Effect of Straw Fiber Content on Properties of Cement-Based Composite

Ji-wei Cai, Zhen Li, Si-jia Yan and Jing Li

ABSTRACT

Straw fiber is a natural polymer material to be utilized fully. Samples of cement-based straw fiber composite were prepared with portland cement and straw fiber pretreated in lye then rinsed and dried. Effects of length and content of straw fiber on properties of cement-based composite were studied by testing their apparent density, water absorption, softening coefficient, flexural strength and compressive strength. Results reveal that overall performance of cement-based composite with short fiber is better than that with long fiber. With increasing content of straw fiber, flexural strength and compressive strength of the cement-based composite decrease gradually, on the contrary, apparent density and water absorption increase gradually, and ratio of flexural strength to compressive strength at 7d decreases more obviously than that at 28d. If the content of straw fiber is limited to not more than 15wt% of cement, the composite can be used as lightweight wall material with reasonable properties.

INTRODUCTION

Straws are wastes generated during harvest of crops including rice, cotton, wheat, corn, soybean and other crop straws [1-2]. Straw materials featuring in light bulk density, short generation cycle, are economical and environmental building materials [3]. There are abundant resources and many different kinds of crops in large area in China [4]. Over the years, Crop straws in China were mainly used in daily life of rural fuel, animal feed, soil fertilizer, etc. With advance of the rural economy and the development of science and technology, coal, oil, gas, electricity and other energy commodities gradually engage into people's lives, so that composition of energy resource for rural life has changed, at the same time, the utilization of crop straw is different from the traditional way. In recent years, straw methane, straw gasification and growing edible fungus in straw have set up in many areas in China, also utilized straw as energy resource [5-6]. Even so, the use of straw consumption is still very low [7]. A great quantity of straw materials can’t be effectively and reasonably used. Burning and discard of straw, not only waste resources, but also seriously pollute the environment. Utilization of straw in production of cement-based composite can not...
only change wastes into valuables, reduce a series of safety and environmental problems caused by straw burning, but also alleviate the problem of high energy consumption of rural area construction [8]. Straw fiber is a natural polymer material. The research on full use of the advantages and potential of plant fibers has become one of the hot interests.

EXPERIMENTAL

Material. 1) Ordinary Portland cement (P·O 42.5) with physical and mechanical properties as shown in Table 1.

| Type  | Density [g/cm³] | Specific surface area [m²/kg] | Soundness     | Flexural strength [MPa] | Compressive strength [MPa] |
|-------|----------------|-------------------------------|---------------|--------------------------|----------------------------|
| P·O   | 3.05           | 364                           | Qualified     | 4.6                      | 9.8                        |
|       |                |                               |               | 18.9                     | 53.6                       |

2) Straw fiber made of wheat straw from suburb of Kaifeng city, Henan province. The chemical compositions of straw fiber are listed in Table 2.

| Moisture | Ash content | Pentosan | Lignin | Cellulose | Extractive in solution of Cold water [g/l] | Extractive in solution of Hot water [g/l] | Aether [g/l] | Benzene-alcohol [g/l] | 1%NaOH [g/l] |
|----------|-------------|----------|--------|-----------|-------------------------------------------|--------------------------------------------|-------------|------------------------|--------------|
| 7.73     | 4.62        | 25.13    | 18.14  | 42.78     | 6.47                                      | 10.02                                      | 0.80        | 1.62                   | 33.60        |

3) Dipper (alkaline) containing 99.0% of NaOH.

Method. In the two groups, the wheat straw fiber used in the experiment was pretreated with 4% NaOH solution for 12 h, then rinsed and dried. Samples of Group A were prepared with straw fiber with different length but in same water-to-cement ratio (w/c) and straw fiber-to-cement ratio (s/c). Samples of Group B were designed in different s/c on the basis of experimental results of group A.

RESULTS AND DISCUSSION

Effect of Straw Fiber Length on Properties of Cement-Based Composite. The mix proportion and experimental results are shown in Table 3. The compressive strength \( f_c \) and flexural strength \( f_f \) of cement-based straw fiber composite, and the ratio between them \( f_f/f_c \) are shown in Fig. 1.

| Table 3. Mix proportion of composites with different length of fiber. |
|---------------------------------------------------------------|
| No | Fiber length | w/c | s/c | Cement [g] | Straw fiber [g] | Water [g] | Apparent density [kg/m³] | Water absorption [%] |
|----|--------------|-----|-----|------------|----------------|------------|-------------------------|---------------------|
| A1 | Short        | 0.60| 0.15| 1300       | 195           | 780        | 878                    | 47.18               |
| A2 | Long         | 0.60| 0.15| 1300       | 195           | 780        | 973                    | 23.21               |
Fig. 1 indicates that fiber length can only promote 7d flexural strength of the composite. In other case, shorter fiber is better for mechanical properties of cement-based straw fiber composite.

Compared with long fiber, short fiber is relatively loose to bring more volume that results in less mass per unit volume, i.e., short fiber per unit mass occupies more space in the cement-based composite. The space in the composite formed by straw fiber is the decisive factor affecting apparent density, so apparent density of short fiber composite is smaller. Homogeneous distribution of short fiber leads to uniformity of cement-based composite. After absorbed water evaporated, there left a lot of tiny pores inside composite. Water absorption of the composite with short fiber is far greater than that with the long one, this reveals that the porosity in composite with short fiber is much higher than that with long fiber.

In Fig. 1, it can be found that, as curing age increases, flexural strength ($f_f$) and compressive strength ($f_c$) of cement-based composite with both kinds of fiber tend to rise, but uniformity of cement-based composite prepared with short fiber is better. With bigger value of length-to-diameter ratio of long fiber, advantageous effect of long fiber on strength at early age is very obvious owing to better toughness of the composite. This can be confirmed by the ratio of flexural strength to compressive strength ($f_f/f_c$), e.g., $f_f/f_c$ of long fiber composite at different ages is higher than that of short fiber composite. This shows that the fracture toughness of cement-based composite with long fiber is better.

Effect of Straw Fiber Content on Properties of Cement-Based Composite. The samples of cement-based composite with pretreated straw fiber were prepared in w/c=0.60 but in different straw fiber-to-cement ratio (s/c). Their mix proportion and experimental results are shown in Table 4 and Fig 2.

| No | w/c | s/c | Cement [g] | Straw fiber [g] | Water [g] | Apparent density [kg/m³] | Water absorption [%] | Softening coefficient |
|----|-----|-----|------------|----------------|-----------|------------------------|---------------------|----------------------|
| B1 | 0.60 | 0.05 | 1300       | 65            | 780       | 1316                  | 8.73                | 0.80                 |
| B2 | 0.60 | 0.10 | 1300       | 130           | 780       | 1070                  | 28.92               | 0.71                 |
| B3 | 0.60 | 0.15 | 1300       | 195           | 780       | 878                   | 47.18               | 0.59                 |
| B4 | 0.60 | 0.20 | 1300       | 260           | 780       | 765                   | 57.43               | 0.45                 |

With increasing content of straw fiber, apparent density and softening coefficient of the cement-based composite gradually decreased but water absorption increased.
gradually. In the composite, density of straw fiber is far less than other constituents; however the volume proportion formed by fiber is much higher. So, apparent density of cement-based straw fiber composite is controlled by the content of straw fiber. The shape of straw fiber is extremely irregular and the fiber contains a large number of voids. In addition, water absorption of straw fiber is very high. Straw fiber dominated for water demand of the composite because of its water absorption, and its dominant position becomes more and more prominent with increasing content of straw fiber. In the process of curing, moisture absorbed by straw fiber will gradually evaporate and form a lot of pores in the cement-based composite. The porosity inside the composite is proportional to the content of straw fiber.

Expansion pressure caused by straw fiber absorbed water, to some extent, results in certain destruction to hardened cement paste, so that flexural strength ($f_f$) and compressive strength ($f_c$) of the composite decreases significantly. It can be deduced that the cement-based straw fiber composite is not suitable for use in wet condition.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fiber_content.png}
\caption{Effect of fiber content on mechanical properties of cement-based composite.}
\end{figure}

Fig. 2 shows that flexural strength ($f_f$) and compressive strength ($f_c$) of cement-based composite at 7d and 28d decreases with increasing content of straw fiber, the strength of the cement-based composite with 5% straw fiber content is 4~6 times of that with more than 15% straw fiber. Therefore, it can be deduced that straw fiber content is one of the key factors that affect the properties of cement-based composite.

After pretreatment with 4% NaOH solution, rough surface of straw fiber leads to improvement of binding to the paste. With less content of straw fiber, the hydration products of cement may fully contact with the surface of straw fiber. The packing effect is more obvious for less straw fiber and the strength of cement-based composite was mainly provided by hydration products of cement that build binding between cement paste and straw fiber. So the strength of cement-based composite with 5% straw fiber is higher than those with more straw fiber. With increasing content of straw fiber, the volume proportion of straw fiber in the cement-based composite gradually increases, contrarily, volume of paste reduces then binding between cement paste and straw fiber will also be weakened.

In order to show further effect of straw fiber content on mechanical properties of the cement-based composite, the ratio of flexural strength to compressive strength ($f_f/f_c$) of the composite with different content of straw fiber is diagramed as shown in Fig. 3.
Fig. 3 shows that, $f_{f}/f_{c}$ of the cement-based composite at 7d is inversely proportional to the content of straw fiber, however decrement of $f_{f}/f_{c}$ of the composite at 28d is relatively slow. Fig. 3 indicates that influence of straw fiber content on flexural strength of cement-based composite is more significant than on compressive strength of the composite. With increasing content of straw fiber, early flexural strength decreases much more than early compressive strength. So, the upper limit of s/c is proposed to be 0.15, so that cement-based straw fiber composite is endowed with reasonable properties as a kind of lightweight wall materials.

CONCLUSION

Through experimental results and analysis, it is concluded that

1) In terms of overall physical and mechanical properties of cement-based composite, short fiber composite is superior to long fiber composite.

2) Apparent density of cement-based composite is inversely proportional to the content of straw fiber, and water absorption is proportional to the ratio of the content of straw fiber. Therefore, this kind of composite is not suitable for use in wet condition.

3) Flexural strength and compressive strength of the cement-based composite decrease with the increment of straw fiber content. However, the effect of straw fiber content on the strength of cement-based composite at 7d is greater than that at 28d.

4) If the content of straw fiber is not more than 15wt% of cement, the composite can be used as lightweight wall material with reasonable properties.

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