Pergamon

Cement and Concrete Research 31 (2001) 1455–1458

CEMENT AND CONCRETE RESEARCH

Some factors affecting early compressive strength of steam-curing concrete with ultrafine fly ash

Liu Baoju*, Xie Youjun, Zhou Shiqiong, Li Jian

Civil Engineering College, Central South University, Changsha, Hunan 410075, China

Received 16 October 2000; accepted 23 May 2001

Abstract

Hardening process and strength gaining rate of concrete under room temperature curing conditions are slow with respect to the production rate of concrete plants in response to demand. In order to reach a desired strength level for concrete in a short time, heat treatment is widely used. When fly ash is included in concrete and the raw materials were selected, the factors affecting early compressive strength are water–binder ratio, fly ash content, etc. In this context, heat-treatment parameters, which are commonly adopted by most plants in China, were determined, and some factors affecting early compressive strength of steam-curing ultrafine fly ash (UFA) concrete were studied. The experimental results indicated that the content of UFA and water–binder ratio are main factors influencing the early compressive strength; the other factors have influence, too. Concrete containing ultrafine fly ash composite (UFAC) and ground blast furnace slag (GBFS) can give a desired early compressive strength.

Keywords: Ultrafine fly ash; Steam curing; Early compressive strength

1. Introduction

The early strength of concrete has assumed a considerable significance in modern construction industry and railway concrete sleeper and bridge plants in order to strike the forms and transfer the prestress early. In this respect, it is a natural aim to provide a desired strength level for concrete in a short time by accelerating its hardening process using various methods. Heat treatment is one of the methods widely used for this purpose. In general, the slump of concrete used in some concrete plants is 10–30 mm, the concrete adopts steam curing, and the compressive strength after demoulding is higher than 70% of designed compressive strength.

The use of fly ash has been accepted in recent years primarily because of resulting economy through the saving cement, secondly because of using industrial wastes, and thirdly because of producing durable materials. Taking account of the condition of fly ash having large output and critical contamination in China, the use of fly ash has significant technical and economic significance.

The use of ultrafine fly ash (UFA) in high-performance concrete has many results [1–3], but there is little study on steam curing of UFA concrete. This is due to the fact that compressive strength and other mechanical properties of UFA concrete depend on the content of UFA, water–binder ratio, and curing conditions. This paper presents the early strength behavior of UFA concrete cured at 60°C, and discusses the factors influencing the early strength.

2. Experimental procedure

2.1. Raw materials used

The cement used for experiments was Type 525# ordinary Portland cement made in Xiangxiang, and its strength index was listed in Table 1. The sand came from Xiangjiang River, its grade conformed to Grade zone II, and its fineness modulus is 2.88. The coarse aggregates were broken gravel, whose qualified grade is 5–25 mm. A superplasticizer of sulfated naphthalene formaldehyde base was used in the

* Corresponding author. Tel.: +86-731-5585211 ext. 75265; fax: +86-731-5571736.

E-mail address: bjliu@csru.edu.cn (L. Baoju).

0008-8846/01/$ – see front matter
PII: S0008-8846(01)00559-2

Table 1
Strength of cement

Flexure strength (MPa)		Compressive strength (MPa)	
3 Days	28 Days	3 Days	28 Days
6.8	8.9	38.0	56.4

mix, whose commercial name is TQN. The ultrafine powder is UFA and ultrafine fly ash composite (UFAC), and some mineral powders were added into UFA in order to get UFAC. The chemical composition and properties of UFA are given in Table 2, and its Blaine surface area is about 600 m^2/kg.

2.2. Specimen preparation and curing technology

Specimen for cubic compressive strength had a measurement of 100 × 100 × 100 mm. The mix was mixed for 2 min in a mixer, and then vibrated for 3 min. The treatment temperature and its duration, together, have a profound effect on the evolution of hydration reaction and the products. In this study, heat-treatment cycle has a total duration of 13 h, the preheating duration and heating duration is 2 h, the treatment duration is 8 h, and the cooling duration is 1 h. The treatment temperature chosen was 60 ± 5°C.

After steam curing, the specimens were demoulded, and some were used to measure the compressive strength (f_{cuz}) at once, the others were put in the standard curing room, its 28-day compressive strength is named as $f_{cuz,28}$. The 28-day compressive strength of concrete with moist curing after moulding is named as $f_{cu,28}$.

3. Results and discussion

3.1. Influence of water–binder ratio

The water content affects significantly on the properties of concrete. In general, the increase in water content will enhance the flowability of concrete, and the specimen will become dense, but the evaporation of water from the mix can result in an increase in porosity during the steam-curing process and in the reduction of compressive strength and durability of concrete. On the contrary, if the water content is lower, the specimen is not dense, hence, the porosity ratio is higher. Therefore, the water content is a significant factor for early strength of concrete. The content of total cementitious material is 500 kg/m^3. Experimental results were presented in Fig. 1.

Table 2
Chemical composition and properties of PFA

	SO_3	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
Chemical composition (%)	0.30	51.2	5.80	28.1	3.70	1.20	1.64	0.71
Rate of water demand (%)				105				
Ignition loss (%)				2.4				
Water content (%)				1				

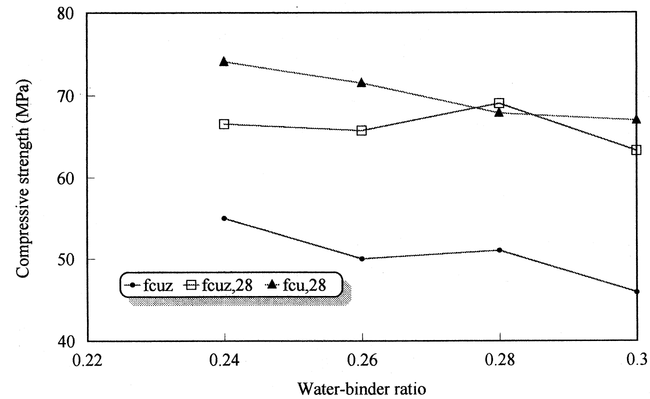

Fig. 1. Influence of water–binder ratio on the compressive strength of concrete.

The results show that the mixer is difficult to mould when the water is lower (such as when water content is 110 kg/m^3 and the water–binder ratio is 0.22), but the compressive strength decreases along with an increase in the water–binder ratio due to an increase in the porosity ratio, which resulted from the evaporation of water. The compressive strength of steam-curing concrete is lower than that of moist curing at the age of 28 days, which predicates that the increment degree in compressive strength is lower after steam curing, and steam curing ordinary concrete has this problem, too. When concrete was exposed to high-temperature steam curing, the hydration rate of cement happens quickly, the generation speed of gel also increases, and the gel wraps the cement or fly ash particle. The hydration rate of cement and the diffusion rate of hydrating production are faster, but the dissolving rate of hydrating production is slower, so the colloid film gradually becomes thick and dense. The penetration of water into the gel layer is counteracted, and the hydration of unhydrated cement particle is counteracted, too. The increment in later compressive strength is also counteracted. The higher the temperature

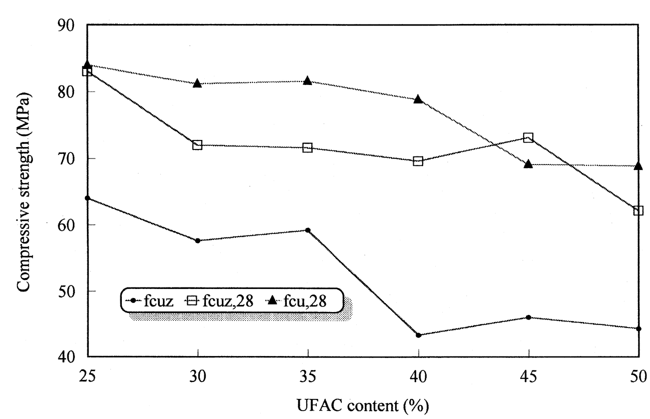

Fig. 2. Influence of UFAC content on the compressive strength of concrete.

Table 3
The mix proportion

	Mix proportion (kg/m^3)					
Specimen	C	PFA	S	G	W	TQN
31#	300	200	600	1225	130	4

is, and the longer the curing time is, the more serious this phenomenon is [4]. Heat treatment also influences the pore structure of cement paste by increasing the proportion of large pores in the cement paste [1].

When superplasticizer content is 0.8%, the water–binder ratio of 0.26–0.28 is selected in order to meet with the need of early compressive strength.

3.2. Influence of UFAC content

When the water content and the superplasticizer content are constant, and 25–50% cement is replaced by UFAC in quality, the compressive strength changes along with the variety of UFAC content. Experimental results were shown in Fig. 2.

When the content of UFAC increases, the compressive strength of concrete decreases, this trend is the same as that of moist curing high-performance concrete containing UFAC [5]. When the content of UFAC is 40%, the demoulding compressive strength of concrete is less than 50 MPa. In order to assure the demoulding compressive strength of concrete satisfying with the need, the content of UFAC must not exceed 40%.

3.3. Influence of vibration method

The problem of the durability of concrete structures was a major topic of interest in the world, and was even viewed as a major problem that society is facing. Sufficient compaction is required in order to realize durable concrete structures. When the lower slump of fresh concrete is adopted in railway bridge plants, the high-frequency vibration is necessary. The steam-curing concrete in this study has lower slump, which is 10–30 mm, hence, a suitable vibration method must be selected.

The mix proportion is shown in Table 3, but different vibration method is adopted. The vibration time is 3 min, including vibration time without pressure and vibration time with pressure using an iron plate, such as 2+1, which means that vibration time without pressure is 2 min and vibration time with pressure is 1 min. Experimental results were shown in Table 4.

Table 4
The mix proportions and experimental results

Vibration method (min)	f_{cuz} (MPa)	$f_{cuz,28}$ (MPa)	$f_{cu,28}$ (MPa)	$f_{cuz}/f_{cuz,28}$ (%)	$f_{cuz,28}/f_{cu,28}$ (%)
3+0	48.0	63.6	71.7	75.5	88.7
2+1	52.3	62.6	77.4	88.2	76.6
1+2	49.8	62.3	76.3	77.0	81.7
0+3	51.9	73.1	77.2	71.0	94.7

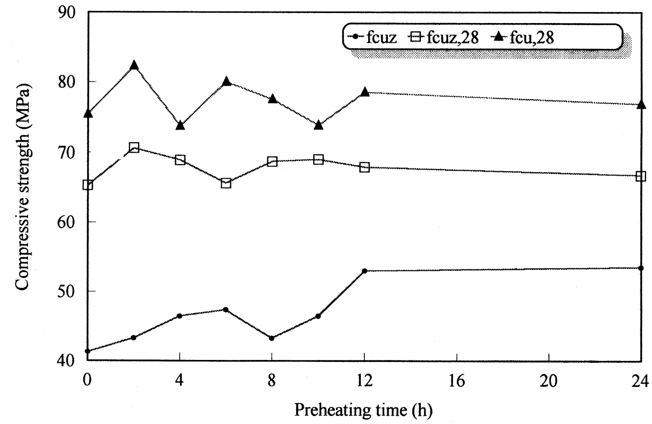

Fig. 3. Influence of preheating time on the compressive strength of concrete.

The experimental results indicated that the vibration method has influence on the early compressive strength, but this influence is not apparent. The compressive strength at the age of 28 days of steam-curing concrete is increased remarkably when 3-min vibration with pressure is adopted. Therefore, the vibration method has influence on the compressive strength of steam-curing concrete, and the vibration with pressure can be selected if possible.

3.4. Influence of preheating time

The preheating duration is the time between molding and heating. The cement had hydrated and the concrete had compressive strength during this duration. Generally, the longer the preheating duration is, the higher the demoulding compressive strength of concrete is [4]. The mix proportion is the same as 31#. Experimental results were shown in Fig. 3.

The results indicated that the preheating time influences the demoulding compressive strength remarkably, this compressive strength increases along with the extension of

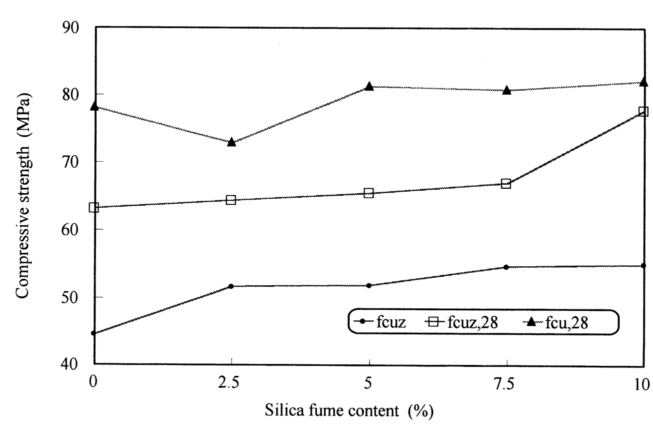

Fig. 4. Influence of silica fume content on the compressive strength of concrete.

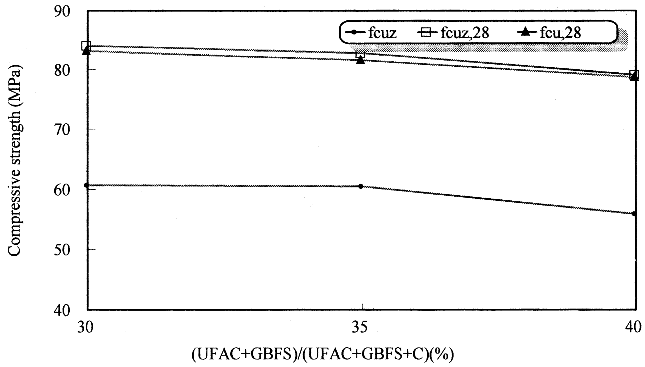

Fig. 5. Influence of UFAC and GBFS on the compressive strength of concrete.

preheating time, but the influence on the compressive strength of 28 days is less. This result is not consistent with that in literature [4]. Compared with Fig. 2, when preheating time is 2 h, the compressive strength of concrete containing UFA is about 10 MPa lower than that of concrete containing UFAC, so UFA must be improved.

3.5. *Influence of silica fume*

When high-performance concrete contains silica fume, its compressive strength is advanced, and when cement was replaced by silica fume and fly ash, the decrease of compressive strength that resulted from fly ash can be compensated by silica fume [6]. The mix proportion is the same as 31#, which is shown in Table 3, the content of silica fume and UFA is 40%, and the content of silica fume is changed from 0% to 10%. Experimental results were shown in Fig. 4.

The results indicated that the mix of silica fume into concrete has not improved the compressive strength of concrete in evidence, therefore, the following experiment does not adopt silica fume.

3.6. *Influence of ground blast furnace slag*

When cement was replaced by UFAC and ground blast furnace slag (GBFS) composite, the experimental results were shown in Fig. 5. It indicated that the compressive strength properties of concrete was improved, and the difference between $f_{cuz,28}$ and $f_{cu,28}$ is small, which demonstrated that this concrete have good steam-curing adaptability, and the development of later compressive strength is the same as the concrete in moist curing and solve the problem of lower compressive strength gaining rate.

4. Conclusion

(1) The content of UFA, pulverized slag, and water content are the main factors affecting the compressive strength of steam-curing concrete. The preheating time and silica fume have influence on early compressive of steam-curing concrete, but have concealed influence on the later compressive strength.

(2) The compressive strength of concrete containing UFA through steam curing after demoulding is lower, and that of 28 days is also lower, which indicates that the steam-curing adaptability of UFA is poor. However, UFA was improved to UFAC, hence, the compressive strength after demoulding was improved, and the ratio of $f_{cuz,28}/f_{cu,28}$ becomes higher.

(3) The addition of UFAC and ground blast furnace slag can solve the problem, wherein the increment ratio of the compressive strength of concrete through steam curing is lower.

References

[1] S. Erdogdu, S. Kurbetci, Optimum heat treatment cycle for cements of different type and composition, Cem. Concr. Res. 28 (11) (1998) 1595–1604.
[2] Y. Maltais, J. Marchand, Influence of curing temperature on cement hydration and mechanical strength development of fly ash mortars, Cem. Concr. Res. 27 (7) (1997) 1009–1020.
[3] C. Shi, R.L. Day, Acceleration of the reactivity of fly ash by chemical activation, Cem. Concr. Res. 25 (1) (1995) 15–21.
[4] Fengtai Bridge Plant, Stem-Curing of Concrete, Chinese Building Industry Publishing, Beijing, 1978 (in Chinese).
[5] Z. Shiqiong, L. Baoju, X. Youjun, Y. Jian, Y. Qianlian, Ultra-pulverized fuel ash composite powder used for HPC, Constr. Technol. 28 (5) (1999) 13–14 (in Chinese).
[6] F. Naiqian, Technology of High Strength Concrete, Chinese Building Material Industry Publishing, Beijing, 1992 (in Chinese).