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Bonding performance of nylon tire cord yarns in fine grained concrete

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Abstract

The performance of bonding between Nylon tire cord grad yarns, and one kind of cement composite called fine grained concrete was studied. The durability of two kinds of Nylon cord yarns, nylon 6 and 66, with different finesse with time in alkaline media was investigated. Meanwhile the effect of usual tire cord coating on bonding performance and alkaline durability of yarns were studied by mechanical testing and SEM images. Then the bonding of these yarns to cement paste and the effects of finesse on bonding performance were investigated by pull out tests. The results show that coating could enhance alkaline durability. Results also show that yarns with higher finesse are more sensitive to alkaline media and their mechanical properties reduced more. SEM images show that in general, alkali damage of Nylon tire cord yarns was not deep and no significant changes were observed on the surface of filaments after exposed to alkali. The bonding of Nylon tire cord to cement composite was suitable and little slippage was observed. The pull out behavior of finer yarns is better than coarse yarns. Meanwhile tire cord coating could enhance bonding of yarns to cement paste.

Keywords: *Nylon tire cord yarns, Pull out, Fine grained concrete, TRC, Cement composites.*

1. Introduction

Concrete is the most heavily used construction material in the world. However, it has low tensile strength, low ductility and low energy absorption. An intrinsic cause of the poor tensile behavior of concrete is its low toughness and the presence of defects. Therefore, improving concrete toughness and reducing the size and the amount of defects in concrete would lead to better concrete performance. Some researches show that one of the effective ways to improve the toughness of concrete is adding a small fraction (usually 0.5–2% by volume) of the short fibers to the concrete during mixing [1-4]. But in spite of several advantages in adding short fibers to concrete there are some limitations, for example they do not highly improve the compressive and bending strength [5].

Textile reinforced concrete (TRC) is a relatively new class of cement based composites which has concerned in recent years [6-9]. TRC is a composite consist of fine grained concrete as a matrix and a textile fabric as a reinforcement which is used in the field of civil engineering for the fabrication of new structural elements and the strengthening of existing constructions [9].

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In contradiction to short fiber reinforced concrete, the TRC reinforcement is a textile structure made of continuous roving or yarns [8-10].

A roving is a bundle of several hundred filaments which act as a tensile reinforcement in the brittle concrete [8]. One of the biggest advantages of TRC is the quasi-ductile behavior after matrix cracking which is crucial with regards to structural safety as well as energy dissipation [11]. It was found that the flexural strength and toughness of the composite increased significantly with woven fabric reinforcement even if the fabric was made of low modulus yarns [12].

There are several fiber types that can be used for TRC composites. Some fibers have hydrophilic characteristics similar to cement, such as polyvinyl alcohol (PVA), Nylon or Acrylic, which causes chemical reaction between functional groups and therefore develop good bonding with cement matrices [13]. On the other hand, it is also possible to use hydrophobic fibers such as polypropylene (PP) or polyethylene (PE) which have relatively poor bonding with cement matrices [14-15]. However, they are often economical fibers with good resistance to the alkaline environment of the cement paste, thus it can be attractive for cement applications.

Research found that bonding between fiber and concrete is an important factor in performance of composites. In general the so-called pull-out test is widely accepted as an experimental technique to determine the basic shear bond characteristics between a single monolithic reinforcing element, such as a rebar or fiber, with its surrounding matrix [16]. So, several researchers have studied the bond characteristics of PP fiber–cement systems using analytical and experimental techniques to improve bonding of PP or other hydrophobic fibers to concrete [12, 17-21]. But the bonding of PP polymeric fibers with cement-based systems is relatively poor, which has limited the use of these ductile fibers.

Peled at. al (2000) found that bond tended to increase with the increase in the modulus of elasticity of a single yarn, so some techniques were performed on the Nylon yarn to improve the bond strength. The results show that single twisted Nylon yarn has a better interfacial bond than twisting together of two Nylon yarns and than straight yarn which is due to the anchoring effect [22]. Although, Nylon fibers have suitable functional groups that can bond to cement but these groups in Nylon fibers will be hydrolyzed in alkaline media. There are not significant researches about Nylon performance in cement composite or improving alkaline durability of Nylon in cement paste.

Nylon tire cord yarn has much higher tensile strength than regular nylons. In this work the bonding performance of multifilament Nylon yarn used in tire cord industry and cement matrix was investigated and the effect of yarn diameter, the number of filaments in yarn and surface coating on the bonding performance was experimentally studied by pull out tests. Another polymeric yarn that can be used in cement composites is Nylon yarn. In general Nylon yarns have low performance in alkaline media, and regular Nylon with low modulus of elasticity is not proper for using in reinforcing concrete. So in this research the mechanical properties and durability of tire cord Nylon yarns and coating which is used as cover on it in alkaline media was investigated and the effect of finesse of yarns on the alkaline durability in cement matrix and bonding performance were studied.

2. Experimental

2.1. Materials

Nylon yarns were in a multifilament form with circular cross section supplied from Saba Company. The diameter of the individual filament was measured by the microscope and was 25 micrometer. The diameter of the bundle was calculated 0.18 mm^2 and 0.36 mm^2 respectively for 213 and 430 tex yarns. Tex is the weight of 1000 m of yarn in grams. So the 213 tex yarn is finer than 430 tex yarn. The coding system for used Nylon yarns in this research is shown in Table 1.

Table 1 Coding of samples

Yarn samples		Sample code
Nylon 6	213 tex	1A
Nylon 6	430 tex	1B
Nylon 66	213 tex	2A
Nylon 66	430 tex	2B
Nylon 66	213 tex (coated)	2AC
Nylon 66	430 tex (coated)	2BC

Coated yarns supplied from Saba tire cord co. and consist of usual RFL (resorcinol-formaldehyde-latex) coating mixture applied commercially to tire cord Nylon yarns. Calcium hydrate, sodium hydroxide and potassium hydroxide are all in analytical grad supplied from Merck Co., Portland cement type II and sand with maximum size of 2.36 mm with continuous grading according to ASTM D75 were used in this research.

2.2. Methods

2.2.1. Sample preparation

The mixing design consist of 700 Kg/m^3 Portland cement type II, sand/cement ratio was equal to 3, water/cement ratio (W/C) equal to 0.4 and the amount of super plasticizer is 0.5% of cement weight. The prepared concrete was poured into the mold which had interned dimensions of 200 mm length, 50 mm width and 25 mm thickness. The yarn was placed in the middle thickness of mold along the length of mold according to figure 1. Embedded length of yarns was 200 mm. All specimens were put out of mold after 1 day and then kept continuously in water until tested at age of 28 days.

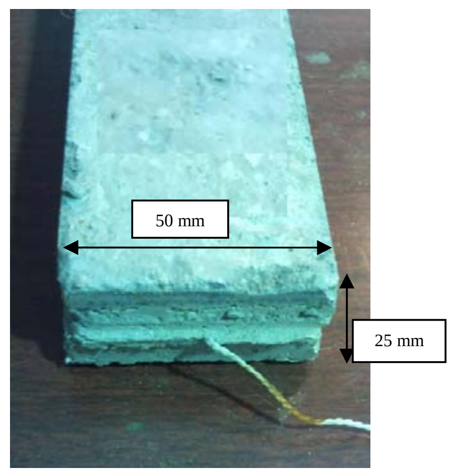


Fig. 1 Prepared sample cross section (25×50 mm) with 200 mm length

2.2.2. Alkali resistance test

To investigate durability of yarns in cement media, alkali resistance test was performed. The alkaline solution should be a composition representative of the Portland-cement concrete. The suggested composition of alkaline solution according to ACI 440.3R [23] consists of 118.5g of $Ca(OH)_2$, 0.9g of NaOH, and 4.2g of KOH in 1L of de-ionized water. The solution has a pH value of 12.6 to 13, a representative pH value of concrete media. The alkaline solution should be covered before and during test to prevent interaction with atmospheric CO_2 and to prevent evaporation for exposure times. The yarns with 30 cm length were immersed in that solution in a 250 ml closed container and maintained for 28, 56 and 84 days. Because the volume of yarns is much lower than the volume of alkali solution, final pH is equal to initial pH. Each experiment was repeated three times.

2.2.3. Microscopic analysis

The scanning electron microscope (SEM) micrographs of Nylon yarns before and after alkaline test were investigated by SEM XL30. For SEM characterization the specimens were dried and coated by gold.

2.2.4. Pullout test

The pullout tests were carried out with Instron testing machine (CRE) at a crosshead rate of 2 mm/min. Schematic descriptions of the test set-up were presented in figure 2. In all cases, a 100 mm free length (gauge length), of the multifilament, was between the cement matrix and grips and load–displacement curves were recorded. In all tests the yarn was anchored in upper end with special claps and resin and marks have been placed on yarn for controlling that no slippage would happen in the upper end. Movement of the claps is monitored with instruments.

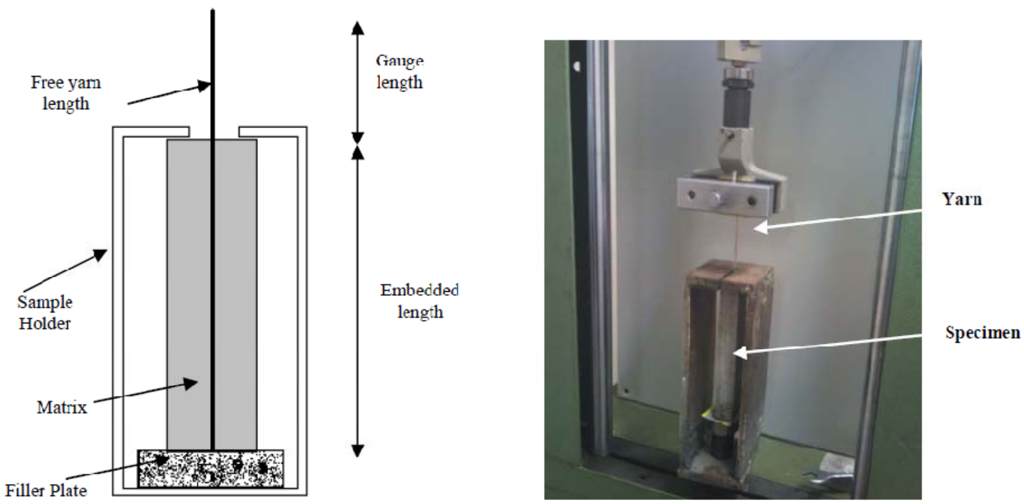


Fig. 2 The set up of pull out test

The test results are an average of at least three specimens.

The stress of pull out calculated as follows:

$$\text{Stress}=\frac{Pullout\,load}{yarn\,area}\Rightarrow \quad \sigma=\frac{P_{max}}{A}$$

$$A=\frac{Tex}{\rho.l}\times 100$$

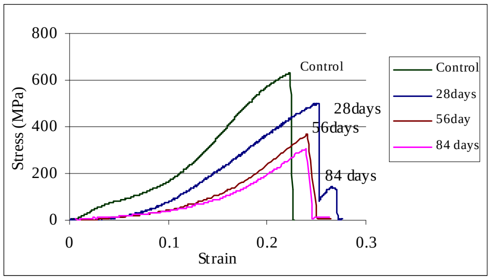
Where σ is pull out stress in MPa , P_{max} is the pull out load in N, A is the area of yarn in mm^2, tex is the mass per length of yarn in grams, ρ is density of Nylon in g/cm^3 and l is the length of yarn in cm.

Nylon yarn is hydrolyzed in alkaline solution and the strength of yarn decreases. In order to calculate the amount of slippage of Nylon yarn in concrete sample, the results of pull out test is compared with the tensile test of the Nylon yarn which had been in alkaline solution for 28 days.

3. Results and Discussions

3.1. Alkali resistance

Alkali resistance of Nylon yarns with different finesse was investigated with time and shown in figure 3.



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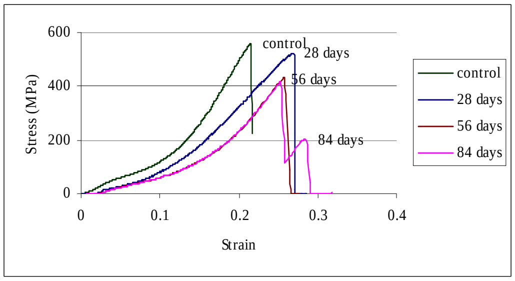

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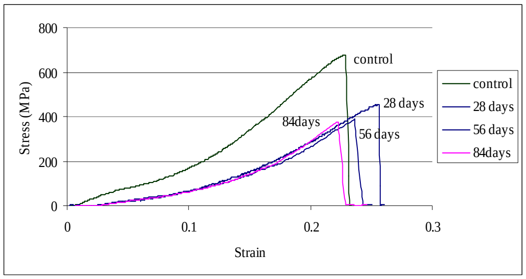

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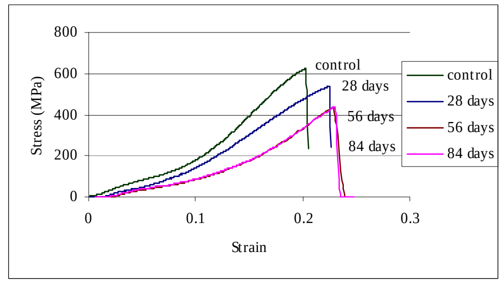

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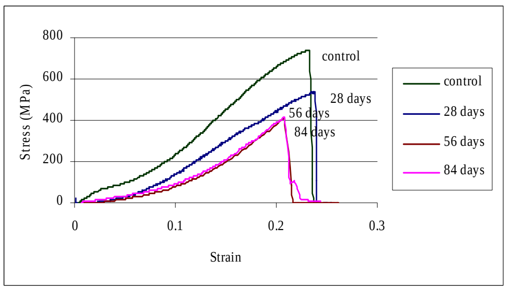
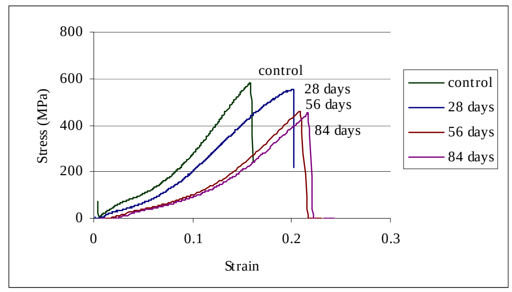


(e)



(f)

Fig. 3 Alkali resistance of Nylon yarns for different types after 28, 56 and 84 days (a) 1A, (b) 1B, (c) 2A, (d) 2B (e) 2AC, (f) 2BC

In figure 3a the alkali durability of Nylon 1A was studied. In which the mechanical behavior of Nylon yarns that have not been immersed in alkaline media (a control sample) and yarns that have been immersed in alkaline media for 28, 56 and 84 days are compared. According to this figure, by increasing the time, the strength of yarn was decreased. Figure 4 presents the decreasing percentage of Nylon strength in alkali solution. As it can be seen, by increasing the time the drop percentage of yarns were increased dramatically. So this type of yarn is not suitable for applying in cement composites. Also the amounts of stress and strain of yarn are summarized in Table 2. The results showed that after 28 exposures to alkali media, the strain reach to a constant value of about 0.24, however the strength decreases continuously. All the results are the mean value of at least three samples.

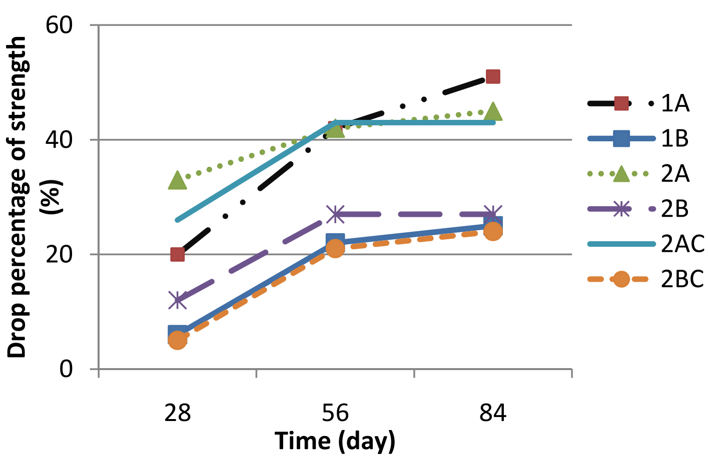


Fig. 4 Drop percentage in strength of Nylon yarn in alkali solution

Table 2 Alkaline resistance of Nylon yarn

Yarn	Stress (MPa)				strain			
	Control	28 days	56 days	84 days	Control	28 days	56 days	84 days
1A	633	502	368	308	0.22	0.24	0.24	0.24
1B	558	521	433	415	0.21	0.27	0.26	0.25
2A	676	452	389	369	0.22	0.25	0.23	0.22
2B	607	532	438	438	0.20	0.22	0.22	0.22
2AC	739	542	416	416	0.23	0.23	0.20	0.20
2BC	582	554	459	442	0.15	0.20	0.20	0.21

In figure 3b the mechanical behavior of Nylon 1B was shown. As can be seen, by increasing the time the stress was decreased but this decreasing is not sharp after 28 days. After 56 days the speed of stress reduction decreased significantly and after 84 days the speed of this decreasing was deducted. The drop percentage of this yarn (Fig. 4) show that drop percentages of this yarn is lower than Nylon 1A. So by decreasing the fineness, from 213 to 430 tex, the amount of alkali damage for this type of Nylon was decreased. Due to the 430 and 213 tex yarns both have made up similar filaments with same characteristics and diameter, this lower decreasing in stress can be related to higher count of filaments existence in 430 tex yarn than 213 tex yarn so penetrating of alkaline solution became harder. Meanwhile external filaments are in contact with alkali and therefore are in exposure of alkaline hydrolyzing, whereas the internal filaments (core filaments) are relatively protected, and they interact and transfer stresses through their surface contacts. The schematic picture of finer yarn (213 tex) and coarser yarn (430 tex) are shown in Fig 5.

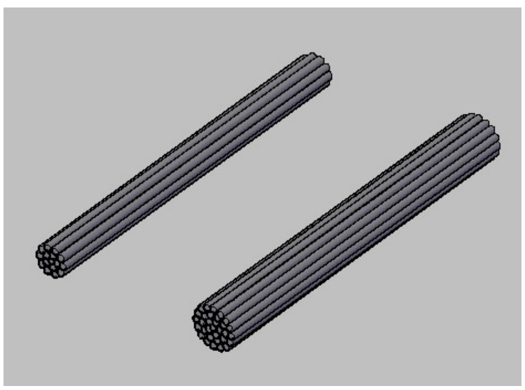


Fig. 5 Schematic diagram of Nylon yarns with 213 and 430 tex

In figure 3c the mechanical behavior of Nylon 2A was shown. According to this figure by increasing the time the strength of yarns exposed to alkaline media were decreased so rapidly. But the mechanical properties of this Nylon were not dropped significantly after 28 days. Also drop percentages of Nylon 2A and 1A (Fig. 4) show that till 56 days Nylon 1A has a higher resistance in alkali media but after that Nylon 2A which is Nylon 66 has a lower drops in strength. So, Nylon 2A has a better performance in long terms of exposure in alkali media, compared to Nylon 1A which is Nylon 6.

In figure 3d the mechanical behavior of Nylon 2B was shown. As can be seen from this figure, by increasing the time that the yarns exposed to alkaline media the strength of yarns were decreased but after 56 days the speed of stress reduction decreased significantly and after 84 days the speed of this decreasing was deducted. Drop percentage of this Nylon show that this Nylon type has fewer drops after 28 days compared to 1B samples (Fig. 4). Also similar to Nylon 2A the mechanical properties of this Nylon type were not dropped after 56 days. According to Table 2, Nylon 2B has a strain of 0.20, and this is not changed significantly in long term exposure to alkali solution.

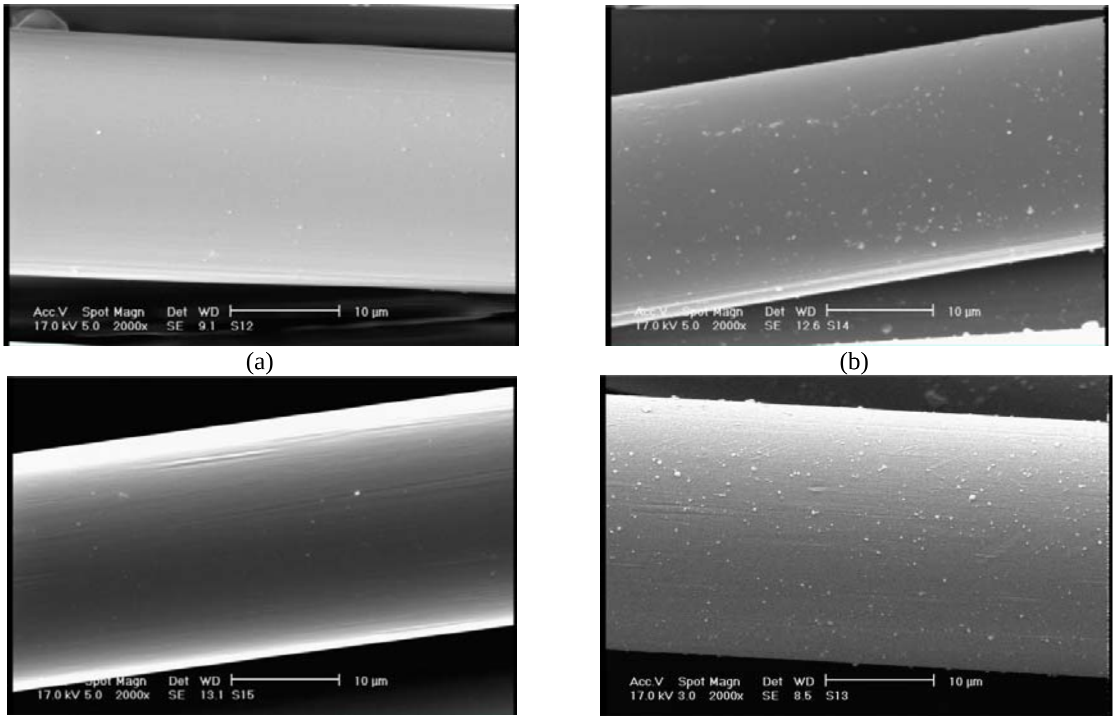
In figure 3e the mechanical behavior of Nylon 2AC was shown. As can be seen, by increasing the time that the yarns were exposed to alkaline media, the strength of yarns was decreased. But after 56 days the speed of decreasing was deducted. According to drop percentages in strength (Fig. 4), Nylon 2AC has a lower drop in strength compared to Nylon 2A (in 28 days), so the coating could enhance alkali durability but after 56 days strength drop percentage of both 2A and 2AC become similar. So the effect of this coating will be reduced in long term exposure.

In figure 3f the mechanical behavior of Nylon 2BC was shown. As can be seen from this figure, by increasing the time that the yarns were exposed to alkaline media the strength of yarns was decreased. But after 56 days the speed of decreasing levels off. According to Fig. 4, Nylon 2BC has the less amounts of drop in strength compared to the yarns investigated above. Also comparison between Nylon 2B and Nylon 2BC indicated that a coating applied to yarn was effective and has lowered the amounts of drop in strength.

The results of coated Nylons show that, tire cord coating reduces the speed of alkali corrosion and this is similar for both fine and coarse yarns. But this effect in preventing of alkali corrosion will be reduced with time (2A become similar to 2AC in 56 days, however, 2B become similar to 2BC in 84 days). Because Nylon with higher finesse absorbs more alkali solution compared to coarse yarns and this phenomenon may be due to higher special area of fine yarn so the speed of alkali sorption and coating resolving is higher than the coarse yarn.

3.2. Microscopic analysis

The results of alkali test show that Nylon with higher finesse has much higher drop in strength due to alkaline corrosion. So, SEM images of the surface morphology of 213 tex (finer) yarn before and after exposure to alkaline media was shown in figure 6.



(a) (b)

(c) (d)

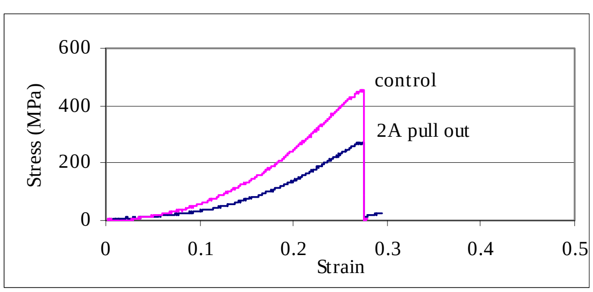
Fig. 6 SEM images of yarns after exposure to alkaline media for 28 days 1A control (b) 1A after exposed to alkali media (c) 2A control (d) 2A after exposed to alkali media

The results show that in spite of the mechanical characteristics of Nylon yarns decreased due to alkali but surface morphology of them was not changed significantly. So the alkaline solution can diminish the mechanical properties but this reduction is not so deep to damage the surface of yarns.

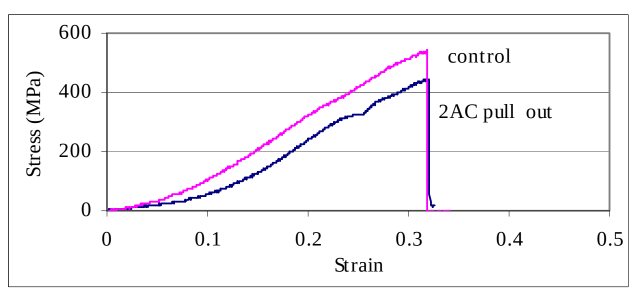
3.3. Pull out behavior

The strength of bonding between yarns and cement matrix was studied by pull out test. The pull out behavior of Nylon 66 yarns with and without coating was shown in figure 7. The time duration of samples prepared for pull out tests in fine grained concrete is 28 days so in figures 7a to 7d the Nylon control samples were kept 28 days in alkali and then mechanical behavior of them were studied.

Pull out behavior of Nylon 66 with finesse of 213 tex (2A) and control sample are presented in Fig. 7a. As can be seen, tensile strength for control sample is 452 MPa and for pull out test is 269 MPa (40% drop). Pull out behavior of coated Nylon 66 with finesse of 213 tex (2AC) and control sample is presented in Fig. 7b. As can be seen, tensile strength for control sample is 541 MPa and for pull out test is 441 MPa (18% decrease). The comparison of pull out behavior of samples 2A and 2AC show that, tire cord coating has increased the tensile strength of control yarn for about 17% and also improved the bond of yarn to cement concrete. Pull out behavior of Nylon 66 and control sample with finesse of 430 tex (2B) is presented in Fig. 7c. As can be seen, tensile strength for control sample is 532 MPa and for pull out test is 340 MPa (36% decrease). Pull out behavior of coated Nylon 66 and control sample with finesse of 430 tex (2BC) is presented in Fig. 7d. As can be seen, tensile strength of control sample is 554 MPa and for pull out test is 405 MPa (26% decrease).



(a)



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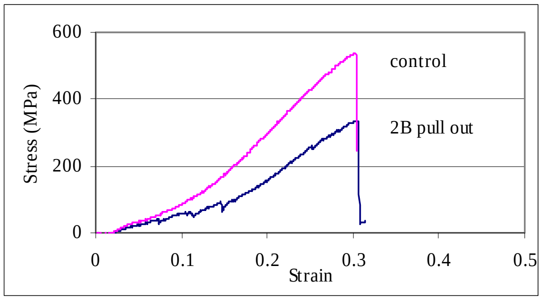

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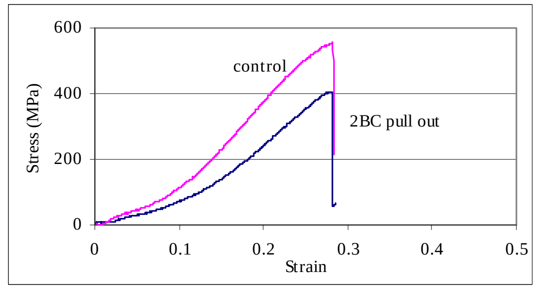

(d)

Fig. 7 Pull out behavior of Nylon yarns (a) 2A (b) 2AC (c) 2B (d) 2BC

In optimum condition with no slippage, the maximum tensile strength for pull out test of yarns is equal to initial tensile strength of yarns. In these test results, tensile strength of pull out is lower than initial tensile strength of yarns in all samples. So the results indicate that Nylon yarns have a little slippage in cement matrix. The tire cord coating has more effectiveness in bonding performance for 213 tex yarn than 430 tex yarn in 28 days. The modulus of elasticity of these yarns decreased compared to control samples. By increasing the finesse of yarns in coated and non coated samples the pull out stress decreased.

Values of pull out stress for Nylon 66 for two finesses with and without coating are presented in Fig.8.

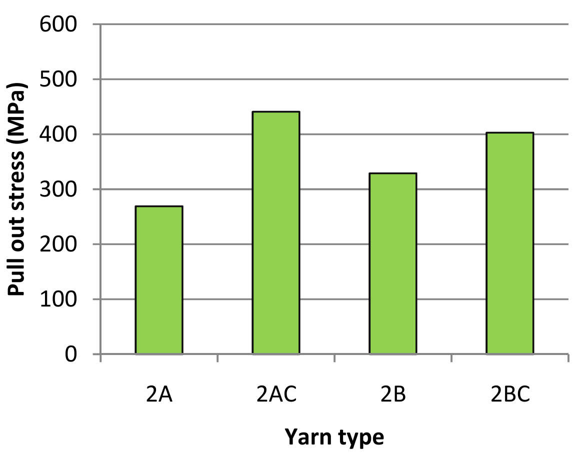

Fig. 8 Pull out stresses of Nylon 66 yarns

As it is seen in Fig. 8, the pull out performance of coarser yarns with 430 tex (2B) is better than finer yarns with 213 tex (2A). In comparison to samples 2A and 2AC it can be concluded that coating could enhance bonding of yarns to concrete and this improving of pull out stress is more visible in finer yarns but this effect will reduce after 28 days for 213 tex yarns because this type of yarn has higher special area which results to the higher speed of alkali absorption. So, coating in finer yarns is resolved sooner in alkali solution than coarser yarns.

4. Conclusions

In this research bonding performance of Nylon tire cord grade yarns to cement composite and the effect of yarn type, the number of filaments in yarn and applying usual tire cord coating on the surface of yarns on it's bonding with concrete matrices was studied by pull out tests. The effect of alkaline media on mechanical properties of Nylon polymeric yarns was investigated and the effect of finesse of yarns and the performance of coating on the alkaline durability in cement matrix were evaluated.

The results show that decreasing in strength in alkali media in finer yarns is higher than coarse yarns and the speed of this decreasing is higher in finer yarns.

Coating could enhance alkaline durability but this effect is diminished in long term exposure.

Alkali damage in Nylons tire cord is not deep and level off after about one month so this type of Nylon could applied for reinforcing cement composites effectively. The bonding of this type of Nylon to cement matrix was suitable with little slippage.

The pull out behavior of coarser yarns is better than finer yarns. Meanwhile the coating could enhance bonding of yarns to cement composite but this effect will be reduced with time.

According to alkali resistance test and pull out results the coarser yarns can show better performance in TRC composites.

The use of multifilament nylon reinforcement for cements has numerous advantages and can be applied in various areas in civil engineering.

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