Experimental Study on Upper Limit of Fly ash's Effective Replacement Ratio in Mortar

Tokyo Metropolitan University Student Member ○ Liang Wang、 Regular Member Kimitaka Uji
Tokyo Metropolitan University Regular Member Atsushi Ueno 、Regular Member Kentaro Ohno

1. Introduction

Fly ash is a kind of remaining by-product after the high temperature combustion of coal from thermal power, currently also one of high-emission industrial waste residues. When using fly ash to replace the cement in mortar, the early compressive strength of fly ash mortar decreases as replacement ratio increases, later strength increases greatly and even over that of normal cement mortar. However, when the replacement ratio exceeds a certain value, the extra fly ash in mortar will no longer react and the compressive strength will obviously decrease. This value is called upper limit of fly ash's effective replacement in mortar. It is still a key problem to be discussed and researched at present. By designing the various mix proportions, this paper studied the upper limits of fly ash's replacement ratio in the conditions of two different curing temperatures, this will provide a reference for the effective utilization of fly ash in mortar and concrete.

2. Experimental Summary

2.1 Experimental Material and Mix Proportion

The experimental materials and equipment used in this study are shown in Table 1, mix proportions of fly ash mortar are shown in Table 2.Regarding the mix proportion, the volume ratio of paste and sand in mortar is determined as 1: 1 in order to emphasize the changes of paste. Water/binder ratio is 50%，the replacement ratios of fly ash in mortar are designed as 0%，10%, 20%, 30%, 40%, 50%, 60% and 70%, respectively.

Table 1 Material and Equipment

Material	Abbr.	Material property	
Water	W	Natural water	
Fly ash	FA	JIS A6201Ⅱ Fly ash	Density：2.24（g/cm^3）
Cement	C	Normal Portland Cement	Density：3.16（g/cm^3）
Aggregate	S	Crushed sand	Density：：2.62（g/cm^3）
Admixture	AE	AE admixture (100times)	
Air meter	－	Air content test apparatus	

2.2 Experimental Method

Based on JSCE-G 505, the compressive strength test for fly ash mortar is conducted. The specimens are made into Φ50×100mm cylinders, three identical specimens were made for each specimen design, the ages of strength test are 28d and 91d, respectively.

Table 2 Mix proportion of Fly ash mortar

NO.	W/(F+C) (%)	Replace ratio (%)	Unit dosage (kg/m^3)			
			W	C	FA	S
FA-a	50	0	306	612	0	1310
FA-b		10	300	540	60	1310
FA-c		20	295	472	118	1310
FA-d		30	294	412	176	1310
FA-e		40	288	345	230	1310
FA-f		50	282	282	282	1310
FA-g		60	279	223	335	1310
FA-h		70	265	165	385	1310

2.3 Curing Temperature

In order to study the upper limits of fly ash's replacement ratio in mortar under different curing temperature conditions , the specimens of mortar are respectively placed in 20 ℃ and 30 ℃ temperature conditions to conduct the standard curing.

2.4 Air Content

Because air content has a great influence on compressive strength's curve of mortar, the compressive strength of different mortar should be compared in the same condition. There is a need to control the air content in a constant range (4 ± 0.5) for mortar of different mix proportions. The air content is in control by adjusting the AE admixture, the using dosages of AE admixture are different because of different replacement ratios. The detailed relationship curve is shown in Figure 1.

Key word: Fly ash, Effective replacement ratio, Upper limit, Compressive strength, Curing temperature
Contact address: 〒192-0397 Minami Osawa 1-1, Hachioji-shi, Tokyo TEL 080-8701-7822

3. Results and Discussion

From Figure 2, the compressive strengths of both 28d and 91d ages overall decrease as replacement ratio increases at 20℃curing temperature .When the age is 28d,the early strength of mortar is low and slow growth, the relationship between compressive strength and replacement ratio is basically linear; When the age is 91d, there seems to be a turning point for compressive strength at 40% replacement ratio.

Less than 40%, for the long-term strength of mortar, because of the pozzolanic effect of fly ash, a large amount of C-S-H gel is generated by the fully reaction between SiO_2 , Al_2O_3 in fly ash and $Ca(OH)_2$ produced by hydration of cement to make up the strength loss due to cement's decrease and improve the strength of fly ash mortar. At 20℃curing temperature, the pozzolanic effect of fly ash at 91d age has not been fully stimulated, so the compressive strength still reduce evenly as replacement ratio increases ; More than 40%,the $Ca(OH)_2$ content produced by hydration of cement is not enough ,the extra fly ash in mortar no longer reacts with it to generate the C-S-H gel and improve the strength, but is filled in the mortar structure as fine aggregate just like sand, the strength decrease obviously. In other words, 40% is the upper limit of fly ash's effective replacement ratio at 20℃ curing temperature.

Similarly, from Figure 3, at 30℃curing temperature ,when the replacement ratio is less than 30%, the pozzolanic effect of fly ash in mortar at 91d age has been more fully stimulated ,the strength tendency of 91d fit a straight line better as replacement ratio increases, the compressive strength of 10% replacement ratio is even over that of normal cement mortar; More than 30%, the extra fly ash in mortar is just like sand and no longer reacts , the compressive strength decreases obviously. Therefore, 30% is the upper limit of fly ash's effective replacement ratio at 30℃curing temperature.

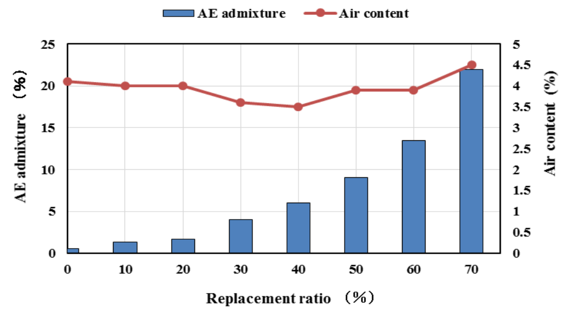

Figure 1 AE admixture and Air content

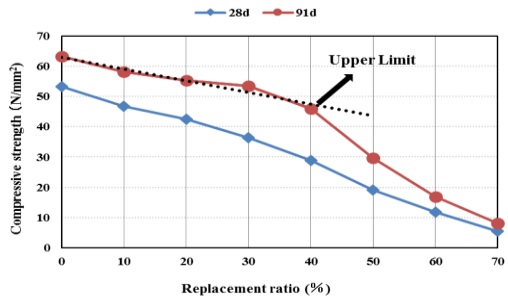

Figure 2 Compressive strength at 20℃

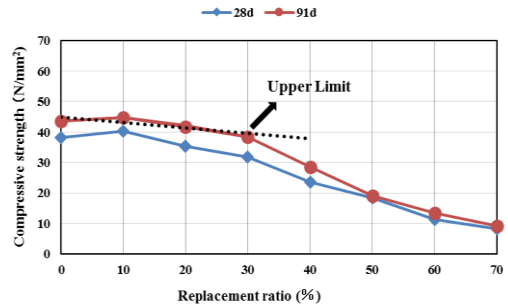

Figure 3 Compressive strength at 30℃

The cause why the upper limit of replacement ratio at 30℃ is different from that at 20℃ is probably that higher temperature accelerates the hydration reaction of cement, greatly promotes the growth of early strength, slows down the growth of later strength, the $Ca(OH)_2$ content produced by hydration reaction of cement at later age is not enough for 40% fly ash, so the upper limit moves forward .

4. Conclusion

(1). The upper limits of fly ash's effective replacement ratio in mortar are different because of different curing temperatures. The upper limits of replacement ratio at 20℃and 30℃ temperature are 40% ,30%, respectively.

(2). Higher temperature greatly promotes the growth of early strength of mortar, slows down the growth of later strength , which is the main reason why the upper limit at 30 ℃ is different from that at 20 ℃ temperature.

(3). The upper limit plays a significant role in researching the $Ca(OH)_2$ consumption and remains in fly ash mortar.

5. Reference: 1) Termkhajornkit P., Nawa T., Kurumisawa K.: A study of fly ash-cement hydration by Rietveld analysis and selective dissolution, JCI, Vo1. 27, pp. 169-174, 2005