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# Study on Performance of Negative Temperature and High Strength Bed Mortar Material for Wind Power Engineering

**Lu Tongwei[1,3], Zhang Jie[2,3], Cai Guisheng[1,3], Wang Linmao[2,3] and Yang Maoqian[2,3]**

[1]Shandong Academy of Building Research Co. Ltd, Ji'nan 250031, PR China, twlu@sina.com (Lu Tongwei), caigs2008@126.com (Cai Guisheng)

[2] Shandong Jianke Building Materials Co. Ltd, Ji'nan 251604, PR China, jessiez1212@126.com (Zhang Jie), 2281517408@qq.com (Wang Linmao), 810692865@qq.com (Yang Maoqian)

[3] Shandong Advanced Cement-based Materials Engineering Technology Research Center for Rail Transit

**Abstract.** *As the development process of affordable wind power projects accelerates, the height of tower hub shows a trend of development to 150m above. The technology of steel and concrete is widely applied. Bed mortar material, as the bonding material between precast concrete rings, is the key material to ensure the lifting speed of steel and concrete tower for wind power. In this study, the basic formula of negative temperature and high strength bed mortar material was explored, and its working performance and strength development under different curing conditions were further studied. The results show that the developed bed mortar material has excellent thixotropy and it is still operable at 50min. Under the condition of negative temperature curing, the early strength of bed mortar material is high, and the late strength develops well. Curing at ultra-low temperature of -15 ℃, the strength of -1d is 35.4MPa, and the strength of -7+21d is over 90MPa. In the outdoor natural curing environment of alternating positive and negative temperatures, the strength of 1d reaches 51.1MPa, the strength of 60d is 113.2MPa. The performance of bed mortar material far meets the requirements of the strength grade of 80MPa which is used in winter construction of wind power engineering.*

**Keywords:** *Low negative temperature; Positive and negative temperature alternating environment; Wind power engineering; Bed mortar material; Strength development*

## 1 Introduction

With the acceleration of development process for affordable wind power projects in China, the market demand for units with large shear that can be applied to medium and low wind speed areas is increasing, and the tower hub height is showing a trend toward 150m or more. The high reliability of steel hybrid tower technology is one of the effective guarantee technologies to enhance the power generation of the large impeller and high hub wind turbines. And how to guarantee the lifting speed of the steel mixed tower, lifting each section of precast concrete ring section between the selection of the bed mortar material is very critical.

Bed mortar material, as a traditional connection method, the necessary performance are high strength, non-shrinkage, and high impermeability. High early strength, corrosion resistance, and other characteristics can be achieved by using various additives. For wind power project construction, if the initial fluidity of bed mortar material is too large, it will be not easy to ensure the paving thickness; if the initial flow of bed mortar material is too small, it is not easy to crane bucket under the material, and not favorable for paving pouring. Therefore, bed mortar material for wind power project should have good plasticity, thixotropy, and squeezability. Meanwhile, water loss on the surface should be slow to avoid the formation of a hard shell on the surface before the last concrete tower section assembling, thus affecting the concrete tower section bonding strength.

After mixing, the bed mortar material has a fluffy relatively perfect initial flow state, which becomes thin under the action of mechanical force during the construction of paving and pouring. After the completion of spreading, the three-dimensional structure will recover by itself, and the bed mortar material will become thick again and not flow, which can well control the pouring thickness and has good plasticity. The bed mortar material after pouring has a good thixotropic plastic state, and forms a layer of water-retaining film on the surface, so that the bed mortar material has plasticity, squeezability, thixotropic and other construction properties in a long time, to ensure the quality of construction

For the wind power project for the winter construction of the strength level of 80MPa bed mortar material, the strength development requirements are as the following: -1d>30MPa, -3d>60MPa, -7+21d>80MPa. In order to meet the higher design strength requirements as much as possible, the bed mortar material to meet the requirements of the strength of 100MPa at -10 ℃ construction was developed in this study.

This paper focuses on the negative temperature high-strength bed mortar material for wind power projects. It explores its performance for the standard construction of wind power projects under a negative temperature environment.

## 2 Experimental work

### 2.1 Materials

Cementitious materials: sulfoaluminate cement, ordinary silicate cement clinker, and composite mineral admixture. The physical properties of ordinary silicate cement clinker are shown in Table 1.

Sand: High-strength quartz sand with three grades: 20-40 mesh, 40-70 mesh and 70-140 mesh, in the ratio of 4:4:2.

Additives: hydration heat regulator, thixotropic agent, antifreeze component, compound expansion agent.

**Table 1.** Physical properties of ordinary silicate cement clinker.

| Water requirement of normal consistency (%) | Setting time (min) | | Flexural strength(MPa) | | Compressive strength(MPa) | |
|---|---|---|---|---|---|---|
| | Initial setting | Final coagulation | 3d | 28d | 3d | 28d |
| 28.70 | 118 | 178 | 7.1 | 9.7 | 51.1 | 70.7 |

### 2.2 Experiment

#### *2.2.1 Program Design*

Through a large number of experimental studies, the selection of various components of raw materials was made. After preliminary selection of raw materials, the best value of various raw materials were then selected, and furthermore the best formula composition of stock was determined. With other factors unchanged, a four-factor, three-level L9 ($3^4$) orthogonal test was used. Four main factors are considered: factor A is hydration heat regulator, containing components of early strength and slow-setting; factor B is ant-freezing components, which is not only to reduce the freezing point in the bed mortar material, but also to promote the role of hydration reaction; factor C thixotropic agent is the organic modified powder of magnesium aluminium silicate modified by ethylene glycol amine; factor D is a compound expansion agent. Each factor level is the proportion of bed mortar material. Factor levels are shown in Table 2.

**Table 2.** Factor level table.

| Level \ Factor | A (%) | B (%) | C (%) | D (%) |
|---|---|---|---|---|
| 1 | 0.2 | 0.5 | 0.01 | 2.0 |
| 2 | 0.4 | 1.0 | 0.02 | 2.5 |
| 3 | 0.6 | 1.5 | 0.03 | 3.0 |

#### *2.2.2 Experimental methods*

Maintenance of specimens:

Negative temperature maintenance: put the molded specimen with mold into the negative temperature environment set in advance -5°C/-10°C/-15°C for curing, respectively 1d (-1d), 3d (-3d), 7d (-7d), and then put the specimens into standard curing room for 21d after de-molding, i.e. (-7+21d).

Outdoor natural maintenance: the molded specimens with mold into outdoor natural maintenance, respectively to 1d, 3d, 7d, 28d, and 60d.

The working performance of the bed mortar material: the fluidity test is carried out according to GB/T 2419 "Determination method of cementitious sand flow". The test ambient temperature is 0~5℃, and the water-to-material ratio is 0.12.

Compressive strength: refer to JGJ/T 17671 "Test method for cementitious sand strength (ISO)

## 3 Results and discussion

### 3.1 Bed mortar material formulation study

The bed mortar material test was conducted according to the orthogonal test design scheme to investigate the effect of formulation composition on the 1d and 3d strength of the bed mortar material under -10°C. The orthogonal test design and analysis of the results are shown in Table 3 by analysing and studying the bed mortar material composition formulation. In this orthogonal test, there were only enough degrees of freedom to estimate the parameters, but no remaining degrees of freedom to estimate the variance of the errors, so an F-test could not be performed to examine the significance of the factors. In this way, intuitive analysis was done while selecting the appropriate level of the factor based on the magnitude of the mean. Factors with large extreme differences affect performance significantly and are the primary factors; those with small extreme differences are secondary factors.

It can be seen that, for the strength of -1d of slurry maintained at -10°C, factor A is the main factor, B is the secondary factor, and the order of influence of the main and secondary factors is A > B > D > C. The best combination is A1-B3-C3-D2. From the viewpoint of -3d strength, the effect of each influencing factor is the same as that for the -1d strength. In terms of polar differences, the differences between the polar differences of factors B2 and B3, and D1 and D2 are not significant, which indicates that the second and third levels of factor B, and the first and second levels of factor D do not differ significantly in their effects on intensity.

**Table 3.** Results and analysis of orthogonal tests.

| Serial No. | | | Impact Factors | | | | -10℃ curing compressive strength (MPa) | |
|---|---|---|---|---|---|---|---|---|
| | | | A | B | C | D | -1d | -3d |
| 1 | | | 0.2 | 0.5 | 0.01 | 2.0 | 36.8 | 62.1 |
| 2 | | | 0.2 | 1.0 | 0.02 | 2.5 | 40.4 | 66.3 |
| 3 | | | 0.2 | 1.5 | 0.03 | 3.0 | 38.2 | 65.2 |
| 4 | | | 0.4 | 5.0 | 0.02 | 3.0 | 30.6 | 56.2 |
| 5 | | | 0.4 | 1.0 | 0.03 | 2.0 | 36.1 | 61.9 |
| 6 | | | 0.4 | 1.5 | 0.01 | 2.5 | 36.5 | 60.8 |
| 7 | | | 0.6 | 0.5 | 0.03 | 2.5 | 26.1 | 55.1 |
| 8 | | | 0.6 | 1.0 | 0.01 | 3.0 | 25.4 | 52.3 |
| 9 | | | 0.6 | 1.5 | 0.02 | 2.0 | 27.9 | 57.6 |
| Analysis of extreme deviations | -1d Strength | $\overline{K1}$ | 38.47 | 31.17 | 32.90 | 33.60 | Primary and secondary relationship: A＞B＞D＞C Best combination: A1-B3-C3-D2 | |
| | | $\overline{K2}$ | 34.40 | 33.97 | 32.97 | 34.33 | | |
| | | $\overline{K3}$ | 26.47 | 34.20 | 33.47 | 31.40 | | |
| | | ω | 12.00 | 3.03 | 0.57 | 2.93 | | |
| | -3d Strength | $\overline{K1}$ | 64.53 | 57.80 | 58.40 | 60.53 | Primary and secondary relationship: A＞B＞D＞C Best combination: A1-B3-C3-D2 | |
| | | $\overline{K2}$ | 59.63 | 60.17 | 60.03 | 60.73 | | |
| | | $\overline{K3}$ | 55.00 | 61.20 | 60.73 | 57.90 | | |
| | | ω | 9.53 | 3.40 | 2.33 | 2.83 | | |

Notes: -1d represents the bed mortar material is cured under -10°C for 1d; -3d represents the bed mortar material is cured under -10°C for 3d.

Through the above orthogonal tests, the optimal formulation composition of the bed mortar material was finally determined, based on which three combination formulations of bed mortar material (ZM1, ZM2, ZM3) were determined, and further tests were conducted to determine the optimal formulation combination.

### 3.2 Working performance of the bed mortar material

The working performance of the three formulations of bed mortar material ZM1, ZM2, and ZM3 is shown in Table 4. It can be seen that there is little difference in the fluidity of them, which can still be squeezed at 60min. This indicates that the bed mortar material has excellent thixotropy, and good plasticity operability, which is conducive to ensuring the smoothness of construction operability, and still has operability at 60min. This is mainly because the thixotropic agent used is the organic modified powder of magnesium and aluminium silicate modified by diethanolamine. The modified magnesium and aluminium silicate modified by diethanolamine intercalation can form hydrogen bonds with water in the slurry, thus generating a three-dimensional network structure, so that the system has a certain gelling strength. After the action of external force, the hydrogen bonds break and the network structure is destroyed. Thus, the system has a good fluidity, at the same time, after modification, the modified magnesium aluminium silicate with special lamellar structure will form a three-dimensional network structure in the bed mortar material, and the network structure will be destroyed by shear force. It shows shear thinning, and the network structure can be quickly restored after resting, thus showing good thixotropy.

**Table 4.** Working performance of freshly mixed bed mortar material (ambient temperature 0~5℃).

| Serial number | Exit material temperature (°C) | Mobility(mm) | 60min |
|---|---|---|---|
| ZM1 | 1.5 | 190 | Plasticity, extrudability, thixotropy |
| ZM2 | 1.5 | 185 | Can squeeze |
| ZM3 | 0.5 | 190 | Can squeeze |

### 3.3 Strength development law of the bed mortar material under negative temperature curing

The compressive strengths of the three types of bed mortar material were studied under the curing conditions of -5°C, -10°C and -15°C, respectively, and the test results are shown in Figures 1, 2 and 3.

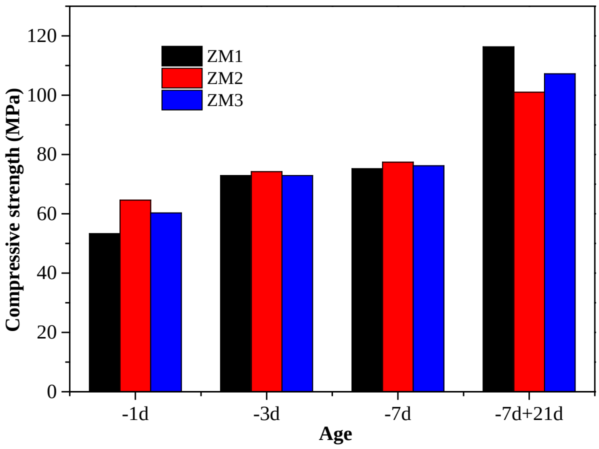



**Figure 1.** Strength development curing under -5°C.

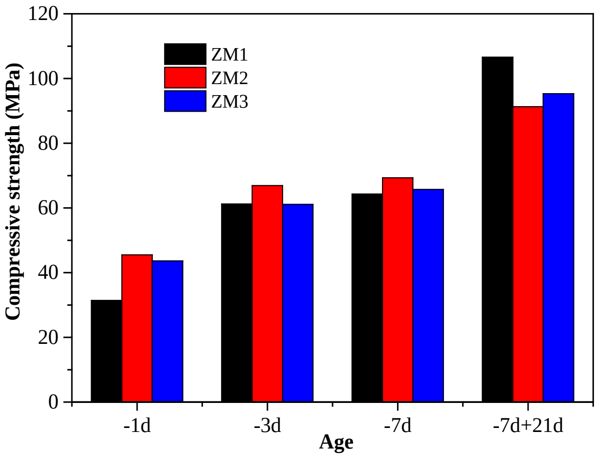



**Figure 2.** Strength development curing under 10°C.

From Figure 1, it can be seen that the 1d strength of both ZM2 and ZM3 exceeded 60 MPa at -5°C curing, with the compressive strength of ZM2 reaching 64.6 MPa. For the 3d and 7d strengths, the difference between ZM2 and ZM3 was not significant. The strength of the ZM1 slurry increased faster and the strength was higher at the later stage when it was cured at 5°C for 7d to standard curing for 21d. The strength of both ZM2 and ZM3 continued to increase, with the strength of ZM3 approaching 110MP.

At -10°C curing (Figure 2), the compressive strength of the bed mortar material showed the same development pattern as at -5°C curing, with ZM2 and ZM3 both exceeding 40 MPa at 1d, 60 MPa at 3d and 7d, and 90 MPa at -7d+21d.

At -15°C curing (Figure 3), the strength of ZM2 and ZM3 at 1d were 40.7MPa and 35.4MPa, respectively, which both met the construction requirements. 3d strength of ZM3 was 59.8MPa, 7d strength was 62.5MPa, and the strength at -15°C curing for 7d to standard curing for 21d was 92.1MPa, which exceeded the 81.3MPa of ZM2.

On the whole, ZM3 was finally selected as the best formulation of the bed mortar material.

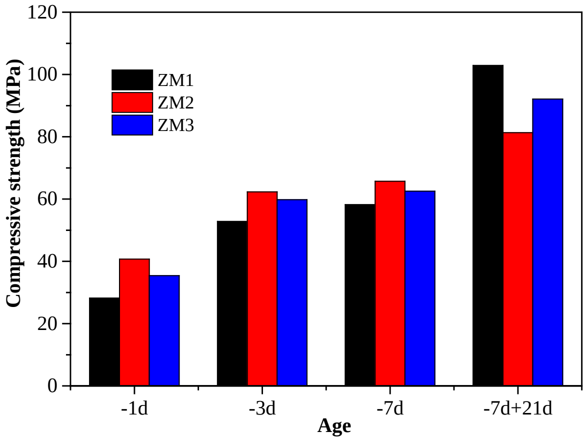



**Figure 3.** Strength development curing under -15°C.

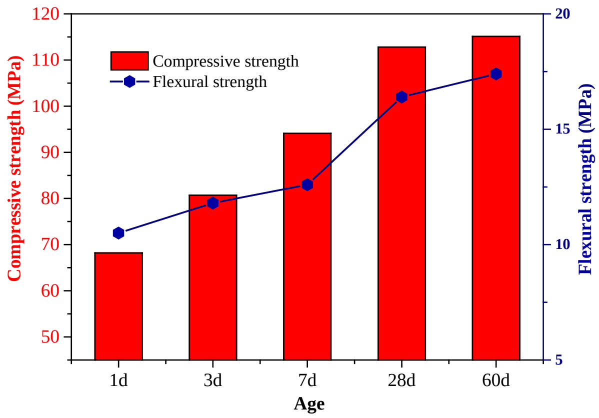



**Figure 4.** Strength development of ZM3 bed mortar material curing under standard environment

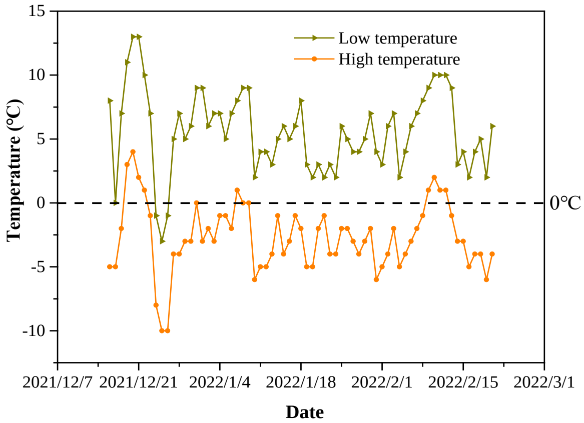
### 3.4 Strength of the bed mortar material under standard curing condition

From Figure 4, it can be seen that the early strength of ZM3 bed mortar material developed rapidly under standard curing conditions, and the flexural strength reached 10.5 MPa and compressive strength reached 68.2 MPa at 1 d. At 7 d, the compressive strength of the bed mortar material was as high as 94.1 MPa. With the extension of the curing age, the strength of the bed mortar material increased steadily, and the compressive strength was 115.1 MPa at 60 d. This indicates that the ZM3 bed mortar material has good early and late strength.

### 3.5 Strength development under natural curing condition outdoors

To better reflect the strength development of the bed mortar material under the actual construction environment, the ZM3 bed mortar material was formed and then placed in an outdoor natural environment for maintenance, and the test time was December 16, 2021, and the temperature distribution curve for 60 days during the maintenance, period is shown in Figure 5. The minimum temperature during the maintenance period reached -10°C, the average minimum temperature was about -3°C and the average maximum temperature was about 5°C.

It can be seen from Figure 6 that the compressive strength of ZM3 bed mortar material reached 51.1MPa and 69.5MPa at 1d and 3d, respectively, and exceeded 80MPa at 7d under the natural curing condition of alternating positive and negative temperatures outdoors. The strong growth was stable at the later stage and reached 113.2MPa at 60d. Meanwhile, the flexural strength was 8.2MPa at 1d and exceeded 10MPa at 7d. It can be seen that under the natural maintenance of alternating positive and negative temperatures, the ZM3 bed mortar material still has a good strength development pattern, with faster strength development in the early stage and stable strength development in the later stage.



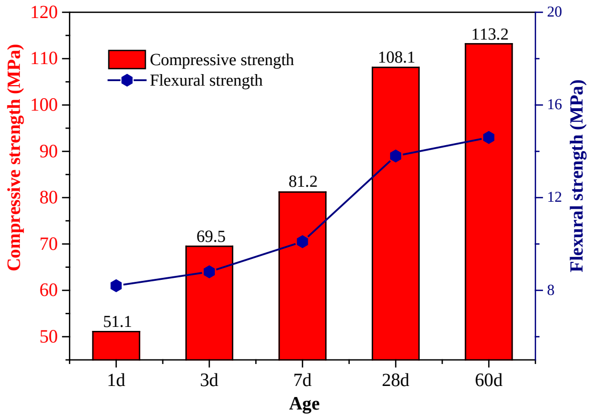




**Figure 5.** Temperature curve during natural environment. **Figure 6.** Strength development of ZM3 bed mortar material curing under positive and negative temperature alternating natural .

## 4. Conclusion

(1) The base formulation of the bed mortar material was determined based on the orthogonal test. The base slurry has excellent thixotropy, good plasticity operability, and can be operated for about 60min.

(2) Under the condition of negative temperature curing, the early strength of bed mortar material is high, and the strength develops well after transferring to standard curing. When curing at -5℃, the compressive strength of -1d exceeds 60MPa; when curing at -10℃, the strength of -1d exceeds 40MPa, and the strength of -3d and -7d exceeds 60MPa. When curing at -15℃, the strength of ZM3 base stock reached 92.1MPa after 7d to 21d standard curing.

(3) The early strength of ZM3 bed mortar material developed rapidly under standard curing conditions, and the flexural strength reached 10.5MPa and compressive strength reached 68.2MPa at 1d. The later strength increased steadily, and the compressive strength was 115.1MPa at 60d.

(4) Under the condition of natural curing with alternating positive and negative temperatures outdoors, the ZM3 bed mortar material still has good early and late strengths, and its 1d compressive strength reaches 51.1MPa and 60d compressive strength reaches 113.2MPa.

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