

# A Moisture Absorption and Adhesion Study of the Process of Blending Film Using *p*-Alkylphenol-Resorcinol-Formaldehyde and Rubber Latex

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**ABSTRACT:** *p*-alkylphenol-resorcinol-formaldehyde-latex (ARFL) films were prepared by co-condensation of *p*-alkylphenols and resorcinol with formaldehyde to generate modified phenolic resins, followed by blending with rubber latex, aging, and finally curing. The weight-gain of the ARFL films and the tensile force of the coated fiberglass were studied under different temperatures and various humidities. The surfaces of the ARFL films were further analyzed by measuring the static contact angle and the findings were confirmed by Fourier Transform Infrared Spectroscopy (FTIR) and X-ray photoelectron spectroscopy (XPS) analysis. The adhesion between the coated fiberglass and neoprene rubber was evaluated using the H-adhesion technique. The best hydrophobicity and the largest water contact angle

were displayed on the surface of the *p*-nonylphenol-resorcinol-formaldehyde-latex (NRFL) film, with a weight-gain percent that was 40.0% (wt %) lower and a static contact angle that was 22.6° more than that of the resorcinol-formaldehyde-latex (RFL) film. The NRFL-coated fiberglass had a higher tensile force and H-adhesion force than the RFL-coated fiberglass. The shelf life of NRFL-coated fiberglass can be raised significantly at 40°C and under 98% humidity. The mechanism of the dramatic drop in the tensile force of the coated fiberglass is also discussed. © 2009 Wiley Periodicals, Inc. *J Appl Polym Sci* 113: 3550–3556, 2009

**Key words:** RFL; fiberglass; moisture absorption; adhesion; films

## INTRODUCTION

Resorcinol-formaldehyde rubber latex (RFL) is a kind of surface coating applied to nearly all types of fibers to make rubber-coated fibers. The rubber-coated fibers are reinforced into a rubber matrix to form a fiber-reinforced rubber product through interfacial adhesion. This process has been extensively used for making tires, conveyor belts/tubes, and timing belts.<sup>1</sup> Various types of fibers, including organic fibers such as polyester fibers or nylon fibers<sup>2–4</sup> and inorganic fibers such as metal fibers or fiberglass,<sup>5,6</sup> have been employed for fiber-reinforced rubber production. The strength of the interfacial cohesion between the rubber-coated fibers and the rubber matrix and the tensile strength of the rubber-coated fibers greatly influence the properties of these fiber-reinforced rubber composites. The interfacial adhesion between the fiber and the rubber matrix can be enhanced by coating the fiber surface with a polymer blend (RFL), which is formed by adding

resorcinol-formaldehyde (RF) resin to rubber latex.<sup>3,7–9</sup> Moisture absorption in the interphase region can be detrimental to the interfacial bond strength of the rubber matrix and the fiber and can impact the performance of the composites.<sup>10</sup> Indeed, it is well known that polymers can suffer substantial losses in their mechanical properties due to the absorption of water.<sup>11</sup> The tensile strength of the rubber-coated fibers has been demonstrated to be easily degraded owing to the absorption of water during processing and application. For example, polyester-type organic fibers can be hydrolyzed easily at high temperatures and in a humid atmosphere, steel fibers can become rusty in high humidity, and the surface of fiberglass can show more micro-cracks at high temperatures and in a humid atmosphere. The diffusion of water vapor through the polymeric coatings to the interface between the fiberglass and primary coating governs the strength of the fiberglass.<sup>12–15</sup> Such fiber degradation greatly influences the application lifetime of fiber-reinforced rubber products. Therefore, coating fibers with RFL could be a good way to enhance interfacial adhesion in fiberglass-reinforced rubber products. However, RFL is still water-based, and moisture can diffuse into the RFL matrix and

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penetrate into the interface of the coated fiberglass, leading to the weakening of the fibers' strength. This weakening becomes especially significant for RFL-coated fiberglass in hot and humid weather because the tensile strength will drop dramatically within 1 week and render the product ineffective. Therefore, it is of great interest to develop new coating systems that can (a) enhance the interfacial adhesion and (b) be applied to fiber surfaces to avoid the growth of cracks and to slow down the hydrolysis of the organic fibers by preventing moisture from penetrating into the coated film.

A lot of research has been carried out with the aim of improving the moisture-proofing on RFL-coated fiberglass surfaces.<sup>6,16–18</sup> RFL has been modified using cyanuric acid, blocked isocyanate and epoxy resins have been used, and a second coating of rubber and organic compounds with reactive functional groups has been applied. A new technology for impregnating and coating fiberglass was introduced by Shaw,<sup>19</sup> in which the resorcinol and formaldehyde crosslinking system was replaced by a rubber impregnation vulcanized in a rubber matrix. Hamed and Ruksakulpiwat<sup>3</sup> studied a chlorophenol/resorcinol condensate system to modify the RFL coating on polyethylene terephthalate fibers to increase the pull-out forces of the fibers.

Based on the consideration that the longer alkyl groups are more hydrophobic, we are interested in introducing hydrophobic alkyl chains in the RF resins in the hope that these chains, which enriched alkylphenol-resorcinol-formaldehyde latex (ARFL) film surfaces, would effectively prevent moisture from penetrating into the interface between the fibers and the coating. On the other hand, a longer alkyl chain could also improve the adhesion strength of coated fiber. We have prepared ARFL film by co-condensation of *p*-alkylphenol with resorcinol and formaldehyde followed by blending with rubber latex, aging, and finally curing. We have studied the moisture absorption behavior of ARFL film in different humidities, the tensile strength, the adhesive properties of *p*-nonylphenol-resorcinol-formaldehyde latex (NRFL)-coated fiberglass, and the effect of alkyl chain length on moisture absorption.

## EXPERIMENTAL

### Materials

Resorcinol ( $\geq 99.9\%$ ), formaldehyde (37%), analytical-grade ethanol, sodium hydroxide, and *p*-cresol were obtained from Shanghai Chemical Reagent Factory; *p*-butylphenol was obtained from Shanghai TCI Co.; nonylphenol ( $\geq 99.7\%$ ) and dodecylphenol ( $\geq 99.9\%$ ) were obtained from Nanjing East Pearl Chemical Trading Co.; vinylpyridine/butadiene/styrene ter-

polymer latex (VPL) was produced by Zibo Heli Chemical Co.; dicarboxylated butadiene/styrene copolymer latex SD516 (SDL) was made by BASF Shanghai Co.; neoprene latex LDR403 (CRL) was made by Sichuan Haitong Co.; gross neoprene rubber was supplied by Taizhou Haining Rubber Production Factory, China; and E-fiberglass (0.204 g/m) was supplied by ZhongCai Science & Technology Industry Co., China.

### Sample preparation

The RF resin was prepared according to established procedures,<sup>20</sup> whereas the ARF resin was prepared as follows (using nonylphenol as an example): Resorcinol (13.2 g) and distilled water (200 g) were weighed into a flask and stirred until the resorcinol dissolved completely. Nonylphenol (1.4 g), ethanol (40.0 g), 10% (wt %) sodium hydroxide (8.0 g), and 37% (wt %) formaldehyde (11.0 g) were then added under continuous stirring in an ultrasonic reactor for 4 h until no oil existed on the surface. The ARF resin contained 5% (mole %, based on resorcinol) nonylphenol.

The rubber latex blend was prepared by mixing VPL, CRL, and SDL in a stoichiometric proportion (VPL : CRL : SDL = 5 : 4 : 1 ratio, solid wt). The above RF or ARF resins were slowly added into the rubber latex blend and stirred gently to get RFL or ARFL. The RFL or ARFL was poured into a Teflon mold and aged at 23°C ( $\pm 2^\circ\text{C}$ ) to form pre-cured RFL or ARFL film. The pre-cured RFL or ARFL film was first vulcanized at 100°C for 1 h before being dried at  $-0.1$  MPa for more than 24 h at 50°C and kept in vacuum desiccators.

### Surface properties

#### Static contact angle

After maturing for 24 h at 23°C, a few drops of the prepared RFL or ARFL was coated on a clean carrier glass and vulcanized at 100°C for 0.5 h. The RFL or ARFL film was then formed carefully on the carrier glass for contact angle measurement. The static contact angle was measured by a CAM 200 contact angle meter (KSV Instrument, Finland) at 23°C. The instrumental error is 0.5°, and a 5- $\mu\text{L}$  droplet of water was used to test the static contact angle of the film.

#### Moisture absorption

The weight-gain of the RFL or ARFL film was valued as a means of discussing the surface moisture absorption of the film. The error is  $\pm 0.1$  mg. The weight-gain percent ( $W\%$ ) of the film was the

average of three samples. It was calculated by following formula:

$$W\% = \frac{W_2 - W_1}{W_1} * 100\%,$$

where  $W\%$  is the seventh day's weight-gain percent of the film and  $W_1$  and  $W_2$  are the weight of the RFL or ARFL film on the initial day and the seventh day, respectively, both under a set humidity. The set humidity was 43%, 87%, or 98% and was prepared by dissolving  $K_2CO_3$ ,  $KBr$ , or  $K_2SO_4$  in a desiccator at the experimental temperature until saturation. The humidity error is  $\pm 0.5\%$ .

### FTIR spectroscopy

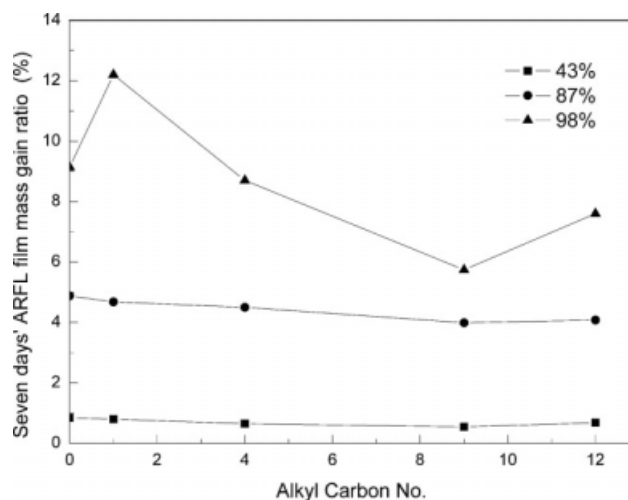
FTIR analysis of the film surface was carried out using a Nexus 870 FT-IR (Nicolet Instrument, Inc) spectrometer with an ATR attachment in close contact with the film surface. The reflectance spectrum was recorded between 675 and 4000  $cm^{-1}$  and at a resolution of 4  $cm^{-1}$ . The average spectra were recorded after 32 scans. The FTIR spectra of the RFL and NRFL films were normalized to the minimum absorption band in order to compare the actual spectra for the two films.

### XPS spectroscopy

XPS analysis of the film was carried out with Escalab MK2 (VG Scientific, UK) X-ray photoelectron spectrometers at 23°C ( $\pm 2^\circ C$ ) by using an Mg  $K\alpha$  source ( $h\nu = 1253.6$  eV). The sample analysis chamber was maintained at a pressure of  $1 \times 10^{-7}$  Pa. The pass energy was set at 100 eV with a scan step size of 0.5 eV for the total scan. The pass energy was set at 20 eV with scan step size of 0.05 eV for the step scan of the high resolution spectra of C1s and O1s. All recorded peaks were corrected based on 285 eV of C1s in full spectra. The peak of C1s was corrected to 285 eV, and that of O1s was determined based on C1s 285 eV in high resolution spectra.

### The tensile and adhesion properties of coated fiberglass

E-fiberglass was dipped into the matured RFL or NRFL and dried and rolled on a bobbin to obtain the continuous RFL- or NRFL-coated fiberglass. The coated fiberglass was, respectively, placed into desiccators with a balanced humidity of 43, 87, and 98% for further periodical tensile force evaluation. The tensile forces were evaluated using a CMT-5105 (Shenzhen Sans) electronic universal testing machine and referring to ISO 3341.



**Figure 1** Weight-gain percent varies with the alkyl carbon number under different humidity.

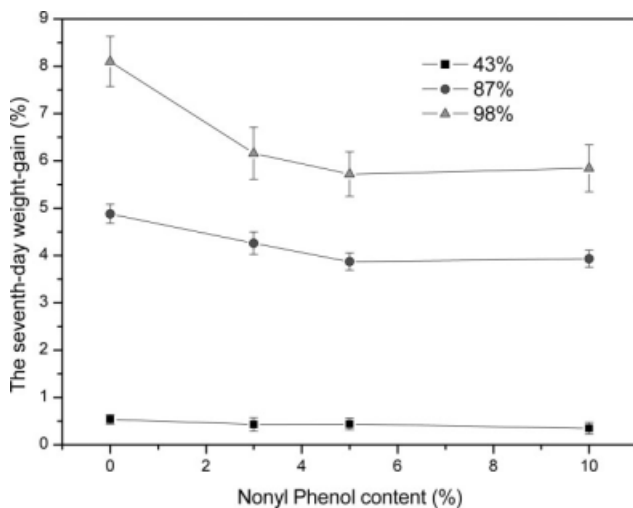
The H-adhesion sample was prepared by embedding the coated fiberglass into gross neoprene rubber.<sup>21</sup> The H-adhesion sample was then vulcanized at 150°C for 0.5 h with a pressure of 20 MPa. The sample was then conditioned for 24 h at 23°C under about 70% humidity. The pull-out force of the H-adhesion sample (H-adhesion force) was measured using a CMT-5105 electronic universal testing machine. The extension rate was set at 50 mm/min. The H-adhesion force of the RFL- or NRFL-coated E-fiberglass was the average of six samples.

## RESULTS AND DISCUSSION

### Moisture absorption

The effect of the alkyl carbon number on the ARFL film's moisture absorption

Water absorption is understood to be a measure of both the efficiency of the structural packing of the polymer network and the polarity of the network structure (the ability of the groups to form hydrogen bonds with water).<sup>10</sup> The results of the seventh-day weight-gain percent and its standard deviations with regard to the ARFL film under 43, 87, and 98% humidity, respectively, are shown in Figure 1. It can be seen that the *p*-alkylphenols in the ARFL films include *p*-cresol, *p*-butylphenol, *p*-nonylphenol, and *p*-dodecylphenol, with *p*-alkyl carbon numbers of 1, 4, 9, and 12, respectively. For the purpose of comparison, the RFL film is indicated by the number 0. The weight-gain data in Figure 1 indicate that the alkyl carbon number had almost no influence on the moisture absorption under medium or low humidity (43% or 87%), but had a greater effect on the moisture absorption of the ARFL film in a high-humidity environment (98%). The alkyl with nine carbon atoms shows the lowest weight-gain percent.



**Figure 2** Weight-gain varies as the nonylphenol content varies.

This can be attributed to the fact that the addition of *p*-alkylphenols may cause (a) a decrease in the crosslink density of RF resin and RFL film; (b) the dangle effect of *p*-alkylphenols (if the alkyl carbon chain is not too long). Based on our study, the dangling effect of *p*-alkylphenols was notable until the alkyl carbon number reached 12. The dangling effect led the alkyl to the surface of the ARFL film, so better hydrophobicity of the ARFL surface was obtained; (c) an increased tangle effect as the alkyl carbon number increases, which could result in the difficult migration of a long alkyl chain to the polymer surface. For this reason, the interaction of alkyl chains was enhanced to lower the rate of outside moisture penetrating into the ARFL film; and (d) the increment of the alkyl carbon number decreased the polarity of *p*-alkylphenol and increased the incompatibility of *p*-alkylphenol with resorcinol, which promoted the migration of alkyl to the film surface. Consequently, the moisture resistance of the film was enhanced and the affinity between the ARF and the rubber was improved.

Weight-gain on the ARFL (1 alkyl carbon atom) surface was greater than that on the RFL surface, and weight-gain on the ARFL (12 alkyl carbon atoms) surface was greater than that on NRFL (9 alkyl carbon atoms) surface, as is shown in Figure 1. This is because when *p*-cresol introduced, the decrease in the crosslink density of the ARF resin or ARFL caused the weight-gain (1 alkyl carbon atom) on ARFL's surface. When the alkyl carbon number reached 12, though the dangle effect was obvious, the tangle became stronger than that of the nonyl chain (9 alkyl carbon atoms) because of dodecylphenol's longer carbon chain. Consequently, the migration of dodecyl from the inner hydrophilic matrix to the surface of the film becomes more difficult. There-

fore, the moisture absorption of the ARFL (12 alkyl carbon atoms) surface increases in comparison with the NRFL surface. Furthermore, the NRFL surface with nine alkyl carbon atoms exhibits the best hydrophobicity.

The effect of nonylphenol content on the NRFL film's moisture absorption

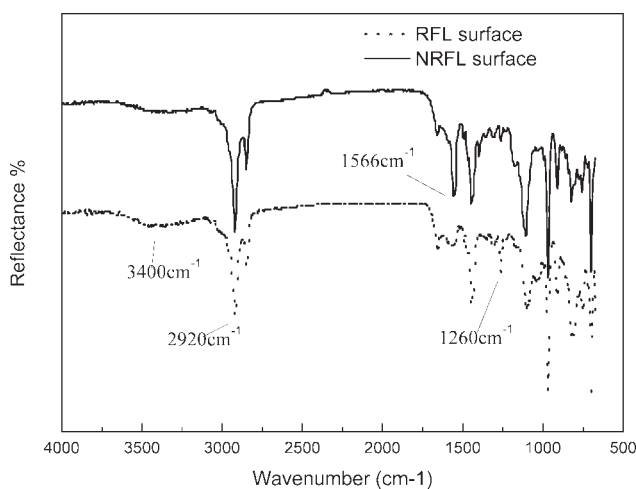
The seventh-day weight-gain percent and its standard deviations of the ARFL film under a balanced humidity of 43%, 87%, and 98%, respectively, were plotted as a function of nonylphenol content, as shown in Figure 2. It can be seen that the weight-gain percent of the ARFL film generally increased with an increase in humidity. The higher the nonylphenol content, the lower the weight-gain percent of the ARFL film under the same balanced humidity. As the nonylphenol content increased, more hydrophobic chains gathered on film's surface, and consequently, the water resistance of the film surface was improved. Consequently, the introduction of 5% or 10% (mole %) nonylphenol-based resorcinol into RFL could lower the seventh-day weight-gain percent of the film when compared to 3% nonylphenol. Our results suggest that a 5% nonylphenol content is enough to improve the hydroscopicity of the film's surface. As the nonylphenol content increased to 10% (mole %), the weight-gain percent increased slightly under 98% humidity, as compared to the nonylphenol content at 5% (mole %). However, 10% nonylphenol may also be considered to modify the RFL film if good interfacial adhesion of the fibers and the rubber can be assured.

Surface characteristics of ARFL films

The contact angle data can also be used to characterize the hydroscopicity of the material surface. The higher the contact angle, the less the hydroscopicity of the material surface. The static contact angle of the ARFL film surface and its standard deviations are summarized in Table I. It can be seen that the static contact angle increases as the alkyl carbon number increases. A maximum static contact angle of 87.9° was obtained when the alkyl carbon number reached 9, which is an increase of 22.6° when compared to a surface with an alkyl carbon number of 0. However, as the alkyl carbon number increased to

**TABLE I**  
Effect of Alkyl Carbon No. on Surface Contact Angle of ARFL Film

Carbon no.	0	1	4	9	12
Contact angle	65.3°	57.0°	65.7°	87.9°	79.5°
STDEV	1.7°	1.7°	4.5°	2.9°	3.5°



**Figure 3** The ATR spectra of the NRFL and RFL surfaces.

12, the static contact angle ( $79.5^\circ$ ) was reduced by  $8.4^\circ$  when compared with the angle of the surface containing 9 alkyl carbon atoms. It is clear that better moisture resistance is obtained when the surface contains 9 alkyl carbon atoms. The results verify the conclusion shown in Figure 1. The best hydrophobicity was achieved on the NRFL film surface.

The FTIR/ATR analysis also supports the above conclusion. The FTIR spectra, based on the comparison of the NRFL and RFL film surfaces, are shown in Figure 3. The FTIR data relating to the NRFL film surface indicate that stronger asymmetric stretching vibration ( $\nu_{as}$ ) of C—H is observed at  $2920\text{ cm}^{-1}$ , and less intense stretching of C—H is at about  $3400\text{ cm}^{-1}$ . Furthermore, stronger bone stretching vibration of the benzene ring (C=C) can be seen at  $1566\text{ cm}^{-1}$ . The stretching vibration of C—H at  $2920\text{ cm}^{-1}$  and OH at about  $3400\text{ cm}^{-1}$  suggest that the nonyl chain with more methylene and methyl are gathered on the NRFL surface rather than on the RFL surface, and the symmetric stretching vibration ( $\nu_s$ ) of the benzene ring (C=C) at  $1566\text{ cm}^{-1}$ <sup>22</sup> is likely due to the benzene ring's interaction with nonylphenol. With regard to the fingerprint region, peaks at  $1260\text{ cm}^{-1}$  and  $1030\text{ cm}^{-1}$  can be observed on the RFL film, while these peaks nearly disappear on the NRFL film. The peaks at  $1260\text{ cm}^{-1}$  and  $1030\text{ cm}^{-1}$  should be assigned to the  $\nu_s$  of Ar—O and C—OH,<sup>22</sup> respectively. This can be explained by the fact that the nonyl chain, which is stretched on the NRFL film surface, produces a shielding effect to prevent resorcinol's benzene ring from reaching the surface of the NRFL film. As a consequence, very little hydroxyl phenol (Ar—OH) and C—OH can be found on the NRFL film surface.

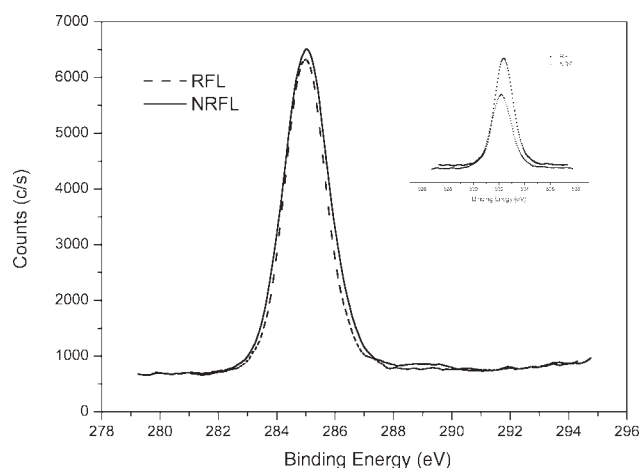
In order to verify the above results, element analysis of the film surface was carried out by XPS based on a comparison of the surface of the NRFL and RFL films, respectively. The element content, based

**TABLE II**  
Element Analysis on the Surface of NRFL Film and RFL Film by XPS

Peak-ID	Atom %	
	NRFL	RFL
C 1s	77.12	68.31
O 1s	22.33	30.76
C 12p	0.55	0.93
O/C ratio %	28.95	45.03

C 1s, O 1s, and C1 2p, is summarized in Table II. More C 1s electrons and fewer O 1s electrons were detected on the NRFL surface than on the RFL surface (an 8.81% increase in C 1s and an 8.43% decrease in O 1s). The O% decreases and the C% increases for the NRFL film is owing to the O/C ratio decreases in the NRFL (a 16.08% decrease in O/C ratio), as shown in Table II. The peak of O 1s on NRFL surface in Figure 4 shift to a lower binding energy in comparison with that on RFL surface. It should belong to the shield effect of nonyl chain to O 1s for the NRFL surface. In addition, more C1 2p electrons from the neoprene latex were found on the NRFL surface. This result may be due to some type of shield effect caused by the nonyl chain segment on the NRFL film surface.

The comparisons of the high resolution XPS spectra of C 1s and O 1s based on the RFL and NRFL surfaces are described in Figure 4. It can be seen that the C1s peak area, based on NRFL, is only slightly bigger than that based on RFL, indicating that more carbon atoms (an increase of 8.81%) appeared on the NRFL film surface. The O 1s peak area, based on NRFL, is smaller than that based on RFL, which indicates that there are fewer oxygen atoms (8.43% fewer) than on the RFL surface. This result is inconsistent with the analysis based on



**Figure 4** The C 1s and O 1s high resolution spectra of the surface of the RFL and NRFL films.

**TABLE III**  
Adhesion of NRFL-Coated Fiberglass

Nonylphenol content, mole % (based on resorcinol)	0	3.0	5.0	10.0
H-adhesion force, N/cm	85.0	93.8	98.3	99.2
STDEV	2.2	2.0	1.8	1.9

FTIR spectra and the contact angle of the surfaces of the RFL and NRFL films.

This information allows us to come to the conclusion that the nonyl groups are apt to migrate from the hydrophilic matrix to the film surface. The nonyl chain stretches towards the surface of the NRFL film and some hydrophilic phenol hydroxyl may be shielded by hydrophobic nonyl chain on the surface of the NRFL film. Therefore, the NRFL film surface is more hydrophobic than the RFL surface.

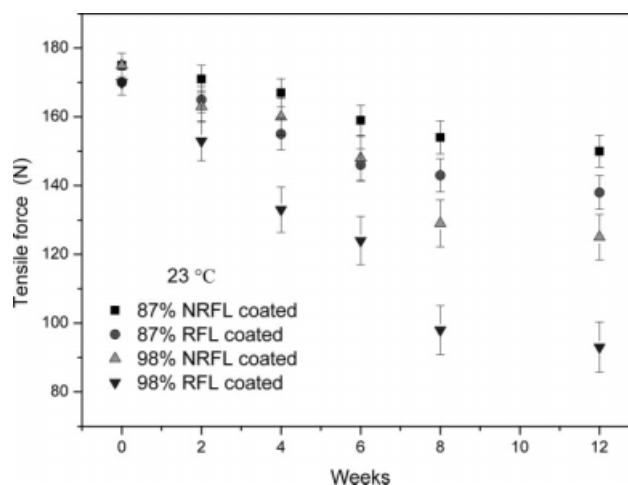
#### Adhesion of NRFL-coated fiberglass

Evaluating polymer adhesion is important both academically and industrially.<sup>23</sup> The compatibility of phenolic resin and rubber can be greatly improved with longer alkyl phenol chains.<sup>24</sup> As expected, in comparison with resorcinol resin, the introduction of nonylphenol affects the adhesion in two ways: (a) the nonyl segment on the film surface interacts with the rubber chain at the interface of the fiber/rubber composites, and (b) the nonyl group with hydrophobicity kept more moisture away from the interface of the fiber/rubber composites. Table III shows the adhesion of the NRFL-coated fiberglass in relation to nonylphenol content.

It is evident that the nonyl substitute can improve the adhesion between fiberglass and rubber. The H-adhesion force increased as the nonylphenol content increased under the same experimental conditions. The maximum adhesion (99.2 N/cm) was observed with a nonylphenol content of 10.0%, which is an increase of 14.2 N/cm when compared to the coating that contained no nonylphenol (85.0 N/cm). Furthermore, the H-adhesion force (98.3 N/cm) at a 5% nonylphenol content increased by 13.3 N/cm when compared to the coating that contained no nonylphenol. However, the adhesion observed with a nonylphenol content of 10.0% is not the best choice for coating fiberglass because of the seventh-day weight gain, as can be seen in Figure 2. It appears, then, that a 5% nonylphenol content is best suited to coating fiberglass.

#### The tensile property of coated fiberglass

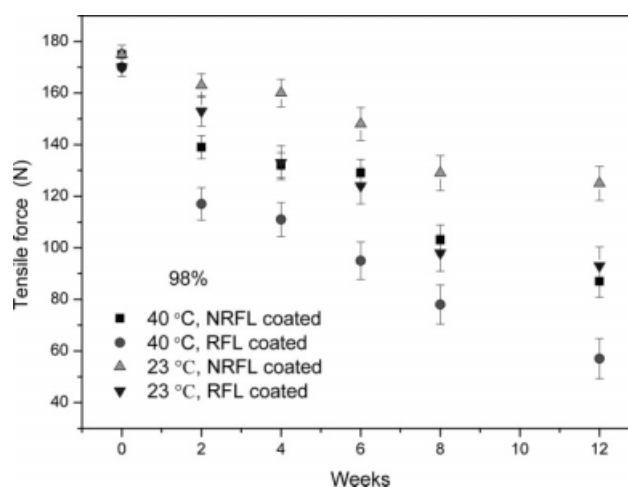
Sequential water corrosion could cause the tensile force of coated fiberglass to decrease.<sup>25</sup> It was found that the tensile force of coated fiberglass dropped



**Figure 5** The tensile force of coated fiberglass varies with storage time under 87% and 98% humidity.

significantly with time in hot and humid conditions during processing and in storage. Figure 5 illustrates how the tensile force of RFL- and NRFL-coated fiberglass vary with time at 23°C and at 87% and 98% humidity, respectively. Figure 6 shows how the tensile force of RFL- and NRFL-coated fiberglass vary with time under 98% humidity and at 23°C and 40°C, respectively.

In Figures 5 and 6, the tensile force of the NRFL-coated fiberglass is higher than that of the RFL-coated fiberglass. The tensile force decreases as humidity or temperature increase. A comparison of Figures 5 and 6 shows that the decrease in the tensile force of the NRFL-coated fiberglass (a drop of 6.9%) caused by increased humidity at 23°C within 6 weeks is less than that (a drop of 13.5%) caused by elevated temperatures under the same conditions; the decent of the tensile force of the RFL-coated fiberglass (a drop of 15.2%) caused by increased humidity at 23°C within



**Figure 6** The tensile force of coated fiberglass varies with storage time at 23°C and 40°C.

6 weeks is less than that (a drop of 23.4%) caused by elevated temperatures under the same conditions. In short, the main factor that causes the decrease in tensile strength can be said to be an elevated temperature, which accelerates the water molecules and allows them to penetrate the rubber film, especially in hot and humid weather.

The hydrophobic group on the NRFL film surface prevents water from penetrating the surface of the fiberglass, and this moisture barrier can delay water penetration into the interface of the fiber or rubber coating to some extent. In summation, it can be said that the decrease in the tensile strength of the NRFL-coated fiberglass is less than that of the RFL-coated fiberglass, especially in hot and humid conditions.

In addition, in comparison with the tensile forces of NRFL- and RFL-coated fiberglass, it was found that there are still 128.1 N remaining in the NRFL-coated fiberglass under 98% humidity and at 40°C within six weeks, while there are only 95.1 N remaining in the RFL-coated fiberglass under the same conditions. This means that the shelf life (based on a tensile force of 127 N of a similar product from Central Glass Co.) of NRFL-coated fiberglass under 98% humidity and at 40°C is 6 weeks, while that of the RFL-coated fiberglass is not nearly as long.

Furthermore, the incorporation of *p*-alkylphenol into the RF resin is a simple procedure that does not affect the existing process. Incorporation of *p*-alkylphenol can be implemented in a number of applications (e.g., NRFL-coated organic fibers or steel fibers) to lower water absorption in reinforced rubber composites.

## CONCLUSIONS

In order to improve the tensile force of RFL-coated fiberglass in hot and humid weather, *p*-alkylphenol was used to promote increased water repulsion on fiberglass surfaces, thereby increasing the shelf life of the coated fiberglass. Our study resulted in a number of interesting findings:

- a. With the introduction of nonylphenol, the seventh-day weight-gain of the NRFL film decreases by about 40.0% and the static contact angle is 22.6° greater than that of the RFL film. A more water-resistant coating formed on the NRFL film surface.
- b. Adhesion between fiberglass and neoprene is obtained by introducing 5% nonylphenol (mole %, based on resorcinol).
- c. The tensile force of the NRFL-coated fiberglass is always larger than that of the RFL-coated fiberglass under the same conditions. Furthermore, elevated temperatures affect the tensile strength more than increased humidity. The shelf life NRFL-coated fiberglass can reach to six weeks at 40°C and under 98% humidity, while that of the RFL-coated fiberglass is not nearly as long-lasting.
- d. The incorporation of *p*-alkylphenol into resorcinol resin is a simple procedure that does not change the existing process, and this modification can be applied to organic and inorganic fibers in order to achieve a hydrophobic coating.

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