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Applications of Basic Magnesium Sulfate Cement in Civil Engineering

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The research in this article is conducted to discuss on the application effect of basic magnesium sulfate cement in civil engineering. Research and Analysis are conducted on strength of reinforced concrete material, structural member corrosion rate and flexural member bearing capacity of reinforced concrete by taking basic magnesium sulfate cement as the research objective. Basic magnesium sulfate cement has relatively high concrete strength, with no significant corrosion in civil engineering buildings, and the member bearing capacity is in accordance with design requirements. Basic magnesium sulfate cement is one of important base materials in civil engineering construction, with research and application values.

1. Introduction

As a new type of magnesium cement, basic magnesium sulfate cement has relatively low strength, giving rise to low building strength. Considering of unfavorable performance of basic magnesium sulfate cement, a lot of scholars at home and abroad are engaged in research on the performance of the material, to improve the performance and enlarge applicable ranges and increase the application effect based on experimental researches. The strength of cement is closely related to cement structure as well as types and contents of hydration products. As a type of cement materials, the strength performance of magnesium cement is related to the above contents. Therefore, foreign scholars conduct research on the strength performance of magnesium sulfate cement and detect close relationship between the porosity and the strength of the cement material. In addition, the strength of basic magnesium sulfate cement may change due to different ingredients; for example,

2. Literature review

To explore the difference in performance between BMS and conventional reinforced concrete (RC) large-eccentric columns, the experiments of eight BMS concrete columns, including their deflection, cracking, yielding, ultimate moments, and failure modes are studied. The results show that large-eccentric compression column of BMS concrete has 20% higher values of cracking load and the ultimate capacity compared with the conventional RC column. The curing relative humidity has no obvious effect on the eccentric compressive performance of BMS concrete columns. There is no obvious difference in the failure modes of BMS concrete columns and conventional columns under large-eccentric compression. In addition, with the increase of the strength of BMS concrete, the cracking moment and the eccentric compressive capacity for BMS concrete columns can be improved. Jiang and others modified the general eccentric compressive theory and current code provisions for eccentric compressive column design to be applicable to eccentric BMS concrete columns (Jiang et al., 2017).
Magnesium-sulfate concrete has the advantages of being fast-setting, having both early and high strength, and being resistant to water and corrosion. To explore the performance differences between basic and magnesium-sulfate concrete, we conduct comparison tests on large-eccentricity columns. The results show that the column made from concrete containing magnesium sulfate has advantages in relation to cracking bending moment and ultimate bearing capacity, and that some differences exist in relation to failure modes in comparison with the common-concrete column. For magnesium-sulfate-concrete large-eccentricity columns

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with the same rebar content, cracking resistance and bending resistance increase with concrete strength, but the ductility decreases. Because the existing formula for calculating the ultimate bearing capacity of a common-concrete large-eccentricity column is not applicable to an alkali magnesium-sulfate large-eccentricity compressive concrete column, Zeng and Yu proposed a revised formula that is applicable (Zeng and Yu, 2017).

Alternating current impedance has been used to study effects of hydration stages and molar ratio on the pore structure and hydration characters of basic magnesium sulfate cement. The alternating current impedance spectra of at early hydration almost appears as a straight line because none crystal hydration phases form. And it appears high frequency semicircle at late hydration stage because of decreasing of porosity and amount of 5Mg (OH)2 00·MgSO400·7H2O gradually form with ages. Besides, alternating current impedance spectra differences among basic magnesium sulfate, magnesium oxysulfate and magnesium oxychloride cement have been studied. Chen and so on pointed out that these differences indicated that additives such as citric acid may change the structure and charge characteristics of MgO hydration layer which make tends to form more 5Mg (OH)2 00·MgSO400·7H2O phase in basic magnesium sulfate cement than that in magnesium oxysulfate cement (Chen et al., 2017).

The flexural strength of the composite sheet decreases obviously with the increase of the time in the aging condition, because the 517 phase of the needle-like magnesium sulfate cement is decomposed into the sheet-like cementation-free Mg(OH)_2. Wu and others believed that it needed 12 d when the strength retention rate of sheet material reached 50% at 80 ℃ aging condition, while the magnesium oxide cement sample failure time is only 3 d, so the glass fiber reinforced alkaline magnesium sulfate cement material aging life of a long time, more suitable for the application in the actual project (Wu et al., 2015). The changes in compressive strength and length of specimens were measured at different time intervals and considered for evaluating the extent of degradation. Allahvedi and Hashemi suggested that after 360 days of exposure to the magnesium sulfate solution, type 2 and 5 Portland cements and alkali-activated slag cement have shown 61, 41 and 34% reduction in compressive strength and 0.093, 0.057 and 0.021% increase in length, respectively (Allahvedi and Hashemi, 2015).

In view of the condition that there have been few investigations on the fatigue damage mechanism of cement concrete under sulfate corrosion, based on coupled function experiment of magnesium sulfate corrosion and fatigue loads, the flexural strength, Zhao and so on detected the relative dynamic elasticity modulus and the water absorption of the dry saturation surface and analysed the microstructures of concrete hydrates at different corrosion age (Zhao et al., 2014). This study evaluated the performance of geopolymer concretes based on a binary mixture of fly ash (FA) with blast furnace slag (GBFS) in an80/20ratio and activated with a mixture of sodium silicate and sodium hydroxide. FA/GBFS and portland cement (OPC) concretes were immersed in 5% by weight sodium sulfate and magnesium sulfate solutions. Volumetric expansion and mechanical resistance loss were measured, and the reaction products were characterized by X-ray diffraction and scanning electron microscopy. Saavedra and so on found the highest levels of deterioration in the probes exposed toMgSO4, indicating the higher aggressiveness of this solution (Saavedra et al., 2016).

Sulfate resistance of mortars containing limestone powder was investigated in a laboratory in which mortar specimens were continuously immersed in 33,800 ppm of sodium and magnesium sulfate solutions for 1,700 days. Mortars made from interground limestone and limestone powder, replacing cements with different proportions (10%, and 20% limestone by weight of the blended cement), were used to compare with the control Portland Type 5 cement mortar. Expansion and weight loss were measured. Microstructural analyses such as SEM, MIP, TGA and XRD techniques were also performed on the paste samples. It was observed that interground limestone cement specimens had higher expansion than the limestone powder replacing cement specimens due to smaller average pore size and lower total porosity, providing less spaces for depositing products of expansion. Contrary to the expansion, Sirisawat and so on thought that the specimens made from inter-ground limestone cement lost less weight than those made from the limestone powder replacing cement because of lower average pore size and total porosity, making the specimens denser (Sirisawat et al., 2014).

Basic magnesium sulfate cement has excellent ability to protect reinforced, its long-term corrosion of reinforcement effect and was equal to that of Portland cement. Basic magnesium sulfate corrosion of reinforced is far below the level in the MOC in the case. To determine the fluidity and strength property of basic magnesium sulfate cement, the cement mortars mixed with different combination of the raw materials were tested on the fluidity and strength. The effects of raw materials combination on the fluidity and strength property of basic magnesium sulfate cement are discussed in detail. The results show that basic magnesium sulfate cement mortars without addition of superplasticizer can get good fluidity. FDN superplasticizer has better effect than polycarboxylic superplasticizer for basic magnesium sulfate cement mortars. The compressive strength and flexural strength of basic magnesium sulfate cement mortars higher than Portland cement mortars at the same curing age. Moreover,basic magnesium sulfate cement mortars have excellent flexural strength property for the needle shape crystals intergrowth into a massive microstructure of the hardened paste.

3. Methods

3.1 Chemical foamed thermal insulation material of basic magnesium sulfate cement

Cement chemical foamed thermal insulation material introduces matters with chemical reactions generating gas, i.e., foaming agents, into the system composed with foam stabilizer, binding material and water, so as to achieve slurry expansion by controlling reasonable foaming speed, to form a material with slight mass, heat preservation, thermal insulation and sound insulation. Chemical foamed thermal insulation material has the following characteristics: Chemical foamed cement has relatively high porosity, which can be adjusted with appropriate technologies. The performance density of the material is within the range of 160-1800 kg/m3, which reduces 25% or even 30-40% of the dead weight of buildings. Therefore, it can be taken as the material of interior and exterior walls or that of non-bearing structures. Reasonable technologies can be utilized to change most holes in the cement chemical foamed material into sealed holes containing large amount of air, with favorable heat preservation effect. It can be utilized as the sound insulation layer in construction floors, expressways, KTV entertainment places and underground structures. Inorganic chemical foamed cement is an inorganic incombustible material. (Please refer to Table 1 for the raw materials and their costs of producing 1 cubic 300 bulk magnesium sulfate cement chemical foamed materials.)

Table 1: The raw materials and their costs of producing 1 cubic 300 bulk magnesium sulfate cement chemical foamed materials

Raw material	Magnesite powder	Magnesium hydrate	Fly ash	Admixtures	Stable foam agent	Waterproofing agent	Fiber	Hydrogen peroxide	A combined (yuan)
Dosage (kg)	80	48	14.4	0.4	0.008	0.8	0.4	5.5	-
The cost of shenyang	40.0	19.2	14.4	2.4	0.12	8.0	4.0	8.25	98.77
Xi 'an cost (yuan)	56.0	28.8	14.4	2.4	0.12	8.0	4.0	8.25	124.4
The cost of xining (yuan)	80.0	21.6	14.4	2.4	0.12	8.0	4.0	8.25	141.2

3.2 Physical foaming heat insulation material of basic magnesium sulfate cement

The physical foaming heat insulation material of basic magnesium sulfate cement is also known as foam concrete, which is prepared by dispersing the foam made in physical and mechanical methods such as mixing or adding of compressed air into the basic magnesium sulfate cement in an uniform way, so as to form a porous light material after hardening. The foaming agents commonly utilized include animal protein type, vegetable protein type and rosin soap type. The foaming agent adopted in this article is a composite foaming agent integrated with rosin and animal protein sold in markets. The foaming agent and water are mixed as per the mass ratio of 1:70, to generate bubbles in foaming machines. Compared with chemical foaming technologies, the basic magnesium sulfate physical foaming technology is simpler and slower in material solidification and lower percentage of close area. Therefore, the strength of material with physical foaming method is lower than that of chemical foaming cement with the same dosage and matching of the same raw materials with the same bulk density. In addition, the thermal conductivity is lower than that of chemical foaming material. In this experiment, the mass mixing proportion of the basic magnesium sulfate cement physical foaming material is listed as follows: basic magnesium sulfate cement (with 40-60% coal ash): water: foam=1:0.3-0.5:0.06-0.10. The stripping time is 24 h. (The bulk density, compressive strength and thermal conductivity of the basic magnesium sulfate cement are listed in Table 2.)

Table 2: The bulk density, compressive strength and thermal conductivity of basic magnesium sulfate cement foamed materials

Bulk density (kg/m3)	The compressive strength (MPa)	25 ℃ coefficient of thermal conductivity (W/(m·K))
220	0.65	0.084
290	1.06	0.095
325	1.26	0.125
360	1.55	0.145
410	2.17	0.169

3.3 Strength grade test of the basic magnesium sulfate cement

In order to promote the basic magnesium sulfate cement, it is required to determine the strength grade of the basic magnesium sulfate cement as per the standard method for colloidal mortar strength test of Portland cement. In this article, raw material after measurement including light burned magnesium oxide powder, coal ash, magnesium sulfate powder and additives are grinded and mixed uniformed, to make the basic magnesium sulfate cement. In which the additive is the mixture of K19 and nitrite corrosion inhibitor. The application method of this type of cement is the same as that of ordinary Portland cement, which shall be mixed with water directly. Table 3 shows the component of the selected basic magnesium sulfate cement; i.e., the coal ash in cement A and C occupies 40% of the total weight of cement; the coal ash in cement B occupies 58%. The colloidal mortar strength experiment of the 3 types of cement shall be conducted as per the methods stipulated in GB175-2007 “General Purpose Portland Cement”. Different from the stipulations in this standard, the water cement ratio of the basic magnesium sulfate cement shall be determined again as per the fluidity. According to this standard, the fluidity in strength experiment of the general purpose Portland cement shall be no lower than 180mm. The water cement ratio of the basic magnesium cement ratio is determined again according to the requirements on fluidity.

Table 3: Ratio of basic magnesium sulfate cement

Serial number	Light burnt magnesia powder (g)	Magnesium hydrate (g)	Industrial trihydrate magnesium sulfate (g)	The fly ash (g)	Admixtures(g)
A	400	194	0	400	6
B	280	136	0	580	4
C	424	0	146	424	6

4. Results and discussion

4.1 Strength of the basic magnesium sulfate cement sand stone concrete

Table 4 shows the compressive strength of the basic magnesium sulfate concrete (BMS Concrete) of different ages. According to the 28d compressive strength of concrete 1#-4#, the samples can be divided into structure purpose concrete materials with strength grades of C50, C40, C30 and C20. Therefore, it is available to prepare structure purpose concrete of different strength grades with appropriate matching as needed in condition that the basic magnesium sulfate cement is adopted as the binding material. In practical works, the following simple formula is often utilized when estimating the strength of the normal concrete (PO Concrete) prepared with Portland cement as the binding material: $R_n = R_a \frac{lgn}{lga}$ When calculating as per the formula, the compressive strengths of general silicate concrete of 3d and 7d are 33.0% and 58.4% of that of 28d, respectively. The compressive strengths of 3d and 7d of concrete 1# are 53.0% and 71.6% of that of 28d, respectively, with higher increase rate in strength than that of Portland cement concrete. The compressive strengths of 3d and 7d of concrete 2# are 40.0% and 64.0% of that of 28d, respectively. The strength increase rate is slightly slower than that of concrete 1#; however, it is still quicker than that of ordinary Portland cement concrete. Based on the comparisons made on concrete 1# and concrete 2#, the concrete compressive strength increase rate reduces with the increase in coal ash amount mixed in the basic magnesium sulfate cement. The development rule for compressive strength of concrete 3# and concrete 4# is close to that of ordinary Portland cement, which is significantly slower than that of concrete 1# and concrete 2# due to large water cement ratio in cement 3# and cement 4#. Therefore, the strength increase rate of the basic magnesium sulfate cement concrete slows down with the increase in water cement ratio.

Table 4: Compressive strength (MPa) values of concrete at different ages

Serial number	3d	7d	28d
1#	31.1	42.2	58.9
2#	18.5	29.8	46.6
3#	13.1	22.2	36.1
4#	8.6	14.5	25.3

4.2 Reinforcement corrosion rate of reinforced concrete small-sized flexural members

There is no trace of corrosion on the main reinforcement and the stirrup of reinforcement cages. Based on the results of acid pickling test on the marked reinforcement section, the corrosion rate of the marked reinforcement section in flexural members is basically within 0.20%-0.35%, i.e., 10.2 mg/m2·h at most in the corrosion rate. The reinforcement corrosion rate in magnesium oxychloride cement can achieve 5910 mg/m2·h at most. The reinforcement corrosion rate in Portland blast furnace slag cement is 1668mg/m2·h at most. That is to say, the reinforcement corrosion rate in the basic magnesium cement concrete is only about 2‰ of that of magnesium oxychloride cement concrete, which is about 6‰ in the Portland blast furnace slag cement (Table 5). The basic magnesium sulfate cement concrete has sufficient strength and favorable endurance quality; in addition, it leads to no significant corrosion to reinforcement. Therefore, it further proves that the basic magnesium sulfate cement concrete can be applied to concrete construction engineering in a favorable way.

Table 5: Corrosion condition of reinforced concrete member internal steel reinforcement

Serial number	Corrosion rate (%)	corrosion rate (um/a)	Corrosion rate (mg/m^2·h)
1127BC2	0.20	6.6	6
1126BC2	0.27	8.9	8.1
1127BC3	0.30	9.9	9.0
1129BC1	0.34	11.2	10.2
Magnesia cement	-	-	5910
Portland slag cement	-	-	1668

4.3 Calculation model for bearing capacity of reinforced concrete flexural members

Table 6: The calculated value and the measured value of the initial crack deflection and failure deflection of the basic magnesium sulfate cement concrete

Serial number	Concrete strength(MPa)	Limit tensile strength of steel bar(MPa)	Number of principal bars	Protective thickness(mm)	B (mm)	h_0 (mm)	X_0 (mm)	Value of ultimate bending moment(kN·m)	Measured value of ultimate bending moment(kN·m)	Measured value/calculated value
1127BC2	53.1	445	1	15	87	69	9.56	0.988	2.384	2.413
1126BC2	31.0	445	2	15	102	69	9.34	1.900	2.078	1.094
1127BC3	30.3	445	2	15	102	69	9.55	1.888	1.866	0.988
1129BC1	36.1	445	2	15	102	69	8.02	1.919	2.192	1.142
C30	31.3	420	2	15	75	57	10.12	1.827	2.037	1.115
C50	52.3	420	2	15	75	57	6.05	1.876	2.256	1.203

The section strain increases with the growth in loads. In condition that the tensile reinforcement achieves yielding and the concrete in the compressive zone is damaged, Mu, the normal section ultimate bending moment of the reinforced concrete beam, is calculated with the following formula:$Mu=af_c(h_0-x/2)$ In addition, the initial crack deflection and the failure deflection of the reinforced concrete are calculated as per “Code for Structural Design of Concrete” in this article, which are listed in Table 6. Based on related values, the measured initial crack deflection is significantly larger than the calculated value, and the measured failure deflection is significantly smaller than the calculated value.

5. Conclusions

Strength of basic magnesium sulfate cement, reinforcement corrosion rate and member bearing capacity are researched in this article. Based on research results, concrete strength may change with influences caused by water cement ratio or additives such coal ash. Due to favorable strength and durability, cement concrete can be applied to civil engineering structure construction. With favorable bearing capacity, no significant reinforcement corrosion occurs to the basic magnesium sulfate cement reinforced concrete. According to the calculation and analysis of the bearing capacity of the basic magnesium sulfate cement reinforced concrete members, the reinforced concrete structure in this research is in accordance with the code for structural design, with certain applicable value in the basic magnesium sulfate cement concrete structure. Considering of limited length in this article, only simple experimental analysis is conducted on the basic magnesium sulfate cement concrete, with no verification on the design contents in a way of computer simulation or practical civil engineering application. Therefore, further experiments shall be conducted to detect the accuracy of the research findings.

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