CHEMICAL ENGINEERING TRANSACTIONS

VOL. 66, 2018

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Songying Zhao, Yougang Sun, Ye Zhou

ISBN 978-88-95608-63-1; **ISSN** 2283-9216

DOI: 10.3303/CET1866205

The Impact of the Particle Ratio on Cement-based Materials in Modern Road and Bridge Construction

Hongmei Cao

Sichuan College of Architectural Technology, Sichuan 618000, China
honghaicao38191@163.com

This paper is to explore the impact of particle ratio on cement-based materials by analyzing the density of mortar, distribution of cement particles and the pore structure of those materials. This paper established four mathematical models of mortar and analyzed the pore structure of cement-based materials, dealing with the secondary interface of the structure by EPMA's backscattering. The results of the experiments show that the decrease of power consumption of cement grinding will increase the density of cement particles and further reduce the porosity between cement particles so as to improve the flexural strength of cement-based materials.

1. Introduction

Cement concrete is widely applied in construction and cement-based materials are greatly affected by the aggregate, which too large aggregate will have a severe effect. Therefore, to improve the quality of cement-based materials, companies should optimize the proportion of cement particles. In this paper, four mathematical models of mortar are established to analyze the pore structure, density of mortar and the distribution of cement particles and evaluate their impact on cement-based materials according to the experimental data.

2. Literature review

In the late 1990s, a material distribution system viewpoint was proposed. The system consists of a central warehouse and multiple retailers. The principle is that the company will use the supplier as a channel for ordering to supplement the inventory of the central warehouse to meet the needs of various retailers. Due to the different nature of retailers, their overall distribution is in a Poisson distribution. This method proposes to calculate the inventory cost and delay cost of the system through accurate calculation. This kind of research method can be used as a reference for road and bridge construction companies. It is the material management of the central warehouse. Inventory belongs to the hub of construction material cost control, which is directly related to the purchase of materials and the use of materials. At the same time, it creates basic conditions for the control of procurement costs and the efficient use of materials (Yepes et al., 2015).
The control of multi-level inventory under the influence of joint supplementary policies was studied. Ordinary point-saving batch order policy is assumed. Combined with the demand list of construction materials for roads and bridges, the inventory will be issued with the minimum inventory status. This kind of ordering policy specifically combines the actual needs of materials for road and bridge construction. The materials are purchased at fixed points to reduce the stock of materials. It has a significant effect on the effective control of material stocks. Compared with quantitative procurement methods, this method requires higher costs and can only occur during the special stage of construction of road and bridge projects (Ferreira et al., 2016).
In the supply chain management, material procurement and effective use system is the most important content. Through research, a three-dimensional supply chain model system for materials, suppliers, and inventory was established. A method combining analysis and simulation was proposed. It solves the disconnect problem of material procurement to use distribution. The system is suitable for long-term material

supply and demand. It is therefore more suitable for the material supply of road and bridge construction companies (Snoeck and Belie, 2015).

In 1960, the concept of "level inventory" was proposed. The level of inventory in the material supply chain is equal to the sum of existing inventory, transfer stock, and moving inventory. A continuous inventory inventory control model for material supply chain was studied. The (s-1, S) strategy was adopted to establish a multi-level inventory model for similar supply chain systems. Based on the (s-1, S) strategy, when the material demand is in the Poisson independent distribution state, the multi-level inventory model of the material order processing mechanism supply chain system is studied. These studies together set up a bridge between dual control of material supply and inventory (Kinnane et al., 2016).

The material management of road and bridge construction companies plays a decisive role in the profit and loss of the company. It is one of the main means of engineering cost control. The company conducts optimal management of materials. Before the construction, careful investigation and detailed planning were planned. The materials were scientifically budgeted and the materials were stored and stacked. During the construction process, the system of acceptance, issuance, return and recycling of materials shall be carefully executed, and measures shall be taken for the maintenance of turnover materials and the management of end-of-work materials. The above studies mainly focus on the consumption management during the material construction process. This part has a certain reference for the research work of this article. However, the procurement research is basically blank (Gu et al., 2015).

Maximizing the strength of engineering materials management can provide enterprises with sufficient competitiveness in market competition. The first is the material budget before construction. The second is the strict implementation of the material management process in the construction process. In the areas of material testing, acceptance, distribution, exit, and reuse, a full range of dynamic reports was produced. The third is the management of the finished material after construction. No research on material procurement was conducted. For material storage management, it is also a forgiveness (Qian et al., 2018).

The road and bridge project is an important part of the national infrastructure construction. Since the reform and opening up, the central and local governments have injected large amounts of financial funds into the construction of roads and bridges. Material equipment is the basic material method for construction. Rational allocation of various data resources must be based on rational construction of mechanical equipment. The work of material procurement, transportation, and management is reflected in the management of materials and equipment. For example, material handling, transportation, and storage all require the use of various materials and equipment. The rational application of these devices directly affects the optimal management of materials (Li et al., 2015). Compared with the above references, although this method has a new and innovative performance, it is relatively weak in terms of content. By drawing on this research idea, it is integrated into the study of material consumption management (Shen et al., 2015).

In summary, although the building materials management system does not directly study the material management of road and bridge construction companies, the material management methods involved in the content have implications for reference. It can realize the scientific and standardized material management of all construction companies, including road and bridge companies, as well as the rationalization of material management business processes. The system construction of building materials management mainly uses the network and database technology. From the perspective of engineering practice, engineering intensity is reduced, information is highly shared, and management costs are reduced. It is conducive to the acceleration of the overall management of information technology in construction companies.

3. The principle and method of the experiment

Cement-based composites are highly heterogeneous and porous, and the initial packing density of powder particles has always been an important direction in cement research. In order to get the maximum packing density, the volume of the concrete aggregate should be increased and the gap between the aggregate should be filled with a slurry of a certain water-cement ratio. Therefore, the research on the compactness between the aggregate and the slurry is very conducive to optimizing the mix ratio of the concrete. At present, common mathematical models of the concrete particle packing density can be divided into two kinds: the discontinuous particle size distribution and the continuous particle size distribution. Raw materials used in the experiment are P·042.5R cement, standard sand, the first-class grounded fly ash, Elkem microsilica, the active NR powder of mineral material with special microstructure (nanofibers with radial scale of 40 ~ 60nm and longitudinal dimension of 1~ 2μm), and FDN superplasticizer.

4. Results and analysis of the experiment

4.1 Mortar density analysis

The experiment designs a mathematical model of particle gradation. First, prepare 4 groups of mortar. And then adjust the plasticizer dosage during its mixing with the mortar so that the fluidity of each group is 160 ± 2mm (the specific mixing proportion is listed in Table 1), under which 4 groups of mortar are the most closely accumulated.

Table 1 : Mixing proportion of mortar

No.	Sand/B	Cement/B	(Flyash)/B	(Silieafume)/B	NR/B	Vater/B	Fluidity/mm
Z	1.200	1.000	-	-	-	0.28	160
H	1.200	1.000	-	-	0.050	0.28	158
A	1.200	0.800	0.150	0.050	-	0.28	159
K	1.200	0.800	0.150	0.050	0.050	0.28	161

Note: a.B-Cement+ (Flyash)+(Silieafume)+(NR powder)

The theoretical basis for the mathematical model of particle gradation is the theory of maximum compaction. And the model is as follows:

$$\rho = \frac{0.59}{1\text{-}0.41\sum_{j=1}^{i-1} g'(i,g)X_j - \sum_{j=j+1}^{n} f'(i,j)X_{j\_}0.942X_N}$$

ρ is the density. Xj and Xn are the mass fraction of j particle and nanofiber particles. Through the above formula, we can calculate that the packing density of the mortar Z, H, A, K particle mixture is 0.8725, 0.9087, 0.9615 and 0.9815.

SEM, EPMA and EDXA were used to observe the microstructure of the secondary interface of the mortar. The cross-section of samples taken from the mortar z, H, A should be fresh, vacuum drying, and then be placed under SEM for observation after coating. And the surface of the sample should be grinded, polished, dried and coating in the EPMA test. The elemental qualitative analysis (EDXA) of the sample was carried out by energy dispersive spectrometer and the high pressure pore testing was by POREsIZER 9320 mercury porosimeter. Mechanical properties of mortar 7d, 28d, 56d and 90d were tested according to the national standard GB / T17671-1999 .

4.2 Analysis of the impact of grinding process on the distribution of cement particles and grinding power consumption

Table 2 shows the composition of P·O42.5R cement (its specific surface area is 360m2/kg±10m2/kg), the standardized consistency water consumption, electricity consumption and the properties of concrete provided by different large-scale grinding technology systems.

As can be seen from the data in Table 2, with the improvement of the grinding efficiency of its process system, the power consumption decreases, the uniformity coefficient n of the cement particles distribution increases, the particles below 3 μm in the cement decreases, and 3~32μm particles increase. When the specific surface area of the cement is similar, particles of the cement made by the traditional open circuit grinding (Combidan) is the most dispersed and the cement grinding power consumption is up to 38KWh / t. However, roller press and closed grinding system for high concentration of powder improved the over grinding: 3 ~ 32μm particle content can be up to 67% and the uniformity coefficient can be 1.17. The cement grinding power consumption also has dropped to 28 ~ 30KWh / t. With the progress of the open-circuit grinding technology, the gap of the power consumption between the large grinding system and the closed circuit grinding system is narrowing. The application of the grinding aid technology based on the open circuit grinding of the roller press, or the technical reform of reducing the concentration efficiency of the closed system of the roller press can make the cement particle distribution and grinding power consumption reach the similar level, which the temperature of the former cement is 20～30℃ higher than that of the latter one.

According to Table 2, no matter which grinding system is used to grind the cement, the gradation of particle composition is far from the Fuller which requires the cement to be the closest packing. To meet the Fuller grading requirements which the order of fineness from particle compactness should be: open-circuit grinding> roller press + open-circuit grinding> roll press + open-circuit grinding + grinding aid + roller press> closed-circuit grinding (when the concentration efficiency is low)> roller press + closed-circuit grinding (with efficient selection of powder), the use of grinding aids can increase the output and save energy. However, the excessive addition of grinding aids will make cement particles more concentrated and the particle accumulation porosity increase, which is unfavorable to the compactness of the concrete structure. Therefore, we can see that when using the vertical roller mill, due to the higher grinding efficiency, cement particle distribution and Fuller gradation deviated more greatly, which is the main reason that concrete production enterprises in some areas do not accept the cement made by the vertical mill.

Table 2: Different large grinding system grinding P·O42.5R cement particle composition and part of the performance evaluation

Grinding system	Uniformity coefficient（n）	The standard consistency of water consumption	Power consumption	Out of the mill cement temperature	Preparation of concrete workability evaluation
Open mill	0.93	24.20	38	High120℃	superior
Roller press, open mill	1.03	24.80	32	High130℃	
Roller press, open mill, grinding aid	1.07	25.00	30	120～130℃	better
Roller press, closed circuit mill	1.0	25.00	30～32	90～100℃	
Roller press, closed circuit mill (efficient powder selection)	1.17	27.20	28～30	90～100℃	Poor
Ideal grade	0.62				The most compact concrete structure

Note: The particle distribution data is measured by a Malvern laser particle size analyzer.

4.3 The pore structure in cement-based materials

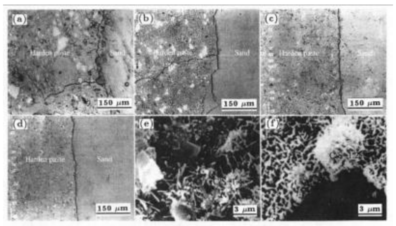

Figure 1: Backscatter electron image of EPMA secondary interface of 128d mortar

Table 3: Parameters of Porestrueture

No.	Thresholdvalue of porediameter	Total specific intrusion volume	Most probable diameter	Meandiameter
Z	120	0.0510	20,40	40
H	60	0.0365	8,12	15.5
A	80	0.0154	8,10	13.5
K	20	0.0074	8	7.1

The pore structure determines the compactness, porosity, permeability and mechanical properties of the cement stone. It includes pore size distribution, porosity, pore shape and pore distribution uniformity. A pore diameter less than 20nm is no-harmful, and the size of 20-50nm is for a less harmful pore, 50 and 200 nm for a harmful hole, and 200nm for a more harmful hole. Since the spherical pore can absorb the energy released when the water in the pore is frozen to alleviate the freezing damage and is beneficial for the frost resistance and impermeability of materials. From Figure 1 and Table 3, we can see that all the parameters of mortar z are greater than those of H and A 's are greater than K's. It indicates that adding the active NR powder can reduce the total porosity of the mortar and refine the porosity, that is, the compactness and uniformity of the mortar can be greatly improved.

4.4 The effect of particle distribution on compatibility of the cement and superplasticizer

As shown in Table 4, when specific surface areas are the same, the more concentrated the particle distribution (the larger the value of n) is, the larger the content of the saturation point in Marsh curve is and the longer the time is. With the increase of the specific surface area, the content of saturation point increases, the compatibility with superplasticizer becomes worse, and the particle distribution is narrower. The adverse effect on compatibility is significant. When the saturation time is similar with that on the Marsh curve, the cost of the superplasticizer will increase by 1.4-2.0 yuan / m3 for the ordinary C30 concrete as the saturation point dosage is increased by 0.2%. If the time of saturation point on the Marsh curve is greatly prolonged, it's hard to make the concrete with high flowabilty and good performance and its formulation cost will also increase dramatically.

Table 4: Sample uniformity coefficient and saturation point parameters

The sample	Specific surface area	The value of n	Saturated point dosage	Marsh time
1	320	0.813	0.7	22.09
2		0.830	0.7	28.98
3		1.035	1.1	26.61
1	380	0.934	1.2	22.63
2		0.960	1.2	41.23
3		1.111	1.4	47.67

Mineral admixture technology is used in making the concrete. The main role of mineral admixtures is to cause the fine aggregate effect, that is, use fine powder to fill the gaps between the cement particles, making the powder grading closer to the Fuller grading, so as to reduce water usage and achieve densification. Having compared particles of the cement and the Fuller gradation, we can see that the amount of particles below 3μm in the mineral admixtures is at least twice to three times more than that in the cement (particles below 3μm is expected to reach 30% to 40% or more). And admixtures were added to the different cement of particle size distribution after grading particles. The compatibility of the superplasticizer test results are shown in Figure 2.

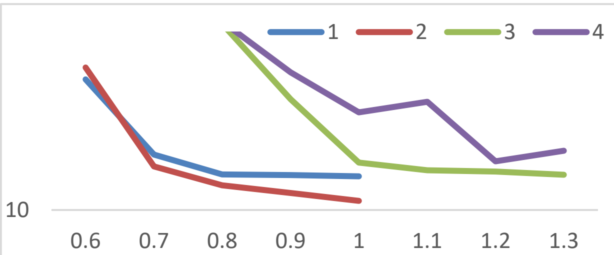

Figure 2: The accumulated porosity of cement samples

Figure 2 shows that the accumulated porosity of cement samples No. 1 and No. 3 is 44.98% and 47.61% respectively. With the addition of the finer admixture A2, the void fraction decreases, the saturation point dosage decreases and the time of the saturation point in the Marsh time shortens. The fine admixture has a correction effect on the particle distribution of the original cement, which is advantageous to improve the compatibility of the cement and the superplasticizer and reduces the gap in compatibility with the superplasticizer due to the different particle distribution. Therefore, regardless of the composition of cement particles, the corresponding admixture and its supporting technology can improve the particle composition of cementitious materials and produce good concrete. This is the basic principle of separate grinding and admixture correction technology. In areas where ready-mixed concrete is well developed and thermal power plants are few, even large quantities of coarse fly ash that does not meet the current standards are in short supply. And if there is no good admixture to correct the particle distribution of the cement, the performance of the concrete to a large extent still depends on the original particle gradation.

The strength of cement mortar is measured at a fixed water-cement ratio, which reflects the degree of hydration of cement particles. And under normal circumstances, to achieve the same workability of the cement, the more concentrated the particle distribution is, the greater the value of n is, which will have the following effects: ① The superplasticizer dosage is larger and the cost is bigger. ② The water-cement ratio increases as the water consumption increases and the concrete strength decreases greatly. That is, since it is tested under the same working condition, advantages of the open circuit system to grind the cement particles are enough to offset its low mortar strength. Overall, with the increase of grinding efficiency, the more concentrated the cement particles are, the greater the water consumption of the standard consistency of cement is, and the worse the compatibility between the cement and superplasticizer is. Therefore, the performance of the concrete made under such conditions becomes worse. From the perspective of the compactness of the concrete structure, it is desirable that the distribution of the cement particles be as close as possible to the Fuller gradation with the best open circuit grinding system.

5. Conclusion

Construction units need to choose proper concrete according to different road and bridge demands and must pay attention to every detail in the mixing process, such as material ratio, aggregates and other grain diameter. From the experimental results, it can be observed that the reduction of power consumption in cement grinding can increase the density of cement particles and reduce the porosity among cement particles so that the flexural strength of cement-based materials can be improved.

At present, China's road and bridge construction progresses towards the direction of environmental protection and high quality, so the quality of cement-based materials and the concrete should meet higher demands correspondently. The construction personnel must consider the actual situation and mix different material properly to improve the construction quality of the road and bridge.

Reference

Ferreira V.J., Vilaplana A.S.D.G., García-Armingol T., 2016, Evaluation of the steel slag incorporation as coarse aggregate for road construction: technical requirements and environmental impact assessment, Journal of Cleaner Production, 130, 175-186, DOI: 10.1016/j.jclepro.2015.08.094

Gu C.P., Ye G., Sun W., 2015, Ultrahigh performance concrete-properties, applications and perspectives, Science China Technological Sciences, 58(4), 587-599, DOI: 10.1007/s11431-015-5769-4

Kinnane O., Reilly A., Grimes J., 2016, Acoustic absorption of hemp-lime construction, Construction and building materials, 122, 674-682, DOI: 10.1016/j.conbuildmat.2016.06.106

Li J., Wu C., Hao H., 2015, An experimental and numerical study of reinforced ultra-high performance concrete slabs under blast loads, Materials & Design, 82, 64-76, DOI: 10.12989/cac.2010.7.2.169

Qian Y., Lesage K., Cheikh K., 2018, Effect of polycarboxylate ether superplasticizer (PCE) on dynamic yield stress, thixotropy and flocculation state of fresh cement pastes in consideration of the Critical Micelle Concentration (CMC), Cement and Concrete Research, 107, 75-84, DOI: 10.1016/j.cemconres.2018.02.019

Shen D., Wang T., Chen Y., 2015, Effect of internal curing with super absorbent polymers on the relative humidity of early-age concrete, Construction and Building Materials, 99, 246-253, DOI: 10.1016/j.conbuildmat.2014.02.060

Snoeck D., Belie N., 2015, From straw in bricks to modern use of microfibers in cementitious composites for improved autogenous healing–A review, Construction and Building Materials, 95, 774-787, DOI: 10.1016/j.conbuildmat.2015.07.018

Yepes V., Martí J.V., García-Segura T., 2015, Cost and CO2 emission optimization of precast–prestressed concrete U-beam road bridges by a hybrid glowworm swarm algorithm, Automation in Construction, 49, 123-134, DOI: 10.1016/j.autcon.2014.10.013