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Splitting Tensile Strength of Ordinary Portland Cement Mortar Reinforced with Nanofibrillated Cellulose

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Abstract— **Concrete is the most widely use material in the world. However the emission from the production of cement has caused a significant issue to this planet. Researchers have looked for methods to use as less cement as possible while in the meantime to achieve good mechanical performance. Natural fibers have been a feasible approach since they are environmental friendly and also can potentially improve the mechanical properties of cemenitious materials. Most recently, efforts have been devoted to the microscopic level in an attempt to modify the microstructures of cement composites. With this fundamental enhancement, the performance at the large scale may be improved. This present work utilized nanofibrillated cellulose to increase the splitting tensile strength cement mortar and it is found that the strength may be increased by up to 21% with only a nanofibrillated cellulose/cement weight ratio of 0.004. This improvement is attributed to the increase in degree of hydration, and also possibly the fiber bridging.**

Index Terms— **ordinary portland cement, mortar, splitting tensile strength, nanofibrillated cellulose**

1) INTRODUCTION

Concrete has been the most widely used material in the world for a long history, mainly because its low cost and relatively high strength [1, 2]. However, associated with the manufacturing of cements is the huge amount of carbon dioxide release [3]. In the current context of climate change caused by carbon dioxide emissions worldwide, leading to a rise in the sea level and other negative influences. In order to achieve a more sustainable construction industry, the European Union established that in a medium term raw materials consumption must be reduced by 30% and that waste production in this sector must be cut down by 40%. The use of renewable resources by the construction industry will help to achieve a more sustainable consumption pattern of building materials. Concrete is known for its high compressive strength and low tensile strength [1]. The combined use of regular concrete and steel reinforced bars is needed to overcome that disadvantage leading to a material with good compressive and tensile strengths but also with a long post-crack deformation (strain softening). Unfortunately reinforced concrete has a high permeability that allows water and other aggressive elements to penetrate, leading to carbonation and chloride ion attack resulting in corrosion problems [4].

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Natural fibers are a renewable resource and are available almost all over the world [5]. They are cost-effective and environmental friendly. Therefore, to promote the use of cementitious building materials reinforced with natural fibers could be a way to achieve a more sustainable construction [6]. Cellulose fibers have been used in cementitious materials for a long time and they are found to be able to improve mechanical properties [7]. Lately the reinforcement in cementitious materials has been scaling down to the nano level. A notable example is the use of carbon nanotubes by various groups [8-10]. Great improvements in mechanical properties were found with this reinforcement at nano level. However, carbon nanotubes have a great deal of health and environmental issues [11]. Very recently, among the trends of employing nanomaterials to modify the microstructures, nanocellulose, i.e., nanofibrillated cellulose (NFC) and cellulose nanocrystal have been added into cement matrix to improve the mechanical behavior [12-16]. It was found that the compressive strengths and flexural strengths can be largely increased with adding the nanocellulose. The most important reason may be the increase in degree of hydration (DOH).

So far the tensile behavior of cement mortars with NFC has not been investigated. For the first time, this paper is aimed at evaluating the potential of using NFC to reinforce cement mortars in an attempt to improve its splitting tensile strength (STS).

2) EXPERIMENTAL DESIGN

OPC Type I was used; The NFC was obtained from Forest Products Laboratory, US. with nominal fiber width of 50 nm and lengths of up to several hundred μm, 31-33 m^2/g (BET), 1.5 g/cm^3 dry powder. The water reducing agent was ADVA® 181 from GCP Applied Technologies Inc.. The mortar preparation conforms to ASTM C305. The experimental design is given in Table 1. In the sample ID, L denotes low w/c ratio of 0.42 and H for high w/c ratio 0.5; the number indicates the amount of NFC. The weight ratio of fine aggregate and cement is fixed at 2.5.

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Table 1. Experimental design of the mortars

Sample ID	NFC/c	WRA/c	w/c
L01	0.001	0.01	0.42
L04	0.004		
L08	0.008		
L16	0.016		
H01	0.001	0	0.5
H04	0.004		
H08	0.008		
H16	0.016		

The slump test follows the method described in ASTM C143. After mixing, the samples were cast into 10cm cylinder (diameter 5cm). The molds were sealed until testing. To determine the influence of NFC on the hydration of mortar, thermogravimetric analysis (TGA) was performed with a TGA 2 SF from Mettler-Toledo. The procedures follow the literatures [17, 18]. The STS were measured with an MTS universal testing machine.

3) Results

3.1. Slump

The slump of the mixtures at w/c ratio of 0.42 (L) and 0.5 (H) are presented in Fig. 1. The slump is generally lower for the L group, indicating a lower workability, even when the WRA was used. The slump is slightly increased when a small amount of NFC (NFC/C = 0.001) was used. This result seems similar with the finding provided in the reference that [18] with small loading of CNC, the yield stress of the cement paste is decreased. As proposed, this increased slump originates from the mechanism steric stabilization. The NFC particles adhere onto the cements and separate them from agglomeration, in this way the cement particles are more mobile and therefore resulting a better workability. With increasing NFC amount, the slump considerably decreases, as a result of the agglomeration of the NFCs. This is a well-known phenomenon in cement mixing that the fillers are not well dispersed leading to a lowered workability [19].

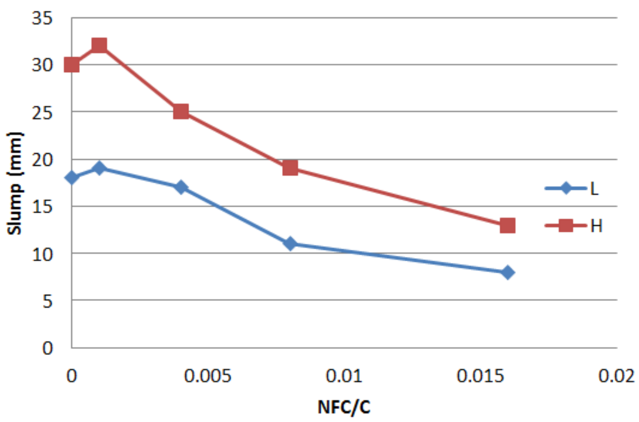


Fig. 1. The slump of the mortars with different amounts of NFC

3.2. Yield stress

Yield stress of the mortars were determined as another quantitative measure to assess the influence of the NFCs on the workability [20], as shown in Fig. 2. This result in high consistency with the slump data described ealirlier, that the yield stress is decreased with a small amount of NFCs (NFC/C = 0.001) and then increased significantly with higher loadings. This confirms that the NFCs slightly increase the workability of the mortars as a result of the mechanism of steric stabilization while negatively affect the workability due at high loadings due to agglomeration.

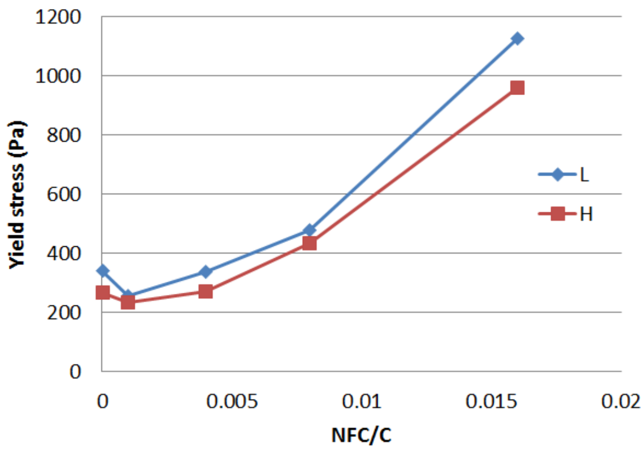
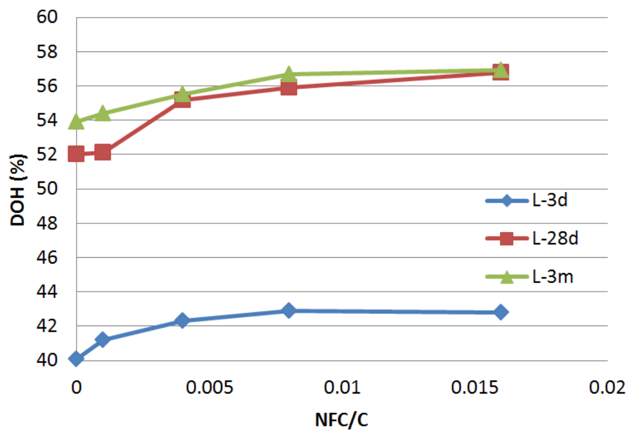


Fig. 2. The yield stress of the mortars with different amounts of NFC

3.3. TGA

For cement pastes, it was reported that CNCs and NFCs are able to increase DOH. In this work, the DOH of the mortars is measured with TGA to study this effect. The TGA data are presented in Fig. 3. As expected, with higher amount of water, the DOH is increased. The maximum DOH is about 57% compared with 59% in Fig. 3 (b). With increasing NFC loading, the DOH values are consistently increased. For example, in Fig. 3 (a) series L-28d, the DOH was increased from 52% to 57% with NFC/C = 0.016. This is because of the effects of steric stabilization and SCD, among which SCD plays a more dominating role. This is an important indication that not only in cement paste, but also in mortars, the NFCs can enhance the DOH. This suggests that the NFC particles are still tightly adhered onto the cement particles [21].



(a)

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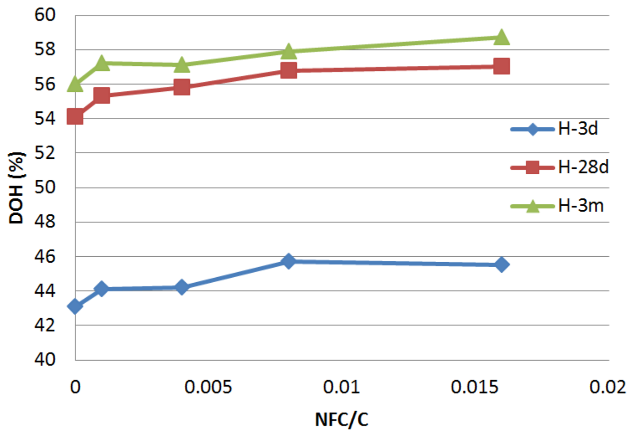
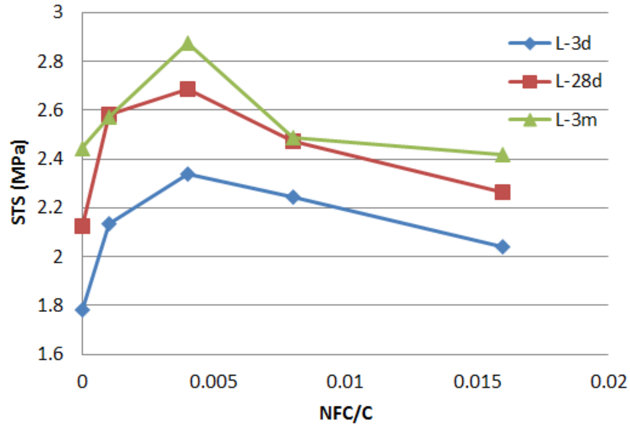


(b)

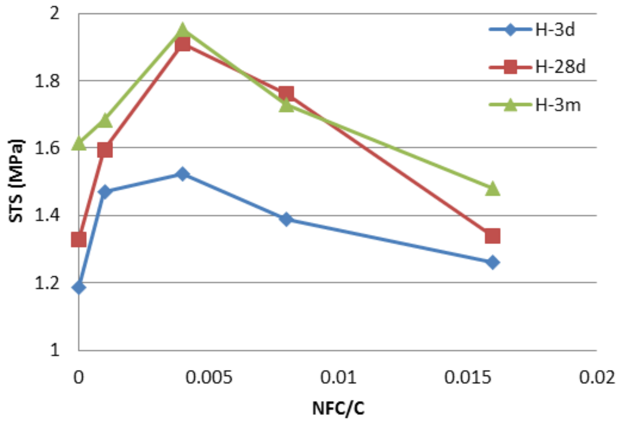
Fig. 3. The DOH with increasing NFC amount for mortars with w/c ratio of (a) 0.42 and (b) 0.5

3.4. STS

The STS were measured at three different ages: 3 days, 28 days and 3 months for the two series of mortars. The results are given in Fig. 4. As expected, the STS are generally lower with higher w/c ratio because of larger amount of pores. It seems that for both mortars with w/c ratios of 0.42 and 0.5 the maximum STS were obtain at the NFC loading of NFC/C= 0.004. A contributing mechanism may be the improved DOH that results in few pores. Another mechanism that is partly responsible for this improvement in mechanical properties may be the well-known “fiber bridging” that the NFCs bridge cracks and prevent them from further growing. This is very different from CNCs because CNCs do not have sufficient length to bridge cracks while NFCs used in this work have lengths ~ several hundred µm that are adequate to do this job. However, this mechanism will need further experimental evidence, such as microscopic images to confirm. Beyond the loading of NFC/C= 0.004, the STS decreases because of the agglomeration of NFCs resulting in stress concentrators in the samples [22]. These stress concentrators lead to premature failure that are detrimental to the mechanical performance of the mortars. As a result it is necessary to disperse the NFCs well before use. Otherwise it is not suggested to use a large amount of NFCs as reinforcement. It is noteworthy that based on previous slump and yield stress results, the agglomeration was observed at NFC/C= 0.004, however the peak STS here were found at NFC/C= 0.004, which suggests that the strengthening from DOH improvement and (possibly) fiber bridging may be more more dominating than the negative influence of agglomeration. At the age of 3 months, the maximum STS are 2.88 and 1.95 MPa for the mortars with w/c ratio of 0.42 and 0.5, improved by 18% and 21%, respectively. This considerable improvement is a great benefit for engineering applications.



(a)



(b)

Fig. 4. the relationship between STS and NFC amount at different ages for the mortars with w/c of (a) 0.42 and (b) 0.5

4) Conclusions

In the present work, the OPC mortars were prepared with NFCs as a reinforcement. The splitting tensile strengths were measured to assess the possible improvement of NFCs on the mechanical performance of the mortars. It was found that the workability of the mortars was slightly increased with small amount of NFCs due to steric stabilization. With larger amount of NFCs the workability gets worse as a result of the agglomeration of NFCs. The TGA studies indicate that the DOH was consistently increased with adding NFCs, which were mainly attributable to the SCD mechanism resulting from the hydrophilic nature of NFCs. The peak STS were reached with NFC/C=0.004, and the values decrease with further increasing NFC loadings due to agglomeration. The improvements are 18% and 21% for the w/c=0.42 and w/c=0.5 mortars respectively. This enhancement is believed to be a result of the improved DOH and also possibly, the fiber-bridging mechanism.

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