Construction and Building Materials 181 (2018) 42–48

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Orthogonal test design for optimization of synthesis of super early strength anchoring material

Xianjun Li [a,*], Jianying Hao [b,*]

[a] Department of Civil Engineering, Shanxi University, Taiyuan, China
[b] Institute of Materials Science and Engineering, Taiyuan University of Science and Technology, Taiyuan, China

HIGHLIGHTS

- The new anchoring capsule is prepared by a ternary complex system.
- Orthogonal experiment is designed to optimize the synthesis of anchoring capsule.
- The optimal combination of the anchoring capsule is $A_2B_3C_1D_2$.
- The strengthening mechanism of cement based anchoring capsule is discussed.

ARTICLE INFO

Article history:
Received 1 December 2017
Received in revised form 18 May 2018
Accepted 5 June 2018

Keywords:
Super early strength
Ternary complex system
Anchoring material
Strength
Anchoring performance

ABSTRACT

Based on orthogonal test design, the mix design of cement based anchoring capsule was optimized. Through the direct analysis and range analysis of the orthogonal test results, of the four factors, lithium carbonate has the strongest effect on the performance of anchoring capsule, while the effect of gypsum is the least. The optimal combination is 710 kg/t of sulphoaluminate cement, 190 kg/t aluminate cement, 0.92 kg/t of lithium carbonate, 16.2 kg/t of sodium carbonate and 96 kg/t of gypsum. The prepared anchoring material has superior performance. Furthermore, the strengthening mechanism of cement based anchoring capsule is discussed.

1. Introduction

Fastening systems are very popular in the design and strengthening of concrete structures in construction projects [1]. Anchor systems are also extensively used in plain or reinforced concrete, as well as for structurally strengthening and retrofitting existing constructions such as supporting tunnels and mines and retaining walls, and for connecting new structural elements to existing ones [2–5]. In the systems resin anchoring material is generally used [3]. Unsaturated polyester resin anchoring material has been used in coal mine, roadway supporting, building strengthening and other projects [6]. Epoxy resin has been designed specifically for fastening anchors in solid base materials such as concrete, grout, stone, and solid masonry as an anchoring agent [7]. However, the specific legislation on the architectural heritage does not allow the use of resin on historical and monumental buildings, but suggest the usage of special mortars [3].

Both fiber-reinforced plastics/polymers (FRP) [8–10] and textile-reinforced mortar (TRM) systems [11–14] have been successfully used for the strengthening of concrete members. The use of FRP has gained popularity due to the excellent performances such as light weight, high strength, corrosion resistance, fatigue resistance, etc. [15–18]. However, FRP has some disadvantages such as high costs, incompatibility with concrete surfaces, difficulty to apply on wet surfaces or low temperatures, and poor performance at high temperature. The latter is due to epoxy resins (bonding agents) used in FRP which lose their tensile capacity under high temperature [19,20]. In addition, epoxies have low compatibility with the concrete substrate [21] and can't be applied on wet surfaces or at low temperatures.

Cement-based grouts or mortars are commonly used in conventional steel strand ground anchors [22]. The last decade, an innovative cement-based composite material, the so-called TRM, identified in the literature also as TRC (textile-reinforced concrete)

* Corresponding authors.
E-mail addresses: lixianjun142232@sxu.edu.cn (X. Li), jianyinghao@tyust.edu.cn (J. Hao).

https://doi.org/10.1016/j.conbuildmat.2018.06.029
0950-0618/

[23–25], was introduced in the field of structural retrofitting as an alternative to FRP solution, addressing cost and durability issues [14,26]. TRM combines advanced fibres in form of textiles (with open-mesh configuration) with inorganic matrices, such as cement-based mortars. TRM is a relatively low cost, high strength, low weight, friendly for manual workers, corrosion resistance and fire resistance, and compatible to concrete and masonry substrates material which can be applied on wet surfaces or at low temperatures. The same material can also be found in the literature as the fiber reinforced cementitious mortar (FRCM) [27]. For the above reasons, using TRM will progressively become more attractive for the strengthening of existing concrete and masonry structures than the widely used FRP [28,29]. TRM system has been found to be a very promising solution. However, limited research is available for concrete and masonry structures with cement based anchoring agent.

It is undesirable for TRM to be used as anchoring agent due to the presence of textile/fiber in TRM. Early Wu [30] developed SF-type series of cement-based anchoring materials, and the practice showed that their properties met the requirements of anchorage engineering completely. Kang et al. [31] proposed a new kind of reinforcement system in deep underground coal mine, which was new type of hollow grouting cable, made of steel strands and cement slurry. The grouting cable was used by resin capsule. Rana et al. [32] studied co-relation between physico-mechanical and chemical properties of cement and resin capsules used in underground mines and pointed out cement capsules were the integral part of roof bolting in Indian coal mines. Contrafatto [3] and Wang et al. [33] reported structural adhesives for adhesive anchor systems included organic and inorganic anchoring agents. Organic anchoring agents were available pre-packaged in glass capsules, while inorganic anchor agents were cement, mortar and cementitious materials. Zhong [34] studied cement-based anchoring capsule, and these capsules had been applied to many anchoring engineerings in China.

Based on the authors' previous research [35,36], it is feasible for the ternary complex system to produce cement based anchoring capsule, as shown in Fig. 1. The ternary complex system consists of sulphoaluminate cement, aluminate cement and gypsum. The aim of this paper was to optimize mix design of super early strength anchoring material with the ternary complex system based on orthogonal experiments. Orthogonal experimental design technique was used to quantitatively evaluate the effects of various factors and their levels were selected based on the past researches. The method has been demonstrated to be a highly efficient, fast, and economical experimental design method in evaluating effects of various factors on the performance. In this method, the studied factors included ratio of sulphoaluminate cement and aluminate cement, dosage of lithium carbonate, dosage of sodium carbonate and dosage of dihydrate gypsum, and representative levels of factors having stronger effects to a property to be studied were selected based on Normalized Orthogonal Table L9 (3^4).

Fig. 1. Anchoring capsule.

2. Experimental

2.1. Orthogonal experimental design

Orthogonal experiment method is a kind of designing method to study many factors and levels. It conducts tests by selecting a suitable number of representative test cases from many test data, which have evenly dispersed, neat comparable characteristics [37]. The design of orthogonal experiment is based on the orthogonal table. The factors in orthogonal test are the parameters which influence the performance of anchoring material, while the level in orthogonal test means the maximum number of the values that can be taken on by any single factor. Consequently, orthogonal experiment was designed to optimize the preparation of anchoring material involving multivariate and multilevel factors.

The studied anchoring material (capsule) consisted of ternary complex system, early strength and procoagulant component. Therefore, ratio of sulphoaluminate cement and aluminate cement (A), dosage of lithium carbonate (B), dosage of sodium carbonate (C) and dosage of dihydrate gypsum (D) were set as four factors in the orthogonal experiment. The levels of each parameter were determined by selecting some typical values of parameters. Three levels of S/L ratio were 690 /210, 710/190, 730/170 (kg/t)/(kg/t). Three levels of lithium carbonate added were 0.46, 0.69 and 0.92 kg/t. Three levels of sodium carbonate added were 16.2, 19.8 and 23.4 kg/t. Three levels of dihydrate gypsum added were 115, 96 and 77 kg/t. These factors and their corresponding levels were shown in Table 1. The orthogonal table with four factors and three levels formed was shown in Table 2. According to the orthogonal experimental design table of L_9 (3^4), a total of 9 mixes (Table 2) were tested.

In order to study the results from orthogonal tests, the range analysis was utilized in this study. Range analysis is a statistical method to determine the factors' sensitivity to the experimental result according to the orthogonal experiment. Range is defined as the distance between the extreme values of the data. The greater the range is, the more sensitive the factor is [38]. The calculation process of range analysis was shown in Eqs. (1)–(3) [39].

$$k_{Xm} = K_{Xm}/3 \tag{1}$$

$$R_{0X} = max(k_{X1}, k_{X2}, k_{X3});\ R_{1X} = min(k_{X1}, k_{X2}, k_{X3}) \tag{2}$$

$$R = R_{0X} - R_{1X} \tag{3}$$

In Eq. (1), K_{Xm} and k_{Xm} respectively stand for the sum and the average value of the experimental results which contain the factor X with m level. In Eq. (3), R stands for the influence degree of the factor X. When R value is high, the influence degree of X is great as a result.

2.2. Experimental work

The anchoring capsule was prepared by a ternary complex system, early strength component and procoagulant component. The raw materials used in the experiment were displayed in Table 3. The cement used was rapid-setting sulphoaluminate cement (grade 42.5, marked S) and aluminate cement (grade 50, marked L) produced by Yangquan Special Cement Factory. The gypsum