cracking. Short life cycle and maintenance costs increase significantly.
- **poor compatibility with cementitious material**: polymer-based materials for molecular structure and special surface properties, engagement of cement and construction materials shall be by means of adhesive or fasteners. But by the different materials and highly alkaline cement concrete, resulting in both material interface compatibility problems, and its application of the composite structure cannot be expanded, resulting in the restrictions of its use or functions.

For applying floating material in river engineering and construction engineering, as structural or non-structural use, and to overcome the weaknesses of polymer matrix composites, this study is intended to select cement as adhesive material, supplemented by self-development of inorganic foaming agents by our research team in order to reduce unit weight of cement-based materials and bond bubbles of uniform material without connecting. Inorganic microspheres were adopted as filling materials due to its small diameter, hollow, lightweight, high strength characteristics, which add to the foam cement bonding material by reasonable mixture. CMFM can reduce the density of floating bodies, maintain higher strength to meet the needs of engineering.

For seeking out optimal mixture of CMFM, regression orthogonal experimental design was introduced in this study, by referring to CNS (China National Standard) standard and ASTM standards respectively, the fresh properties and hardened properties of CMFM were individually investigated. Through the analysis of factors' significance impact of CMFM material on its performance, then discuss the optimal combination ratio for various projects use. Research flow of this study was illustrated in Figure 1.

Figure 1 Research flow of this study

2) COMPOSITION MECHANISM OF CMFM

It was found in the work of (Puttappa, 2008): currently floating material formulated mostly based on polymer material and foam agents, fillers and other components, with features such as low-density, low water absorption, low thermal conductivity, good durability, etc., supplemented by foam agent for resulting in non-connected pores to reduce weight, and the selection of lightweight filler with good compressive strength and excellent chemical resistance properties such as hollow microspheres, constitutes polymer floating composite material. Since the polymer or polymer composite floating material remains polymers properties of the polymer materials, such as flame poor fire resistance, UV-resistant and rigid, etc., they yet meet the requirements of building materials. Furthermore, the polymer or polymer commonly used in building materials and float cementitious material, poor compatibility with the cement-based material, cannot be fully used in concrete structures with cement-based materials as the main cementing material. Thus, this research intends to develop CMFM for applying on traditional concrete structure, by using cement as main bond material, inorganic microsphere as light fill material, and auxiliary self-developed foaming agent added to base material, through chemical reactions, produced good-distributed but non-connected pores, to reach basic requirements of the mid-strength and low-density for floating material, as shown in Figure 2. In order to reduce the unit weight of the material to comply with the basic requirements of floating bodies, high unit weight of cement (specific weight 3.12) for bonding materials and low unit weight (specific weight 0.18) of inorganic microspheres as fill material were adopted. The adding of inorganic microsphere not only reduces the unit weight of CMFM, its particle size distribution and accumulation also help cement matrix form close packing, so as to enhance the overall strength of the material. From SEM view: cement paste can evenly and tightly wrap inorganic microspheres, as shown in Figure 3-4.

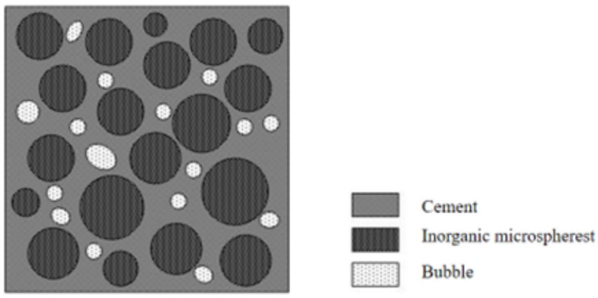

Figure 2 Composition Mechanism of CMFM

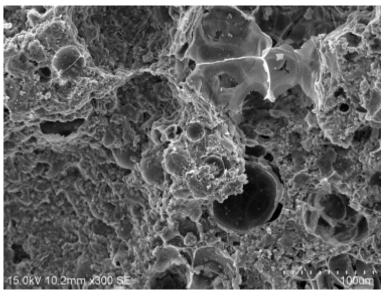

Figure 3　SEM view for cement and inorganic microspheres (300 times)

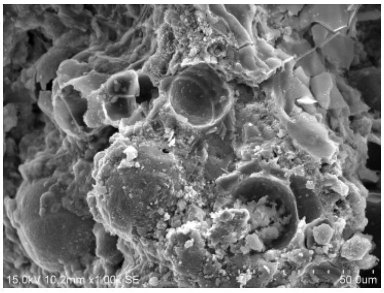

Figure 4 SEM view for cement and inorganic microspheres (1000 times)

3) EXPERIMENTAL PROGRAM

This study, by adopting cement as main cementing material, inorganic microspheres as filler, self-developed foaming agent, supplemented by superplasticizer to improve workability, made up floating material with non-connected porosity. Main experimental processes were composed of the preliminary experiment, design of experiment and validation experiment. First, planning analysis and preliminary experiments help to determine the optimal combination ratio of inorganic microspheres, foaming agent and superplasticizer. By regression orthogonal experimental design method, planning for group consolidation analysis of variance and regression analysis of the results of the test, ratio of different ratio, compressive strength and density of floating material trends that affect performance, and to facilitate the analysis of experimental data. Validation against the optimal combination ratio obtained from regression tests to evaluate their test results to determine the accuracy of results of regression analysis, so that we can have reasonable, scientific and practical conclusions.

3.1 VARIABLES OF EXPERIMENTS

In order to clarify the material factors of CMFM, the mixture on the properties of fresh and hardened concrete, inorganic microspheres with added volume, added foam agent ratio and superplasticizer ratio were chosen as experimental variables. Factors of the material level parameters collection are shown in Table 1.

Table 1 Level of factors and material parameters of CMFM

Items		Level of factors		
		1	2	3
Material factors	W/C	0.7	0.85	1.0
	inorganic microspheres volume ratio	3.5	4.0	4.5
	foam agent ratio(%)	1.0(0.06)*	1.5(0.10)	2.0(0.13)
	superplasticizer ratio (%)	2.0(0.43)**		

*: the value in () =>ratio of foam agents to solids content by weight
**: the value in () =>ratio of superplasticizer to solid content by weight

- Water/cement ratio: weight ratio of mixing water and cement, according to preliminary test results, add inorganic microspheres for maintaining the cement mortar workability, and reduced density after harden of cement, water cement ratio of 0.7, 0.85, 1.0 were decided to use.

- Inorganic microspheres volume ratio: volume ratio and cement content of inorganic microspheres. In preliminary tests buoyant density, microspheres adding 3.5 min. For exploring inorganic microspheres content on the floating effect of material properties, 3.5, 4.0, 4.5 were chosen as added ratios of inorganic microspheres.
- Foam agent ratio (%): according to the results of (Dransfield, 2003): "most foam agent as cement additives content is less than 2%." To inquire into the foaming agent added to the floating body effect of material properties, it is capped at 2%. The added foam agent ratio were designed as 1%, 1.5%and 2%, respectively.
- Superplasticizer ratio (%): according to the result of (Sun, 2010): "in the condition of water cement ratio of 0.4, add superplasticizer admixture of the optimal dose is about 1.7%". Since the inorganic microspheres in this study for their geometric mean particle size around 70.223μm, for the dispersion of cement particles with inorganic microspheres, superplasticizer was utilized for raising workability, as relative amount of cement 2%.

3.2 DESIGN OF EXPERIMENTS

Experimental planning of this study followed the application of experimental design (Design of Experiments) (Montgomery, 2005), according to the characteristics of the test object, the idea of reasonable tests, testing procedures and the number of tests to get the best effect. There are two main connotations for design of experiments :

- Experimental plan: find out the test may be the most suitable for the purpose of the test results.
- Data analysis: methods of test data in analysis, and analysis of its conclusions.

To predict bulk density, water absorption and compressive strength of hardened CMFM at different age as well to estimate the mixture after obtaining the compressive strength or density according to the demand for engineering purposes, regression orthogonal experiment scheme with applying statistical methods such as regression analysis and analysis of variance analysis of experimental data were implemented in this study, through self-developed data-processing software to quickly access relevant statistics and charts, the characteristics and significance of the material factors could be recognized and led to the optimal combination ratio and regression equations.

Three levels of factor ($L_3 3$) regression orthogonal configuration testing were adopted in this study. The mixing proportion arrangement for this study is shown in Table 2, where T1 ~ T14 designated for three-level orthogonal test group,T15 ~ T17 designated for mean value group and a total of 17 groups of test proportioning were used.

Table 2 Design Mixing Summary for CMFM

Exp. Item	W/C	inorganic microspheres volume ratio	foam agent ratio (%)
T1	0.961	4.37	1.87
T2	0.961	4.37	1.13
T3	0.961	3.63	1.87
T4	0.961	3.63	1.13
T5	0.739	4.37	1.87
T6	0.739	4.37	1.13
T7	0.739	3.63	1.87
T8	0.739	3.63	1.13
T9	1	4	1.5
T10	0.7	4	1.5
T11	0.85	4.5	1.5
T12	0.85	3.5	1.5
T13	0.85	4	2
T14	0.85	4	1
T15	0.85	4	1.5
T16	0.85	4	1.5
T17	0.85	4	1.5

3.3 CALCULATION FOR EXPERIMENT MATERIAL RATIO

The main composition of CMFM includes cement, inorganic microspheres, foaming agent, superplasticizer and water. In addition, the additives in the fixed ratio include dispersing agents, foaming agents and viscosity agent. Ratio of material added volume content per unit volume were first calculated, then the proportion of material added weight content by specific weight were covert as the basis of mixing. The fixed proportion of additives respectively according to the weight of cement or mixing water added is not included in the unit volume. Set water cement ratio W/C to $\alpha = W_W/W_C$, inorganic microspheres with added volume (to volume of cement) added for β_{SG}, foaming agent added ratio (to weight of cement) as β_{Ag}, superplasticizer added ratio (to weight of cement), β_{SP}, cement per unit volume (m^3) of adding as W_C.

Mixture ratio design for CMFM:

Volume of water before replacement (V_W)

$$\frac{W_w}{W_c} = \alpha \quad \therefore W_W = \alpha \times W_C$$

$$V_W = \frac{W_W}{\gamma_W} \tag{1}$$

Volume ratio of Inorganic microsphere (V_{SG}) (to volume of cement)

$$W_{SG} = \frac{\beta_{SG} \cdot W_c \cdot \gamma_{SG}}{\gamma_c}$$

$$V_{SG} = \frac{W_{SG}}{\gamma_{SG}} = \beta_{SG} \times V_c = \beta_{SG} \times \frac{W_c}{\gamma_c} \tag{2}$$

Volume of foaming agent (V_{Ag}) to replace water

$$W_{Ag} = \beta_{Ag} \times W_C$$

$$V_{Ag} = \frac{W_{Ag}}{\gamma_{Ag}} \tag{3}$$

The volume of superplasticizer (V_{SP}) to replace water

$$W_{SP} = \beta_{SP} \times W_C$$

$$V_{SP} = \frac{W_{SP}}{\gamma_{SP}} \tag{4}$$

Where W_C: cement dosage, W_W: water dosage, W_{SG}: inorganic microsphere dosage, W_{Ag}: foaming agent dosage, W_{SP}: superplasticizer dosage, V_C: cement volume, V_W: water volume, V_{SG}: inorganic microsphere volume, V_{Ag}: foaming agent volume, V_{SP}: superplasticizer volume, γ_c: cement specific weight, γ_W: water specific weight, γ_{SG}: inorganic microsphere specific weight, γ_{Ag}: foam agent specific weight, γ_{SP}: superplasticizer specific weight, β_{SG}: replacement ratio of inorganic microspheres, β_{Ag}: replacement ratio of foam agent, β_{SP}: replacement ratio of superplasticizer.

According to Unit-volume method, Eq.(5) can be expressed in the following form：

$$V_c + V_w + V_{SG} + Air = 1 \tag{5}$$

Where Air: air content(%)

By introducing Eq.(1)-(4) into Eq.(5), Eq.(5) can be expressed as Eq.(6)

$$\frac{W_c}{r_c} + \frac{\alpha W_c}{r_w} + \frac{\beta_{SG} \times W_c}{r_c} + Air = 1 \tag{6}$$

Therefore, Wc can be expressed W_C in the form of Eq.(7)

$$\therefore W_c = \frac{1000(1-Air)}{\left(\frac{1}{r_C} + \frac{\alpha}{r_W} + \frac{\beta_{SG}}{r_C}\right)} \qquad \text{(unit：kg/m}^3\text{)} \tag{7}$$

after obtaining W_C, the rest material weight of the mixture design can be calculated individually in Eq.(8)-(10).

$$W_{SG} = \frac{\beta_{SG} \cdot W_c \cdot \gamma_{SG}}{\gamma_c} \qquad \text{(unit：kg/m}^3\text{)} \tag{8}$$

$$W_{Ag} = \beta_{Ag} \times W_C \qquad \text{(unit：kg/m}^3\text{)} \tag{9}$$

$$W_{SP} = \beta_{SP} \times W_C \qquad \text{(unit：kg/m}^3\text{)} \tag{10}$$

After seeking out of W_{SG}, W_{Ag}, W_{SP}, mixing water dosage after replacement can be calculated as follows:

$$\mathrm{V_w} = V_w{}' + V_{Ag} + V_{SP}$$

$$\frac{W_w}{\gamma_w} = \frac{W_w{}'}{\mathrm{r_w}} + \frac{W_{Ag}}{\gamma_{Ag}} + \frac{W_{SP}}{\gamma_{SP}}$$

$$W_w = W_w{}' + \frac{\gamma_w \cdot W_{Ag}}{\gamma_{Ag}} + \frac{\gamma_w \cdot W_{SP}}{\gamma_{SP}}$$

$$\alpha W_c = W_w{}' + \frac{\gamma_w \cdot \beta_{Ag} \cdot W_c}{\gamma_{Ag}} + \frac{\gamma_w \cdot \beta_{SP} \cdot W_c}{\gamma_{SP}}$$

$$W_w{}' = \alpha W_c - \frac{\gamma_w \cdot \beta_{Ag} \cdot W_c}{\gamma_{Ag}} - \frac{\gamma_w \cdot \beta_{SP} \cdot W_c}{\gamma_{SP}}$$

$$\therefore W_w{}' = W_c\left[\alpha - \gamma_w\left(\frac{\beta_{Ag}}{\gamma_{Ag}} + \frac{\beta_{SP}}{\gamma_{SP}}\right)\right] \quad (11)$$

Where $V_w{}'$: the volume of water after replacement; $W_w{}'$: the weight of water after replacement.

3.4 EXPERIMENTAL PROGRAM

In order to carry out in-depth and complete study material factors on fresh, hardened properties of CMFM, the preliminary test, regression orthogonal design of experiment and verification experiment were sequentially implemented. First, in preliminary test, the composition of CMFM (i.e. cement, inorganic microspheres, foaming agent and superplasticizer) was determined, in which compressive strength and density were chosen as indicators. Then, regression orthogonal design experiment was executed with reference to fresh properties (i.e. flow and setting time) and hardened properties (i.e. compressive strength, density, water absorption, porosity and sulphate resistance) of cement mortar. Verification experiment was carried out on optimal estimation of material composition ratio in accordance with the results given by performance expectations such as maximum compressive strength or minimum density, test, its purpose is to validate the correctness of predicted optimum ratio by regression orthogonal experiment analysis.

3.5 DATA ANALYSIS METHOD

In this study, experiment design method was first adopted to determine the composition of CMFM and w/c ratio, followed by regression orthogonal table for experiment plan. The measured results as performance pointer of main factor and parameter level will be further analyzed by analysis of variance and regression analysis respectively. Theoretical forecast value for the best performance pointer of most suitable ratio combination could be induced by regression equation, and verification experiment is to validate the correctness of regression equation. Analysis of variance (ANOVA) was execute by calculating sum of squares of deviations of the material factors and experimental error, degrees of freedom and variance, followed by f-value test. ANOVA can be used to quantitatively explore the impact of significant interaction between factors on measurement results. On orthogonal multi-factor analysis of variance table, calculate the sum of squared deviations of each factor and error and obtained degrees of freedom, variance and finally the f-value test. Regression analysis, by using statistical regression analysis of the measurement data, can help establish the relationship between dependent variables and independent variables. The correlation between variable relations can be applied to regulate characteristics and prediction of optimum materials ratio purposes.

4) EXPERIMENTAL RESULTS AND DISCUSSION

4.1 DENSITY

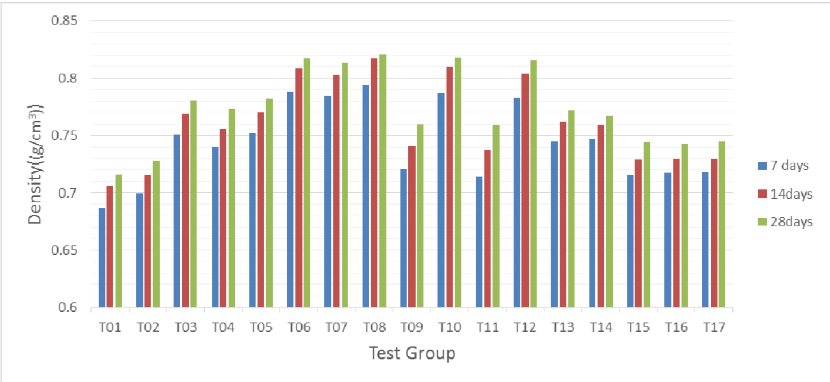

Figure 5 experimental results of density at 7, 14, 28-day for CMFM

By referring to ASTM D792 buoyancy density test method for the determination of density and specific gravity of plastic (relative density) standard test method, the ratio of cement floating bulk density values at the age of 7, 14 or 28 days specimens were measured. The results of the measurement and the optimal ratio of material factors were illustrated in Figure 5 and tabulated in Table 3.

Table 3 Optimal ratio for significant levels of density at different ages

Curing age	Effect Factors	significant level	Partial regression coefficients	Predicted density (g/cm^3)	Optimal ratio		
					W/C	inorganic microspheres volume ratio	foam agent ratio (%)
7days	z_1	Highly sig.	-129.31	0.68	1.00	4.50	1.60
	z_2	Highly sig.	-35.84				
14days	z_1	Highly sig.	-182.29	0.71	1.00	4.46	1.54
	z_2	Highly sig.	-55.69				
28days	z_1	Highly sig.	-142.40	0.72	1.00	4.49	1.74
	z_2	Highly sig.	-57.01				

From Table 3, it can be found that the density of CMFM at different age most influenced by water cement ratio, further verified by analysis of variance and partial regression coefficients. Among them, the density at each age was both significantly influenced by z1 (w/c) and z2 (inorganic microspheres volume ratio), density increases with age. This may be inferred that hydration of cement at 7-day age has not been completed, with relatively low density characteristics while ages up to 28 days, the density could be close to 0.830 g/cm^3 since the influence by water/cement ratio has been stabilized. In addition, by checking partial regression coefficients, it can be informed: there exists maximum negative correlation of the partial regression coefficients for z1 at age of 7, 14 and 28 days, which means water/cement ratio the most significant influence on density at each age while the partial regression coefficient for z2 increases with age. Thus, to reduce the density of CMFM clearly depends on the synthetic effects of water/cement ratio and inorganic microspheres volume ratio.

4.2 POROSITY

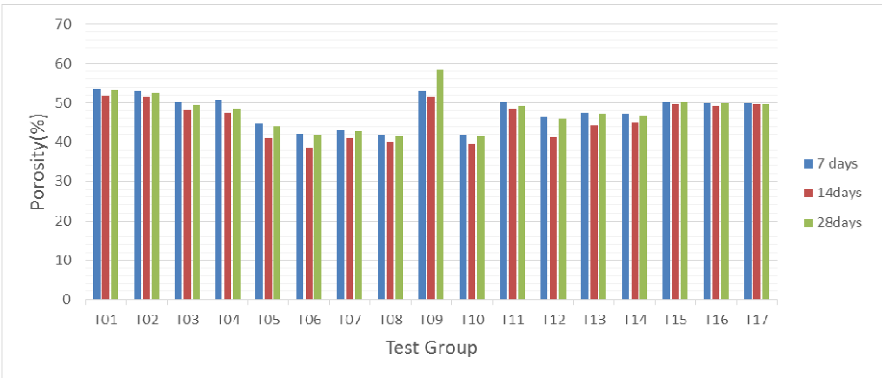

Figure 6 experimental results of porosity at 7, 14, 28-day for CMFM

Porosity tests refer to ASTM D792 buoyancy method for the determination of density and specific gravity of plastic (relative density) standard test method, age 7, 14, 28 days specimens for determination of quality of each State, and according to the measurements calculated the ratio of porosity of cement float. The results of the measurement and the optimal ratio of material factors were illustrated in Figure 6 and tabulated in Table 4.

Table 4 Optimal ratio for significant levels of porosity at different ages

Curing age	Effect Factors	significant level	Partial regression coefficients	Predicted porosity(%)	Optimal ratio		
					W/C	inorganic microspheres volume ratio	foam agent ratio (%)
7days	z_1	Highly sig.	137.43	55.2	1.00	4.50	1.53
	z_2	Highly sig.	17.92				
	z_3	Insignificant	21.24				
14days	z_1	Highly sig.	80.22	54.4	1.00	4.36	1.49
	z_2	Significant	66.42				
	z_3	Insignificant	39.26				
28days	z_1	Highly sig.	125.30	54.6	1.00	4.50	1.55
	z_2	Highly sig.	30.88				
	z_3	Influential	24.58				

From Table 4, it can be realized that the porosity of CMFM at different age most influenced by water cement ratio, further verified by analysis of variance and partial regression coefficients. Among them, the porosity at each age was very significantly influenced by z1 (w/c) and significantly influenced by z2 (inorganic microspheres volume ratio), density increases with age. This may be inferred that hydration of cement at 7-day age has not been completed, with relatively high porosity characteristics while ages up to 14 days and 28 days, porosity was slightly reduced due to cement hydration but foaming porosity less affected by cement hydration and the distribution of inorganic microspheres in pore peripheral, resulting in decreased porosity is not obvious trends.. In addition, by checking partial regression coefficients, it can be informed: there exists maximum positive correlation of the partial regression coefficients for z1 at age of 7, 14 and 28 days, which means water/cement ratio the most significant influence on porosity at each age while the partial regression coefficients for z2 and z3 (foam agent ratio) first increased and then decreased with age. Therefore, to increase the porosity of CMFM depends on the synthetic effects of water/cement ratio and inorganic microspheres volume ratio, and supplemented with suitable foaming agent ratio.

4.3 WATER ABSORPTION

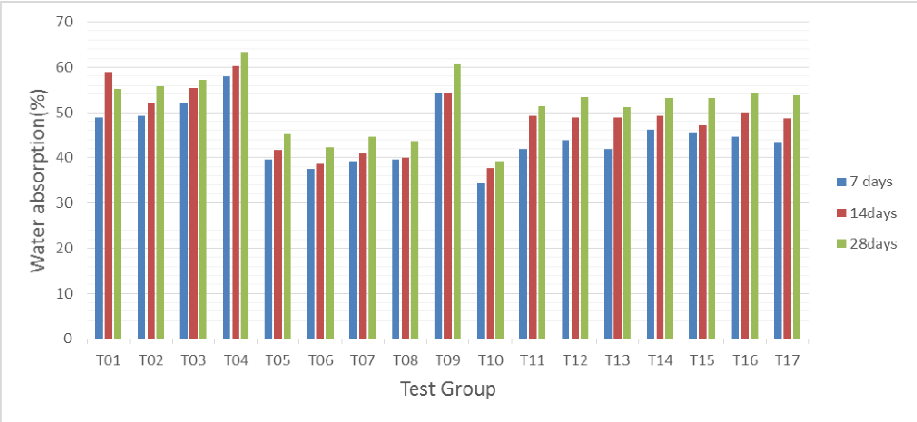

Figure 7 experimental results of water absorption at 7, 14, 28-day for CMFM

By following ASTM C642 density, water absorption, porosity measurement test standard for hardened concrete, the water absorption of specimens of CMFM at curing age 7, 14 and 28 days were measured. The results of the measurement and the optimal ratio of material factors were illustrated in Figure 7 and tabulated in Table 5.

Table 5 Optimal ratio for significant levels of water absorption at different ages

Curing age	Effect Factors	significant level	Partial regression coefficients	Predicted water absorption (%)	Optimal ratio		
					W/C	inorganic microspheres volume ratio	foam agent ratio (%)
7days	z_1	Highly sig.	+125.05	34.7	0.7	4.5	1.0
	z_2	Significant	+17.95				
	z_3	Influential	-22.60				
14days	z_1	Highly sig.	+296.40	34.0	0.7	4.5	1.0
	z_2	Insignificant	-46.72				
	z_3	Insignificant	-58.30				
28days	z_1	Highly sig.	+446.63	35.7	0.7	4.5	1.0
	z_2	Highly sig.	+30.43				
	z_3	Insignificant	+9.51				

From Table 5, it can be observed that the water absorption of CMFM at different age most influenced by z1 (w/c), further verified by analysis of variance and partial regression coefficients. The partial regression coefficient of z2 (inorganic microspheres volume ratio) showed the trend of first decline, followed by rising. It may be explained that, although hydration at 7 days is not completed, specimen could be denser due to electrostatic attraction between inorganic microspheres. Thus, the increases of inorganic microspheres volume ratio results in the decrease of water absorption. When the age of 14 days, due to the hydration products produced, resulting in inorganic microspheres dispersed, so the partial regression coefficient of z2 was negatively correlated. When the age of 28 days, since the hydration stabilized, z2 was shown as age 7 days, minimum water absorption tends to 35.7%. Therefore, to reduce the water absorption of CMFM depends on the synthetic effects of inorganic microspheres volume ratio and foaming agent ratio.

4.4 COMPRESSIVE STRENGTH

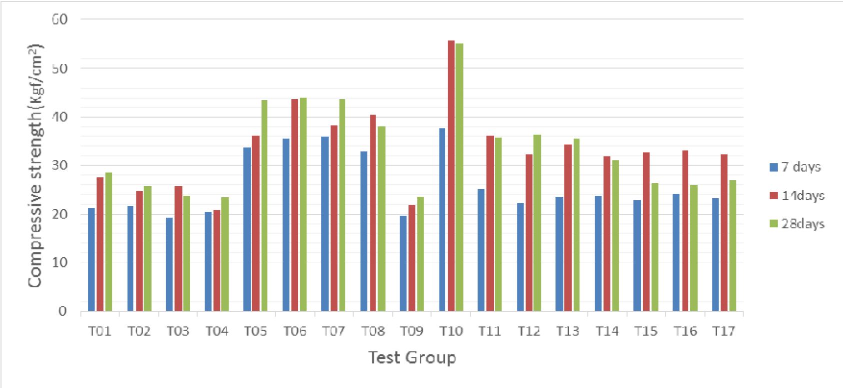

Figure 8 experimental results of compressive strength at 7, 14, 28-day for CMFM

By following CNS 1010 testing method for compressive strength of hydraulic-cement plastered, the compressive strength of specimens of CMFM at curing age 7, 14 and 28 days were evaluated. The results of the evaluation and the optimal ratio of material factors were illustrated in Figure 8 and tabulated in Table 6.

Table 6 Optimal ratio for significant levels of compressive strength at different ages

Curing age	Effect Factors	significant level	Partial regression coefficients	Predicted compressive strength (kgf/cm^2)	Optimal ratio		
					W/C	inorganic microspheres volume ratio	foam agent ratio (%)
7days	z_1	Highly sig.	-515.64	40.8	0.70	4.50	1.00
	z_2	Influential	-25.80				
14days	z_1	Highly sig.	-421.40	50.7	0.70	4.21	1.11
	z_2	Insignificant	+61.91				
28days	z_1	Highly sig.	-606.35	53.3	0.70	4.50	1.00
	z_2	Insignificant	-107.44				

According to Table 6, the compressive strength of CMFM at each age are significantly affected by z1 (w/c), and compressive strength increases with age. It may be inferred that 7 days of hydration of cement has not been completed, with relatively low strength characteristics. When ages up to 28 days, the hydration effect stabilized, compressive strength approaching 53.3 kgf/cm^2. In addition, it can be informed: since the partial regression coefficients of z1 (w/c) at different age are all negative, water/cement ratio was the most significant influence on compressive strength at various age while the partial regression coefficient of z2 (inorganic microspheres volume ratio) at age of 7, 14 and 28 days, which first increased and then decreased with age increase. Therefore, to increase compressive strength of CMFM depends on the synthetic effects of water/cement ratio and inorganic microspheres volume ratio.

4.5 SULPHATE-RESISTANCE

Table 7 ACI 318-05 concentrations of sulfate environment

Erosion	Soil (wt,%)	Solution (ppm)
Ignorable	<0.1	<150
Moderate	0.1~0.2	150~1500
Severe	0.2~2.0	1500~10000
Very severe	>2.0	>10000

Durability test originally refers to CNS 1167 using sulfate or magnesium sulfate aggregate method of strengthening the test, in which the durability specimens at age 28-days were dried and soaked sulfate solution at five cycles, and using weight-loss rate to represent the characteristics of durability. However, since the concentration of sulfate solution up to 25.9%, it led to excessive accelerated deterioration so that early damage take place only to three cycles. Therefore, later on, this test took reference to ACI 318-05 definition of sulfate environments, in which the concentration of exposure environment can be divided into four levels, as shown in Table 7. For CMFM specimens at age 28 days, the specimens after initial drying would be soaked in sulfate solution and dried again and to measure its weight at five cycles.

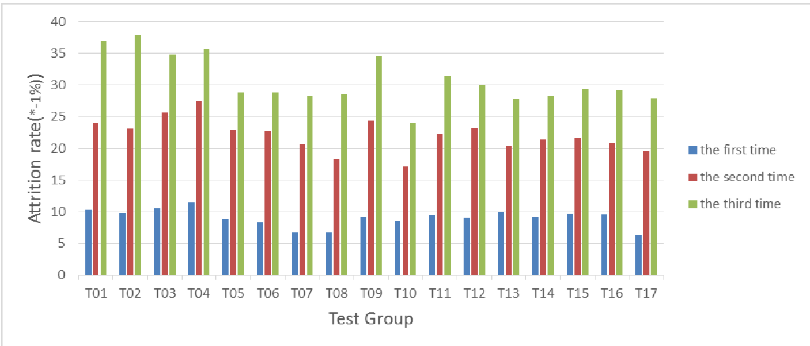

Figure 9 experimental results of attrition rate at 7, 14, 28-day for CMFM

Based on the above, the impact factor significance of weight-loss rate as well the optimum ratio are as shown in Table 8. By partial regression coefficients, it can be informed: the partial regression coefficients of z1 (w/c) as 174.40 positive, so z1 on the weight-loss rate at age 28 days be the highly significant, followed by z2 (inorganic microspheres volume ratio) on the weight-loss rate 127.14 significant.

Table 8 Optimal ratio for significant levels of weight-loss rate at different ages

Curing age	Effect Factors	significant level	Partial regression coefficients	Predicted attrition rate (%)	Optimal ratio		
					W/C	inorganic microspheres volume ratio	foam agent ratio (%)
28days	z_1	Highly sig.	174.40	-25.1	0.70	4.00	1.50
	z_2	Influential	127.14				

5) CONCLUSION

This research developed CMFM, mixed with self-developed foaming agent and inorganic microspheres. Research and analysis for the compressive strength, density and the durability of CMFM, by orthogonal regression experiment plan, and analysis of variance and regression analysis on the test results, to find out the optimum ratio of the combination of CMFM with the regression equation to predict for future production system and engineering application of reference.

- **Density**: the most suitable combination for density at age 28-days was in the case of w/c 0.998, inorganic microspheres volume ratio of 4.49, foam agent ratio of 1.74%. Water/cement ratio and inorganic microspheres volume ratio on density are both highly significant. Both can be regarded as the main material factors to control density of CMFM.
- **Porosity**: the most suitable combination for porosity at age 28-days was in the case of w/c 0.70, inorganic microspheres volume ratio of 3.50, and foam agent ratio of 1%; Water/cement ratio and inorganic microspheres volume ratio on porosity are both highly significant while foam agent ratio is influential. The main material factors to control porosity of CMFM are water/cement ratio and inorganic microspheres volume ratio. And the interaction between w/c and inorganic microspheres volume ratio on porosity is also significant.
- **Water adsorption**: the most suitable combination for water adsorption at age 28-days was in the case of w/c 0.70, inorganic microspheres volume ratio of 4.50, and foam agent ratio of 1%. Water/cement ratio, inorganic microspheres volume ratio, interaction between w/c and foam agent ratio on water adsorption are all highly significant, all of which are the main material factors to control water adsorption of CMFM. Besides, the interaction between w/c and inorganic microspheres volume ratio and the interaction between inorganic microspheres volume ratio and foam agent ratio on water absorption are both significant.
- **Compressive strength**: the most suitable combination for compressive strength at age 28-days was in the case of w/c 0.70, inorganic microspheres volume ratio of 4.50, and foam agent ratio of 1%. Since water/cement ratio on compressive strength is highly significant, the main material factor to control compressive strength of CMFM is water/cement ratio.

- **Durability**: the most suitable combination for durability at age 28-days was in the case of w/c 0.70, inorganic microspheres volume ratio of 4.00, and foam agent ratio of 1.50%. Since water/cement ratio on durability is highly significant, the main material factor to control durability of CMFM is water/cement ratio

With the impact of global warming, sea-level rise, climate change, habitat destruction and change and develop appropriate materials are necessary and urgent issues, and through research and development of CMFM can resolve land caused by sea-level rise effects, can also solve the ecological destruction and other related issues. In this study, one kind of CMFM with low density and pore characteristics of non-connected fabrics, with mid strength, low permeability and low thermal conduction properties was developed. This research successfully overcomes the durability and concrete structure compatibility of defects issues for polymer-based floating material, through material composition mechanism, and through design of experiment and statistics analysis. Future research can be performed on the following issues, such as strength enhancement of the floating material, surface waterproof of the matrix material and the material weight of composite material, etc. in wide range of engineering application.

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