

# 패킹모델 이용한 초고성능 콘크리트 배합설계 및 성능 평가

## Mix design and Performance Rvaluation of Ultra-high Performance Concrete based on Packing Model

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### Abstract

This paper introduces the mix design and performance evaluation of Ultra-High Performance Concrete (UHPC). The concrete mixture is designed to achieve a densely compacted cementitious matrix via the modified Andreasen & Andersen particle packing model. The compressive strengths of UHPC designed by this method reached 154MPa. The relationship between packing theory and compressive strength of UHPC is discussed in this paper.

키 워 드 : 초고성능 콘크리트, 패킹모델,

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## 1. Introduction

Based on the close packing theory, the modified Andreasen and Andersen particle packing model<sup>1)</sup> was adopted to design densely compacted UHPC with low porosity. The effect of micro silica contents on compressive strength of UHPC was explored.

## 2. Experimental methodology

Type1 Portland cement is used in this study, micro silica serves as fillers to replace cement, One type of zirconium silica fume is selected as pozzolanic material. The diameter of sand between 0.22–0.75mm is selected as fine aggregate. Polycarboxylic ether based superplasticiser is added to adjust the workability of concrete. Short straight steel fibres (length of 13 mm and diameter of 0.2 mm) are employed to produce UHPC. Modified Andreasen and Andersen model (Eq. 1) is used as the target function to optimize the composition of the granular material mixture. An optimization algorithm based on least squares (LSM) (Eq. 2) are used to adjust the proportion of each individual material in the mixture until an optimum fit between the composed mix and the target curve is reached. ( Where  $P(D)$  is a fraction of the total solids being smaller than size  $D$ ,  $D$  is the particle size ( $\mu$  m),  $D_{max}$  is the maximum particle size ( $\mu$  m),  $D_{min}$  is the minimum particle size ( $\mu$  m) and  $q$  is the distribution modulus,  $P_{mix}$  is the composed mix, and the  $P_{tar}$  is the target grading calculated from Eq. 1.) After the determination of the flow, the fresh UHPC was placed in the  $50 \times 50 \times 50$  mm cube mould and compacted. The specimens are demolded approximately 24 h after casting, cured in air with RH60% and 20°C for 24h, then steam cured under 90°C for 48h. After cool down to 20°C, compressive strengths of the specimens are tested according to ASTM C109. The reported strengths are the average of six tests.

$$P(D) = \frac{D^q - D_{min}^q}{D_{max}^q - D_{min}^q} \quad \text{-----} \quad (1)$$

$$RSS = \sum_{i=1}^n (P_{mix}(D_i^{i+1}) - P_{tar}(D_i^{i+1}))^2 \quad \text{-----} \quad (2)$$

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### 3. Result and Discussion

#### 3.1 Mix design of UHPC

The particle size distribution and target curve calculated by modified A&A model of the granular material mixtures are shown in Figure 1. The developed UHPC mixtures are listed in Table 1. In total, Five different types of UHPC composite are designed, the resulting integral grading line of the mixes compared with the target curve are shown in Figure 2. The deviation between the target curve and the composed mix is calculated with Eq. 2, that shown in Figure 3. It can be found that UHPC1 has the maximum deviation compared with other mixes obviously.

#### 3.2 Compressive strength

The compressive strengths of UHPC at 5 days are shown in Figure 3. UHPC3 has the maximum compressive strength with 154MPa. In the meanwhile, the deviation of UHPC3 from the target curve is minimal. It can be concluded that in the Figure 3 UHPC1 with no micro silica added has the minimum compressive strength, while the compressive strengths of UHPC2, UHPC4 and UHPC5 reach 151MPa, 144MPa and 146MPa, respectively. Hence, the addition of micro silica can increase the compressive strength due to its filling effect.

Table 1. Recipes of developed UHPC

No.	W/B	Cement	Micro silica	Zr Silica Fume	Sand	Steel Fiber (vol%)	SP (%)
UHPC1	0.16	960.00	0	240.00	1056.00	1.5	1.5
UHPC2		888.89	88.89	222.22	977.78		
UHPC3		827.59	165.52	206.90	910.34		
UHPC4		774.19	232.26	193.55	851.61		
UHPC5		727.27	290.91	181.82	800.00		

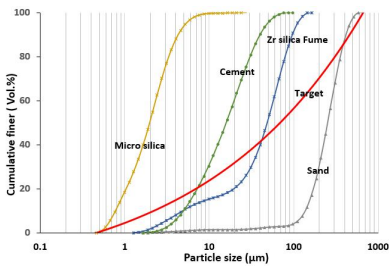


Figure 1. PSDs of the granular material mixture and target curve

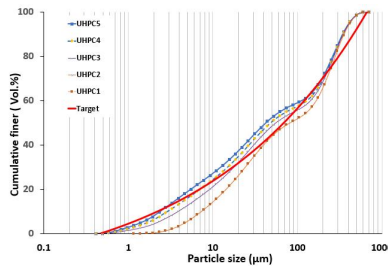


Figure 2. Resulting integral grading line of the mixes UHPC1, 2, 3, 4, 5

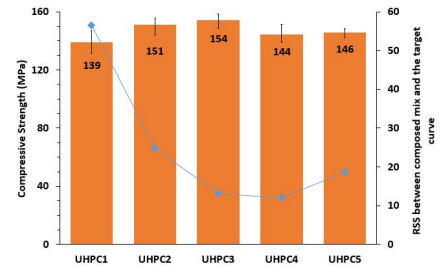


Figure 3. RSS and compressive strengths of UHPC after steam curing.

### 4. Conclusion

In this study, the maximum compressive strength at 5 days of the obtained UHPC (with 48h steam curing) is about 154 MPa. It's feasible to replace part of the cement with filler material (micro silica) and pozzolanic material to improve the efficiency of the cement. Using fillers (such as micro silica) as a cement replacement to produce UHPC can significantly improve its mechanical properties.

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