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Development of cementitious foamed floating material and its engineering properties

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ABSTRACT

Due to the influence of global warming, extreme climate and flooding has become common. Many countries, which ground are lower, are facing rising sea level and land submergence. The application of floating structure of foamed material is a feasible solution for disaster caused by climate catastrophe. Also, the material has a good nature itself; therefore, it can be used as multifunctional materials in construction, such as heat and sound insulation material as well as lightweight materials. However, the strength of the material itself is not high, so the application range is limited.

In this study, cement will be used as a cementing material. Also, epoxy resin will replace part of cement. The foaming agent, foam stabilizer, and strength synergist as material factors will be applied to test mix proportions of the materials in accordance with regression orthogonal table planning. And the compressive strength, density and porosity were measured. The results of the tests are used to analyze the degree of influence of material factors on the nature of the engineering properties at different levels through the analysis of variance.

The results of this study proved that the foamed test group had compressive strength of 234.97 *kgf*/cm^2, density of 1.43 g/cm^3 and its weight is 0.6 times that of ordinary concrete. With the regression analysis, the strength is predicted to be as high as 250.74 *kgf*/cm^2 and the density prediction is 0.92 g/cm^3. By the mix proportion design, the material can have both excellent strength and density. The cementitious foamed floating material by this research has low-density, high-strength, and pore-independent structural characteristics. Under the global warming and dramatic changes in environment, this may be a kind of indispensable floating material in the future.

1. INTRODUCTION

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Global warming has caused severe changes in extreme climates and the environment. According to the annual Global Climate Report issued by the World Meteorological Organization at the 2017 Climate Change Conference, the global average annual temperature in 2016 is 0.56 ^{o}C higher than that of 1981 to 2010, which was the hottest year in history, as shown in **Fig.1**. In 2017, the world experienced a number of extreme weather events, including temperatures as high as 50^{o}C in Asia, and extending to Atlantic and Caribbean regions. Record-breaking typhoons or hurricanes flood in many subcontinents. According to research provided by the Australian Academy of Sciences, as shown in **Fig.2**, the current rising rate of sea levels is about 0.3 meters per 100 years. In the future, there may be a trend of crisis for all continents submerged by sea. As a result, a kind of floating material, featured as low-density and high-strength, is expected to be developed in this study for possible floating structure constructed in the future.

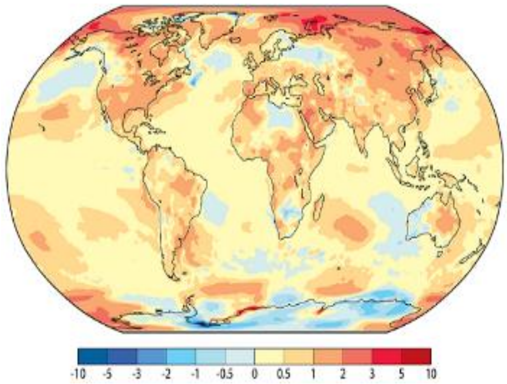


Fig.1 Global Temperature Status

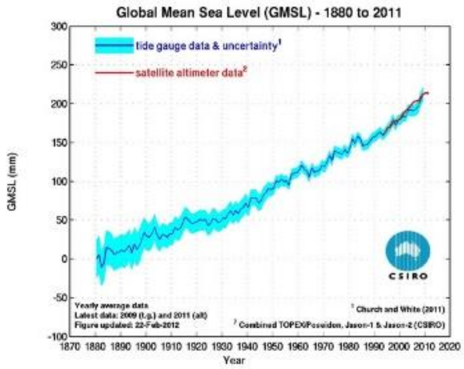


Fig.2 Rise Trend of Global Sea Levels

At present, the commonly used floating materials for engineering are mainly polymer-based composite materials, which have the advantages of low density, low cost, and easy processing. However, the application of these materials in rivers and seas projects will have defects such as poor durability and poor weather resistance, so that service life will be shortened and maintenance costs will increase, and their molecular structure has special surface characteristics, poor compatibility with cement, and limited application. On the other hand, the foamed concrete (abbr. as FC) used in engineering is mainly made of cement as the base material, due to inside-pore characteristics, FC itself has good functionality, including good heat insulation, excellent sound insulation, light weight, good workability, etc. In recent years, the use of FC in engineering is becoming more frequent, mainly used for non-structure members, such as insulated roofs and partition walls. According to ACI 301-16 specifications for structural concrete, it is pointed out the strength of structural concrete should be larger than 210 *kgf*/cm^2, which can be applied to general reinforced concrete buildings. Since the developed strength of FC in the past research was not high enough, this study expects to adjust the composition of FC, cementitious materials used as the base material, the volume per unit weight can be reduced while enhancing strength to a certain degree, combined with the characteristics of FC, in addition to the low-density characteristics of the floating material, to achieve a certain bearing strength and other excellent performance.

2. LITERATURE SURVEY

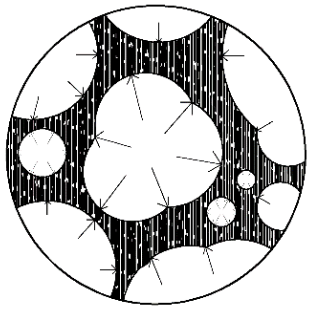


Fig.3 pore structure of foamed concrete

FC usually consists of either Portland cement paste or mortar filler matrix, in which air voids are entrapped in cement mortar and generated by the reaction with foaming agent (Jitchaiyaphum *et al.* 2011). The material itself has good fluidity, light weight, insulation properties, and so on. FC with various densities (400~1600kg/m^3) can be developed by controlling the amount of foams, which can be used in materials such as structure, filling or insulation, etc. The improvement (reduction in porosity) at the interface between the cement paste and aggregates due to pozzolanic additions can affect the failure mechanism in concrete leading to strength effect (Giaccio *et al.* 2007). It would clearly be expected that the pore structure of FC has an important influence on its properties. (Nambiar and Ramamurthy 2007). In order to reduce the density of FC, (Pickford 1996) pointed out that replacement ratio for using pozzolanic materials as cement replacement can be best at 10 to 50% not only to reduce the cost of materials but also to reduce the heat of hydration during the cement reaction and improve the durability of the material. (Nambiar & Ramamurthy 2006) indicated that under the condition of high water content, the foams and materials obtained after mixing may be separated and the pore distribution may be uneven. (Puttappa 2008) pointed out that the suitable water-cement ratio of foamed concrete is 0.4~0.8. Therefore, in order to make FC itself have good performance on engineering properties, such as insulation and light weight, etc., the composition of FC may consist of foam additives, like foaming agent, foam stabilizers ,etc.. (Valore 1954a & Valore 1954b) proposed the concept of synthetic foaming agent. The use of foaming agent has shown good improvement in the properties of the material. With the help of foaming agent and foam stabilizer, the foams can be firm and stable to provide the cement mortar pressure at the initial stage, as schematized in **Fig.3**. Given that the subject of this paper is foamed concrete, this suggests that the validity of additives for improving the performance of FC be demonstrated later in this paper. Thus the aim of this paper is to investigate the performance of FC with the developed additives combination, including the density and strength and their effect on the pore structure of foamed concrete.

3. EXPERIMENTENTAL PROGRAM

In this study, Portland ordinary cement was used as the main cementing material, epoxy resin was used to replace part of the cement and self-developed additives, including foaming agents, foam stabilizers and strength synergists, were added to prepare foamed floating material, mainly made up of non-connected pores. The test procedure is to carry out preliminary tests, confirm the upper and lower limits of the use of material factors, and use the experimental design method to plan the regression orthogonal table, perform the test combinations, conduct the variance analysis and regression analysis based on the test results, and explore the degrees of influence of material factors for strength and density.

3.1 Preliminary tests

The preliminary experimental results of this study (Hsu et al. 2017), mainly involved the process steps and additive test results, are summarized as follows. There are many factors that affect the cement-based foamed materials. Among them, the mixing method is one of the important factors that affect the material properties. Therefore, the appropriate mixing method selected for this study is shown in **Fig.4**.

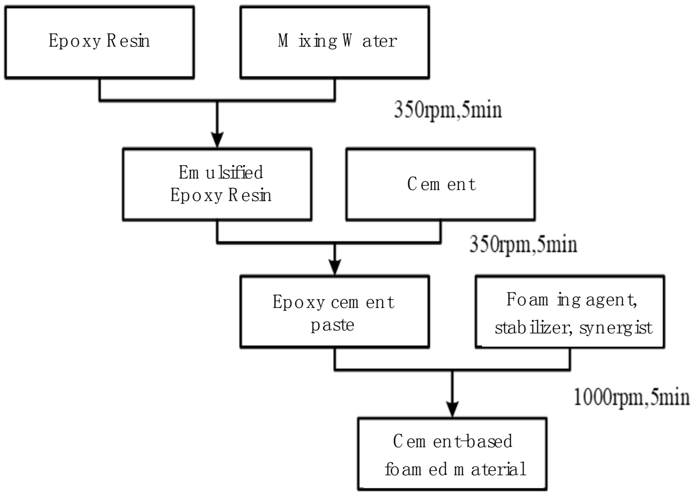


Fig.4 Flow of FC mixing process

- **Cement/glue ratio**: According to the preliminary experiment plan, the test combinations of cement/glue ratio (cement /epoxy resin) were 0, 0.45, 0.53, 0.67, 1.23, 1.60, 1.78, 1.87 and 3.55 individually. It was found that the density of the low cement/glue ratio was lower than that of the high cement/glue ratio. The main reason was that there is higher polymer addition of the low cement/glue ratio. However, the poor strength of some low cement/glue ratio may result from the excessive polymer addition. Only when the cement/glue ratio was controlled at 3.55, good strength could be developed, and it could reach 248.53 *kgf*/cm^2 at 28 days. Therefore, the appropriate proportion of cement, epoxy resin and mixing water formulated by the preliminary test was set on 53.3:15:26.7.

Fig.5 foaming agent

Fig.6 foam stabilizer

Fig.7 strength synergist

- **Foaming agent**: The foaming agent adopted is shown in **Fig.5**. After the chemical reaction of the foaming agent initiates, the water and oxygen can be dissociated and reacted with the cement slurry. In addition to be harmless to the material itself, the dissociated water can also be involved in the hydration of cement slurry. According to preliminary tests, when the addition ratio of the foaming agent reached 0.5%, the foaming magnification of the material could reach 1.2 times, taking into consideration that the synergist added in this study will interact with the foaming agent, and the upper limit of the foaming agent usage was set at 1.0% and the lower limit value was 0%.

- **Foam stabilizer**: In this study, suitable surfactant were selected as the main raw material for foam stabilizers (**Fig.6**). According to the preliminary experimental test, if the addition ratio of the foam stabilizer exceeds 10%, the phenomenon of setting retardation may occur. Therefore, without affecting the test results of the material, the proportion range of the foam stabilizer was set to be between 0 to 10%.
- **Strength synergist**: The effect of the synergist in this study is to hopefully enhance the material strength. **Fig.7** shows the synergist tested in the preliminary experiment and it was found that the interaction between the foaming agent and the synergist affected the development of the strength properties of the material, followed by the collapse of slurry once the addition ratio exceeded 0.7% and the strength increase of the material about 20% at the dosage of 0.7%. Therefore, the upper limit value of synergist was set at 0.7% and the lower limit value was 0%.

Table 1 Material factors and parameter levels

Items		parameter level		
		foaming agent (z_1)	foam stabilizer (z_2)	strength synergist (z_3)
material factors	upper limit	1.0	10.0	0.7
	lower limits	0.5	0.0	0.0
	unit	%	%	%
	cement	53.3%		
	epoxy resin	15.0%		
	water	26.7%		

3.2 Test variables

In order to study the influence and correlation of composition factors and proportions of cement-based foamed floating materials on their material properties, The upper and lower limits of the amount of material obtained from preliminary experimental test results of foaming agent (z_1), foam stabilizer (z_2) and strength synergist (z_3) were set as the compositional factors of the material, and the variables of the test were planned. The upper and lower limits of the variation factor established through the preliminary experimental stage for each material and test parameters are summarized in **Table 1**.

3.3 Test planning

3-factor 3-level (L3) regression orthogonal table configuration test were adopted in this study, as shown in **Table 2**. Among them, T1~T14 are 3-level orthogonal test groups and T15~T17 are the central test groups, a total of 17 sets of test proportions. The content of the test was conducted with compressive strength and density at the ages of 7, 14 and 28 days respectively.

4. RESULTS AND DISCUSSION

4.1 Density test analysis

Density test was executed in accordance with the ASTM D792 buoyancy method for determining the density and specific gravity of plastics. The tests were conducted on densities at the age of 7, 14 and 28 days, the results of which are summarized in **Table 3**. According to the test results, at 7 days, the lowest density in T09 was 0.952 g/cm^3, while the highest in T12 was 1.406 g/cm^3. The addition ratio of the synergist for T09 to T12 was the same and the amount of the foaming agent was 1.0% and 0.75% respectively. Based on this amount of addition, it can be found that the foaming agent is indeed effective to provide chemical foaming reaction to reduce the density of the material. While the foam stabilizer is between 10% and 0%, there can be the lower density of the material since the foams entrapped by the foam stabilizer itself are dense and can be well mixed with the cement slurry, filled with air voids. Besides, the half-life time of the stabilizer was found to be 4.5 hours, so the surface pressure of the slurry can be supported in the initial stage and no slurry collapse occurs. Along with the hydration reaction proceeded, though each the engineering properties of each test group developed over time, the density development at the age of 14 to 28 days tended to be slow. Through the obtained data of each age, the analysis of variance was conducted. The significant influence by foaming agent and foam stabilizer on the development of density properties could be verified, which are shown in **Table 4**. From the analysis in **Table 4**, the optimum mix proportion and best predictive density at each age can be obtained. Through the significance analysis, it is possible to understand the factors and interaction effects at different ages. The degree of influence, by virtue of this result, is conducive to the adjustment of the factors in the mix proportion design and to a better density value.

Table 2 Regression orthogonal table for material factors

specimen label	material factors		
	addition ratio of foaming agent	addition ratio of foam stabilizer	addition ratio of synergist
T01	0.935	8.695	0.609
T02	0.935	8.695	0.091
T03	0.935	1.305	0.609
T04	0.935	1.305	0.091
T05	0.565	8.695	0.609
T06	0.565	8.695	0.091
T07	0.565	1.305	0.609
T08	0.565	1.305	0.091
T09	1	5	0.35
T10	0.5	5	0.35
T11	0.75	10	0.35
T12	0.75	0	0.35
T13	0.75	5	0.7
T14	0.75	5	0
T15	0.75	5	0.35
T16	0.75	5	0.35

T17	0.75	5	0.35

At the age of 7-day, the effect of z_1 (foaming agent) was significant and the effect of z_2 (foam stabilizer) was very significant, with z_1 partial regression coefficient of -0.015 as well as z_2 partial regression coefficient of -0.137, indicating that z_1 and z_2 separately has a substantial reduction in the effect of density. But, the initial material development of density may be reversely affected by the interaction effect of factors z_1z_2 and z_2z_3, which lead to the increase of density. As a result, if desired to have a smaller density in the early stage, the addition ratio of the foaming agent as well as the foam stabilizer should be increased, but the amount thereof still needs to consider its rationality, otherwise the influence of the interaction may oppositely increase the density of the material. From the age of 14 days to 28 days, the density of the material would increase slightly due to hydration. However, the interaction between the material factors was still significant with the addition ratio of z_1 (foaming agent) and z_2 (foam stabilizer). The interaction effect between the material factors was little obvious after 7 days, so the density development of the latter period needs to pay attention to the individual influence results of each factor. Based on the test results, the expected density (y) by regression analysis at the age of 28-day was given in **Eq.(1)**. The regression formula R^2 is 0.925 and the corrected R^2 is 0.829.

$$\mathbf{y = 2.033 - 0.820z_1 - 0.124z_2 - 0.605z_3 + 0.064z_1z_2 + 0.804z_1z_3 + 0.019z_2z_3 - 0.033z_1^2 + 0.003z_2^2 - 0.131z_3^2} \quad (1)$$

Table 3 Result for density test

specimen label	density (g/cm^3)		
	7 days	14 days	28 days
T01	1.077	1.097	1.115
T02	0.969	0.990	1.009
T03	1.187	1.216	1.233
T04	1.123	1.149	1.166
T05	0.987	1.005	1.021
T06	0.996	1.016	1.036
T07	1.248	1.266	1.281
T08	1.363	1.389	1.400
T09	0.952	0.969	0.987
T10	1.117	1.237	1.259
T11	0.954	0.972	0.991
T12	1.406	1.420	1.433
T13	1.043	1.071	1.094
T14	1.088	1.103	1.124
T15	1.075	1.098	1.117
T16	1.086	1.107	1.127
T17	1.077	1.090	1.112

By means of the variance analysis, it was confirmed that the synergist had no significant effect on the density. Therefore, the addition ratio of strength synergist was fixed at 0.0 and the density would decrease with the addition of the foaming agent and the foam stabilizer. As shown in **Fig.8** and **Fig.9**, when the density was low at the age of 28 days, for the case of the addition ratio of the foaming agent between 0.86 and 1.0 and of foam stabilizer between 6.60 and 10.0, the minimum value of density was at the optimum mix proportion at the intersection point, i.e. the addition ratio of foaming agent was 1.0 and that of foaming stabilizer was 8.63, was 0.92 g/cm^3. The value of yellow point in **Fig.8&9** is the density of optimum mix proportion.

Table 4 Significant level and optimal mix proportion of Material factors for density at each age

age	influence factor	level of significance	partial regression coefficient	predicted density	optimal mix proportion		
					addition ratio of z_1(%)	addition ratio of z_2(%)	addition ratio of z_3(%)
7 days	z_1	significant	-0.015	0.88	1.0	7.80	0.0
	z_2	very significant	-0.137				
	z_1z_2	significant	0.066				
	z_2z_3	significant	0.775				
14 days	z_1	significant	-0.870	0.90	1.0	8.48	0.0
	z_2	very significant	-0.128				
28 days	z_1	significant	-0.820	0.92	1.0	8.63	0.0
	z_2	very significant	-0.124				

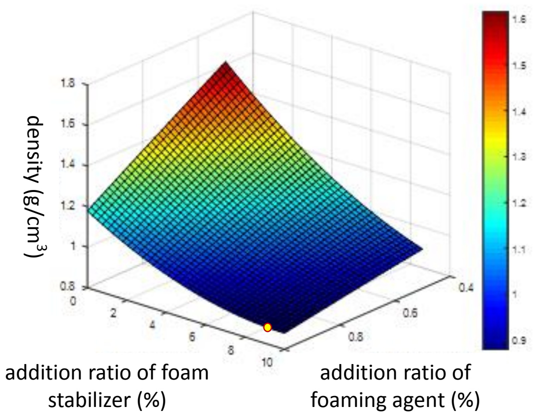


Fig.8 density regression surface plot at the age of 28-day

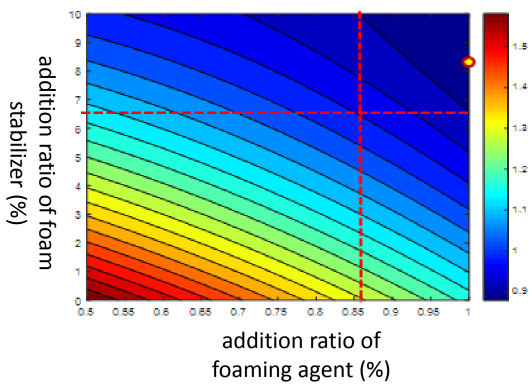


Fig.9 density regression contour map at the age of 28-day

4.2 Strength test analysis

The strength test was conducted by following the ASTM C270 test method for the compressive strength of hydraulic cements. Tests for different mix proportion were conducted at the ages of 7, 14 and 28 days, which were concluded in **Table 5**.

Table 5 Result for strength test

specimen label	Compressive strength (*kgf*/cm^2)		
	7 days	14 days	28 days
T01	84.670	90.800	104.383
T02	29.747	44.713	48.713
T03	90.747	120.227	137.520
T04	70.866	80.911	87.659
T05	60.557	71.866	79.488
T06	36.198	46.678	58.239
T07	135.555	142.687	153.120
T08	125.809	135.418	180.662
T09	54.212	63.183	70.964
T10	76.856	84.824	95.269
T11	30.719	37.784	48.073
T12	172.109	197.864	234.971
T13	65.102	85.844	92.440
T14	41.244	48.521	52.015
T15	64.193	70.466	82.079
T16	64.327	70.239	81.433
T17	64.332	69.454	82.359

Table 6 Significant level and optimal mix proportion of Material factors for strength at each age

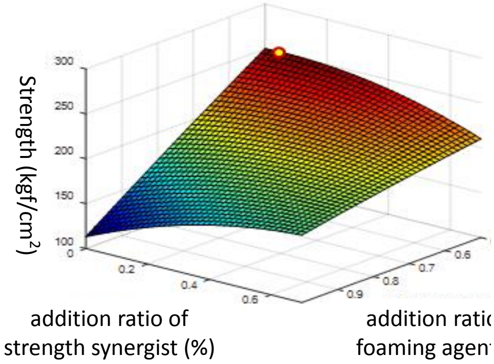
<table>
<tr><th rowspan="2">age</th><th rowspan="2">influence factor</th><th rowspan="2">level of significance</th><th rowspan="2">partial regression coefficient</th><th rowspan="2">predicted strength</th><th colspan="3">optimal mix proportion</th></tr>
<tr><th>addition ratio of z_1(%)</th><th>addition ratio of z_2(%)</th><th>addition ratio of z_3(%)</th></tr>
<tr><td rowspan="4">7 days</td><td>z_1</td><td>Influential</td><td>-228.010</td><td rowspan="4">189.894</td><td rowspan="4">0.50</td><td rowspan="4">0.0</td><td rowspan="4">0.282</td></tr>
<tr><td>z_2</td><td>very significant</td><td>-42.628</td></tr>
<tr><td>z_3</td><td>significant</td><td>-2.571</td></tr>
<tr><td>z_1z_2</td><td>significant</td><td>21.477</td></tr>
<tr><td rowspan="2">14 days</td><td>z_2</td><td>very significant</td><td>-42.003</td><td rowspan="2">199.595</td><td rowspan="2">0.5</td><td rowspan="2">0.0</td><td rowspan="2">0.398</td></tr>
<tr><td>z_3</td><td>significant</td><td>-28.017</td></tr>
<tr><td rowspan="3">28 days</td><td>z_2</td><td>very significant</td><td>-54.472</td><td rowspan="3">250.735</td><td rowspan="3">0.5</td><td rowspan="3">0.0</td><td rowspan="3">0.060</td></tr>
<tr><td>z_3</td><td>influential</td><td>-134.429</td></tr>
<tr><td>z_1z_2</td><td>influential</td><td>22.678</td></tr>
</table>

According to the test results at the age of 7-day, the highest strength in T12 was 172.109 *kgf*/cm^2, while the lowest in T11 was 36.198 *kgf*/cm^2, where the addition ratios of the foaming agent and strength synergist for the mix proportion of T11 and T12 were the same and the addition ratio of foam stabilizer was between 10% and 0%, respectively. Comparing with the addition ratio, it was found that the foam stabilizer should have significant effect on the strength of the material. In the early stage, the strength development of the slurry gradually decreases with the increase of the amount of the stabilizer. The result of strength development was concluded in **Table 5**, since it was observed that the material could have significant strength development at the ages of 14 to 28 days, it could also be speculated that the strength development should be stabilized after the age of 28-day. From the obtained data at each age, the analysis of variance was conducted. The level of significance for material factors at each age was shown in **Table 6**. Through the analysis of **Table 6**, the optimum mix proportion and best predictive strength at each age could be obtained. Significant analysis can be used to understand the degree of influence of factors and interaction effects at each age, and to use this result, it is beneficial to factor adjustment when designing, and better strength values can be obtained.

At the age of 7-day, the effect of z_1 (foaming agent), the effect of z_2 (foam stabilizer) and the influence of z_3 (strength synergist) were influential, very significant and significant respectively while the partial regression coefficient for each single factors was negative and the initial material development was positively correlated under the interaction effect of z_1z_2. In other words, if desired to have good strength performance in the early stage, special attention to the addition ratios should be paid, otherwise the strength development may be affected by various factors. From the ages of 14 to 28 days, the strength of the material increases with time, affected by z_2 and z_3. Therefore, in order to take into account the development of the strength, the rationality of the additive amount must be considered. The synergist used in this study originally was expected to increase the strength, but, through the analysis, it was found that z_3 itself has negative correlation with the strength development, but also interact with other factors to obtain positive correlation. According to the mechanism of the material itself, it is inferred the synergist has very significant reaction with the foaming agent, which especially may result in the phenomenon of violent reaction in the foaming process, but the degree of influence is only greater at the age of 7, 14 days while strength development at the late stage still relies mainly on the distribution of pores and slurries, so the reaction between foaming agent and foam stabilizer is also of great significance. Based on the test results, the expected strength (y) by regression analysis at the age of 28-day was given in **Eq.(2)**. The regression formula R^2 is 0.915, and the corrected R^2 is 0.807.

$$\boldsymbol{y = 376.719 - 241.849z_1 - 54.472z_2 - 134.429z_3 + 22.678z_1z_2 + 292.813z_1z_3 + 7.129z_2z_3 - 21.676{z_1}^2 + 2.288{z_2}^2 - 99.696{z_3}^2} \tag{2}$$

Based on the maximum strength ratio combination at the age of 28-day, the addition ratio of foam stabilizer was fixed at 0.0, the X-axis was the addition ratio of foaming agent, the Y-axis was the addition ratio of strength synergist, and the Z-axis was the estimated strength. The development trend of the surface map can be used to determine the peak and valley distribution of the estimated value. As shown in **Fig.10** and **Fig.11**, when the amount of the foam stabilizer was fixed at 0.0, with the low addition of the foaming agent, the strength increased with the decrease of addition ratio of strength synergist. With the increase of foaming agent, when the material reaction becomes larger, the effect of synergist on strength would increase with the increase of usage, the strength at the age of 28-day was higher at the case of the addition ratio of foaming agent in the range of 0.5-0.525 as well as the addition ratio of synergist in the range of 0.0-0.310 while the maximum value was at the optimum mix proportion at the intersection point; that is, the foaming agent addition ratio at 0.5 and synergist addition ratio at 0.06, the maximum strength of 250.735 kgf/cm^2 could be obtained. The value of yellow point in **Fig.10&11** was the strength of optimum mix proportion.



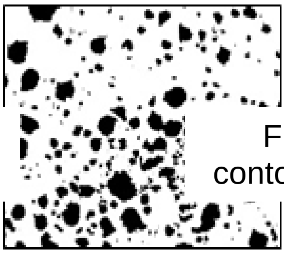
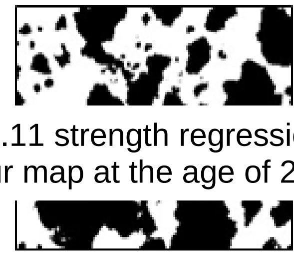
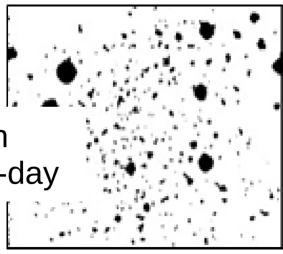




Fig.10 strength regression surface plot at the age of 28-day

Fig.11 strength regression contour map at the age of 28-day

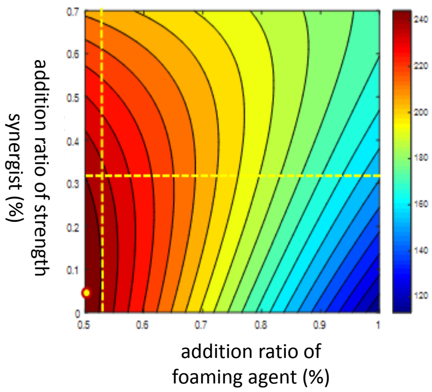


Fig.12 T09 Fig.13 T11 Fig.14 T12

4.3 pore microscopic analysis

According to the test results, the ratio of the highest strength T12 to the lowest T11 and the ratio of the highest density T12 to the smallest T09 were compared for pore microscopic analysis. The microscopic photographs are shown in **Figs. 12-14**. T12 has both the highest density and the highest strength. After analysis, it has found that the number of pores is large, with 178 units per unit area, but the pore area ratio is only 6.156%. Most of the pore diameters are less than 0.01cm, because the air voids are small and the characteristics of non-connectivity, the development of strength is high, and the standard deviation of the pore microscopic analysis is only 0.012. However, because the addition ratio of foam stabilizer in T12 is 0.0, the number of pores is also relatively small, resulting in high density, but the use of foaming agents and synergists can have a positive effect on the subsequent development of the material. Only if the density of the material needs to be reduced, the addition of foam stabilizer must be taken into account.

In the pore micrograph photo of T11, it can be found to have a large and irregular pore type, and some pores are connected, and the pore size has a large difference. The number of pores per unit area is only 36, but the distribution area up to 42.12% and the standard deviation of the pore microscopic analysis is 0.129. The numerical value was larger, indicating that there was a large difference in the formation of internal pores, and this phenomenon was likely to be uneven under the force of the pore microcosmic development of strength. Under the circumstances, the material strength is poorly developed. Through the mechanism of material structure, it can be found that the addition ratio of the foam stabilizer is up to 10%, but the foaming agent and synergist also have a certain amount. Foams caused by foam stabilizers cannot effectively maintain their state during severe reaction, indicating that they are influenced by the three additives and cause more pores during the foaming reaction, but may cause the generation of voids. If it is too violent, the foams appear connected, broken, or seriously irregular, affecting the strength.

It can be clearly found in the microscopic photo of T09, the size of the majority of foams is around small and medium range, the number of air voids per unit area up to 70, accounting for unit area of 16.415%, the standard deviation of microscopic analysis of 0.082. For the overall distribution of pores, the density properties of the material can be developed better because of the large number of pores and the uniform size, but it can be found that the pore distribution in **Fig.12** is not very ideal, and some foams are concentrated in the lower left, which is why the phenomenon of T09 in the development of strength is unsatisfactory. According to the material structure mechanism assessment, while the upper limit of foaming agent for FC is 1% and the amount of foam stabilizer and synergist is relatively small, the strength cannot be improved by the effect of foam stabilizer in terms of the stickiness properties of the slurry, air voids may be unstable during the setting process, resulting in uneven distribution of the air voids and affecting the strength.

From the microscopic analysis of the pores, it can be found that the form and distribution of the air voids will have a great influence on the engineering properties, and a good pore result must rely on the foaming mechanism of the foaming agent to trigger the reaction of the material, and to stabilize the air voids by promoting the viscosity of the slurry and the introduction of dense foams, and then with the help of synergists, the material maintains good properties in the porous state. With the development of material strength and density, there should be a good interaction with each other to obtain the desired goals. Therefore, the control of air voids is a very important issue for foamed materials.

5. CONCLUSIONS

In this study, experimental design methods for carrying out the strength, density, and microscopic tests of FC were used to understand the relative influences of FC. The characteristics of FC established by regression analysis may be helpful for references of engineering applications.

Based on the analysis of the test results, a kind of foamed material with high strength can be developed and manufactured through suitable combination of materials. The strength and density at the age of 28-day can reach 234.971 *kgf*/cm^2 and 1.433 g/cm^3 respectively, and its weight is 0.6 times that of concrete. Density at the age of 28-day can reach 0.981 g/cm^3, and its corresponding strength still has 70.964 *kgf*/cm^2. The properties of the two have better results by regression prediction. If the strength property is analyzed with 100% expectation, it can reach 250.735 *kgf*/cm^2. The strength value of the material can be applied to ordinary concrete structures. If the density property is analyzed with 100% expectation, the expected value prediction can be reduced to 0.920 g/cm^3. However, if both strength and density of 50% of the expected value is designed, the material can have strength of 143 *kgf*/cm^2 and density of 1.235 g/cm^3 at the age of 28-day. With the mix proportion design of the regression equation, the influence of material factors and the results of interaction effects should be considered, and to avoid irrational design, which will seriously affect the properties of materials. The experimental results believe that under the excellent characteristics of materials, it is bound to be effectively applied as floating material in the global warming environment.

REFERENCES

Giaccio, G., de Sensale, G. R. and Zerbino, R. (2007), "Failure mechanism of normal and high-strength concrete with rice-husk ash" , *Cement and Concrete Composites*, **29**, 566-574.

Hsu, K.L., Haw, G.I, Chang, C.S. and Sung, K.Y. (2017), "Development on Material Raito and Preliminary Study on Factor Impact of Foamed Concrete", TCI 2017 Conference on Concrete Engineering (in Chinese).

Jitchaiyaphum, K., Sinsiri, T. and Chindaprasirt, P. (2011), "Cellular lightweight concrete containing pozzolan materials" , *Procedia Engineering*, **14**, 1157- 1164.

Kearsley, E.P., and Wainwright, P.J. (2001), "The effect of high fly ash content on the compressive strength of foamed concrete" , *Cem. Concr. Res.*, **Vol.31**,105~112.

Nambiar, E.K., and Ramamurthy, K. (2006), “Influence of filler type on the properties of foam concrete” , Cem. Concr. Res., Vol.28, 475~480.

Nambiar, E. and Ramamurthy, K. (2007), “Air-void characterisation of foam concrete.” *Cem. Concr. Res.*, **37(2)**, 221-230.

Pickford, C., and Crompton, S. (1996), “Foam concrete in bridge construction”, *Concrete*, 4~15.

Puttappa, C.G. (2008), “ Mechanical properties of foamed concrete” , *Con. & Build. Tech.*, **Vol.43**, 491~ 500.

Ramamuthy, K., & Kunhanandan, E. K. (2009) , “A classification of studies on properties of foam concrete”, Cem. Concr. Res., Vol.31, 388–396.

Valore, R.C. (1954a), “Cellular concrete part 1 composition and methods of production”, *ACI J*, **Vol.50**, 773~796.

Valore, R.C. (1954b), “Cellular concrete part 2 physical properties”, *ACI J*,**Vol.50**, 817~836.