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The effects of drying parameters and conditioning on mechanical properties of latex-backed carpet

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In this study, the effects of drying parameters and conditioning on the mechanical properties of latex-backed carpet were investigated. Mechanical properties clearly correlated with the lowest moisture content (MC) experienced by samples in either drying or conditioning. Lowering MC was necessary to develop mechanical properties; however, the highest mechanical properties were achieved at the highest latex temperature, indicating that raising latex temperature can improve mechanical properties. The effect of conditioning on mechanical properties depended on the MC of the latex backing at the end of drying.

Keywords: tuft carpet; latex; curing; drying

Introduction

Tufted carpet is the most common type of carpet produced in the USA. During tufting, face yarns are inserted through a primary backing, but are not locked in. Therefore, back coating is needed to hold the yarns in place. There are several methods of carpet backcoating; however, most carpets are backed using a latex coating and a secondary backing, as shown schematically in Figure 1. The secondary lamination process (Figure 2) involves use of latex to adhere a secondary backing to the underside of tufted carpet. Unbacked carpet is introduced on one end of the machine and is pulled through an applicator that applies a layer of latex adhesive to the reverse of the carpet. The coated carpet is then brought in contact with a secondary backing which has a thin layer of adhesive applied to it. A tenter frame is used to transport the backed carpet through a convection oven which dries and cures the latex. After leaving the oven, the carpet is removed from the tenter frame and is transported using rollers.

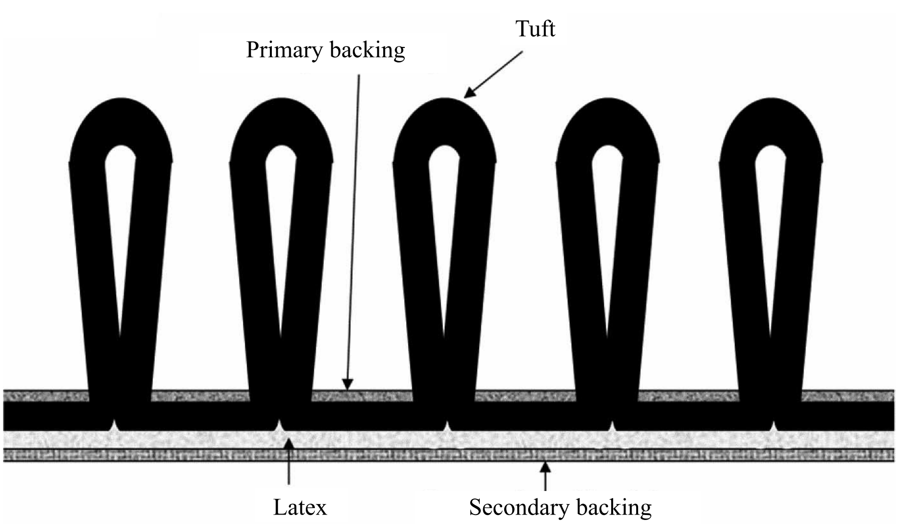

Figure 1. Schematic of latex-backed carpet.

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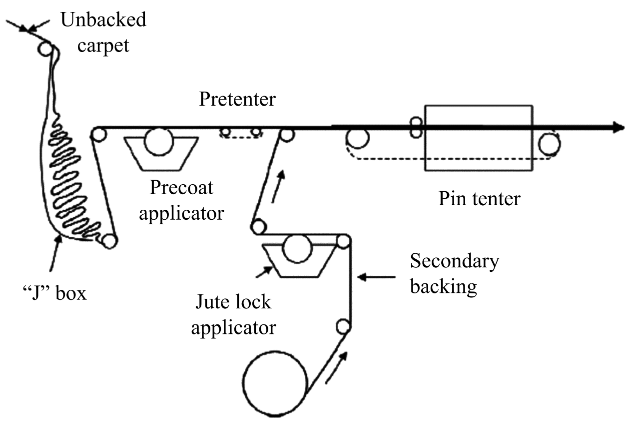

Figure 2. Schematic of secondary lamination process.

The drying and curing of latex adhesive back coating on carpet is one of the largest areas of energy consumption in the carpet manufacturing process. Making the process energy efficient is very important since energy costs have risen at such an alarming rate over the last few years. It is commonly believed that the carpet industry overdries the latex back coating, wasting a considerable amount of energy; however, curing must be sufficient to ensure that the required mechanical properties are achieved. Carpet growth or buckling after installation is a quality parameter that may be affected. Carpet growth is usually associated with poor tuft bind and delamination; however, there is no approved standard method for growth analysis.

Although drying of latex films and film formation have been investigated (Hutton & Gartside, 1949; Poehlein, Vanderhoff, & Witmeyer, 1975; Pramojaney, Poehlein, & Vanderhoff, 1980; Vanderhoff, 1977; Vanderhoff, Poehlein, Pramojaney, & Yenwo, 1980), drying and curing of latex adhesive back coating on carpet have received little attention in the literature. In fact, we have not been able to find any papers in the refereed literature on this subject. In this paper, the effects of drying parameters (dryer temperature and moisture content (MC) and temperature of the latex-backed carpet leaving the dryer) and conditioning on mechanical properties (tuft bind, TB, and delamination strength, De) of latex-backed carpet are discussed.

Experimental

Materials and equipment

Unbacked tufted nylon 6,6 carpet used in this study was provided by Milliken & Company. The carpet had an areal density of 1017 g/m^2, a stitch density of 19.7 stitches/cm^2, a pile height of 5.56 mm, and a woven polypropylene primary backing with an areal density of 145 g/m^2.

Latex materials were supplied by Textile Rubber & Chemical Company. One compound (MJ1-27A), referred to as precoat, was applied to the unbacked carpet. A second compound (MJ1-27B), called jute lock, was applied to the secondary backing. The precoat and jute lock contain several components that are listed in Table 1. The polymer in each compound was carboxyl styrene-butadiene, made by Dow Chemical Company. The amount of styrene in the polymer was considered proprietary, but typical amounts used for latex backings range from about 56 to 65%. The precoat containing a frothing agent was foamed before application. The wet and dry weights refer to the weight contribution of each component to the compound before and after drying.

A convection oven was used in the drying and curing tests (Figure 3). It was a 1.6 kW Blue M oven (model number OV-490A-2) with a chamber space of 48.7 cm × 46.2 cm × 38.3 cm. A fan, located at the bottom of the oven, blew air across heater coils. An Athena 1800 PID controller was used with the heater coils to maintain the oven temperature at the set point to within ±1.67°C (3°F). The carpet sample was placed on a suspended basket that was held in position by four rods that were attached to the top of a balance (Fisher Scientific XT 1200 Top Loading Electric Balance).

Sample temperature was measured at the locations shown in Figure 4. An IR thermometer (Omega IS-64 IR), installed on the top of the oven, was used to

Table 1. Components of precoat and jute lock.

Material	Compound	Dry weight (parts)	Wet weight (parts)
MJ1-27A	Polymer	100.00	192.31
Precoat	Water	0.00	40.00
	Filler	550.00	550.00
	Thickener	0.75	5.77
	Frothing aid	1.50	5.00
MJ1-27B	Polymer	100.00	192.31
Jute lock	Water	0.00	27.00
	Filler	400.00	400.00
	Thickener	0.75	5.77

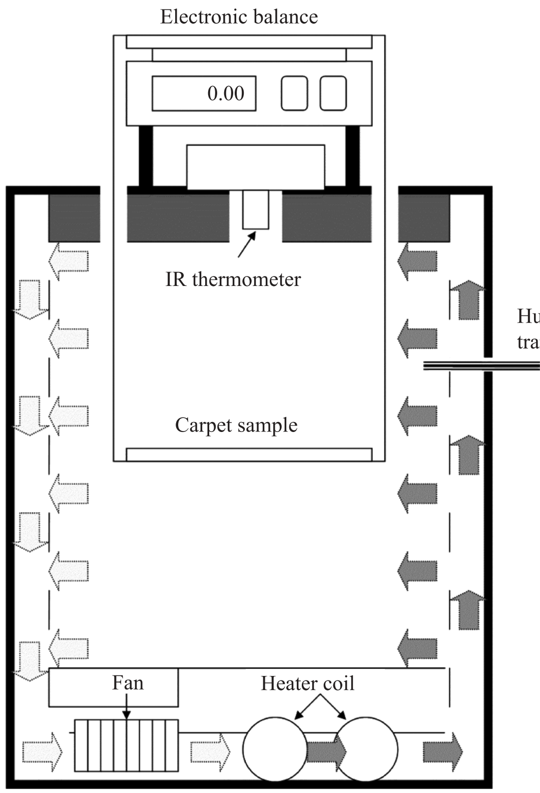

Figure 3. Schematic of convection oven.

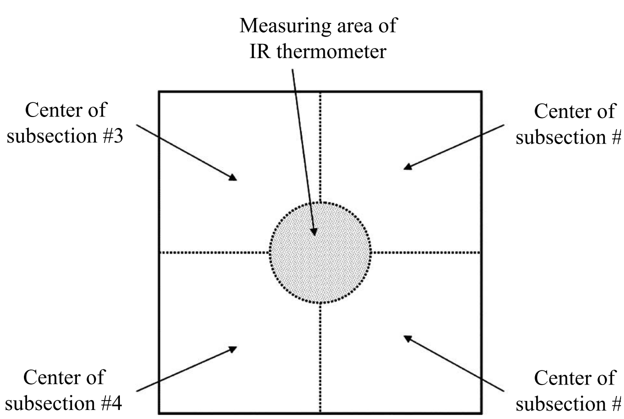

Figure 4. Locations of latex temperature measurement.

measure the sample surface temperature at the center of the sample, and four J-type thermocouple probes (Omega DP 25-TC) were used to measure temperature inside the latex. The temperature variation among the five measurements was small, and the average of the five temperatures is presented as the latex temperature. Relative humidity (RH) was measured by an OMEGA HX15 relative humidity probe transmitter.

A mixer (Kitchen Aid, Model No. K45ssD) was used to foam latex to a desired density (770 kg/m^3). Tuft bind and delamination strength were measured using an Instron machine (Model No. 5567).

Secondary lamination procedure

The procedure used to apply latex backing to tufted nylon carpet was recommended by Textile Rubber & Chemical Company. Sections of unbacked carpet and secondary backing having the dimensions of 28.0 cm × 30.5 cm were cut out. Steam was used to increase the MC of the unbacked carpet by approximately 10%, and precoat (75 g of MJ1-27A) was applied. A Teflon® sheet was placed over the latex, and a PVC hand roller (2.27 kg) was used to level the latex over the back of the carpet. After the roller was rolled from one edge to the opposite side and back, it was rotated 90° and rolled in the new direction from one edge to the other side. During this procedure, a small amount of latex stuck to the Teflon sheet, reducing the weight of latex by about 8 g. Approximately 40 g of jute lock was applied to the secondary backing, and it was placed on the unbacked carpet. The rolling procedure described above was repeated.

The uncured sample was then dried in the convective oven. Sample weight and temperatures were recorded as a function of time. After drying, each sample was divided into two parts. Tuft bind and delamination tests were conducted on one part directly after curing. The second part was held in a standard testing laboratory for 24 hours, and then tuft bind and delamination tests were conducted.

Standard tests

ASTM D1335 and D3936 standards (ASTM, 1998, 2000) have been widely used in the US carpet industry for measuring latex mechanical properties, and were used in our study. Tuft bind indicates the ability of the tufted carpet to resist zippering and yarn pull-out. Delamination strength is related to the ability of the carpet structure to resist delamination when subjected to flexing during use. Federal Housing Authority (FHA) minimum requirements of tuft bind and delamination strength for cut pile floor covering are 13.3 N (3.0 lbf) and 4.4 N/cm (2.5 lbf/in), respectively.

Almost all of the values of tuft bind reported in this paper are lower than the FHA recommended value. From our tests not reported here, the many of the values of tuft bind could be increased above FHA minimal values by optimizing the roller pressure used to marry the secondary backing to the carpet. However, our carpet industrial partner recommended that we use the sample preparation procedure, which specified the roller weight and consequently marrying pressure, provided by the company supplying the latex. Since the conclusions concerning the effects of MC and latex temperature on mechanical properties are not affected, the sample preparation procedures recommended by the latex supplier was used for our tests.

Test parameters

Latex-backed carpet samples were dried at four different oven temperatures (52°C, 79°C, 107°C, and 135°C) using heated atmospheric air. The primary parameter monitored during the drying tests was MC of the entire sample (tufts and backing). In this study, MC was defined as the ratio of sample wet weight minus sample dry weight over the sample dry weight. Although other materials such as finish may be driven off during drying, the associated weight loss is insignificant compared to that of water.

Relative humidity is defined as the ratio of partial pressure of the vapor in the air to the saturation pressure of the vapor at the temperature of the air. Since ambient air continuously flows into the oven, the vapor pressure in the oven is equal to that of the ambient air for long drying times after the sample is in equilibrium with air in the oven. RH in the dryer was low, but not zero, and thus MC_{EQ}, the equilibrium MC of the sample measured after a very long drying time, was also not zero. RH in the oven was measured and found to be about 10% for the drying tests conducted at 52°C. However, at the higher oven temperatures of 79°C, 107°C, and 135°C, the RH in the oven was too low to be accurately measured using the RH probe. For these tests, values of RH were calculated assuming that the humidity ratio in the oven was the same for all oven temperatures. At an oven temperature of 135°C, RH was only 0.71%. MC_{EQ} of nylon 6,6 at RH of 0.71% is only 0.07% (Hutton & Gartside, 1949). Latex-backed carpet and unbacked carpet (primarily nylon 6,6) have similar MC at a given RH. Thus, for an oven temperature of 135°C, values of MC_{EQ} of latex-backed carpet and its components were assumed to be approximately 0.07% and neglected in this study.

To determine MC_{EQ} of unbacked carpet, a 28.0 cm × 30.5 cm sample was prepared, and placed in the oven at a temperature of 52°C. Then, the weight was monitored until the equilibrium weight was reached. The sample was kept in the oven, and the air temperature was increased to 79°C. Similarly, after the sample had reached equilibrium, its weight was measured and recorded. The procedure was repeated at a temperature of 107°C, and then at 135°C. The equilibrium weights were recorded, and the values of MC_{EQ} at lower temperatures were calculated assuming MC of zero for an oven temperature of 135°C. Then the same procedure was used to obtain values of MC_{EQ} for a layer of latex and for latex-backed carpet at the four oven temperatures.

The sample was dried in the oven, and its weight was monitored until the equilibrium weight was reached. Each tests replicated three times. Then the variation of MC with time was determined and used to establish drying times required to obtain desired MC, which was needed to show the effect of MC on TB and De.

Absorption tests with sample initial MC ≈ 0% were conducted in a standard testing laboratory ((65 ± 2)% RH and (21 ± 1.1)°C) to determine the variation of MC with conditioning time. Tests were conducted using unbacked carpet, a layer of latex, and latex-backed carpet. A 28.0 cm × 30.5 cm sample was prepared and placed in the oven at a temperature of 149°C, and the weight was monitored until the equilibrium weight was reached. The sample was removed from the oven, and MC versus time was measured for 24 hours in a standard testing laboratory.

The effects of conditioning the samples in a standard testing laboratory ((65 ± 2)% RH and (21 ± 1.1)°C) were studied. The mechanical properties of the samples were measured soon after drying and after the samples had conditioned for 24 hours.

Results and discussion

Equilibrium moisture content

Equilibrium moisture content (MC_{EQ}) of latex-backed carpet versus oven temperature is shown in Figure 5. Based on MC_{EQ} of 0% for an oven temperature of 135°C, MC_{EQ} of latex-backed carpet for oven temperatures of 52°C, 79°C, and 107°C were 0.73, 0.23, and 0.07%, respectively. As shown in the Figure 6, the values of MC_{EQ} of unbacked carpet and a layer of latex were similar to those of the latex-backed carpet.

Moisture absorption

The results of moisture absorption tests for unbacked carpet, a layer of latex and latex-backed carpet are shown in Figure 7. The unbacked carpet absorbed moisture from the atmosphere much more rapidly than the latex layer. MC of the unbacked carpet reached the absorption equilibrium value (MC_A) of 4.0% in about two hours, but it took approximately 16 hours for the latex layer to reach its MC_A of 0.7%. Once water is removed from the latex, the structure condenses (Brown, 1956; Dillon, Matheson, & Bradford, 1951; Vanderhoff, 1977), and the addition of water will not return the structure to its original form. Thus, at the same RH, MC_A of cured latex layer is much lower than MC_{EQ}.

The absorption behavior of the latex-backed carpet has characteristics of the two components. MC rose

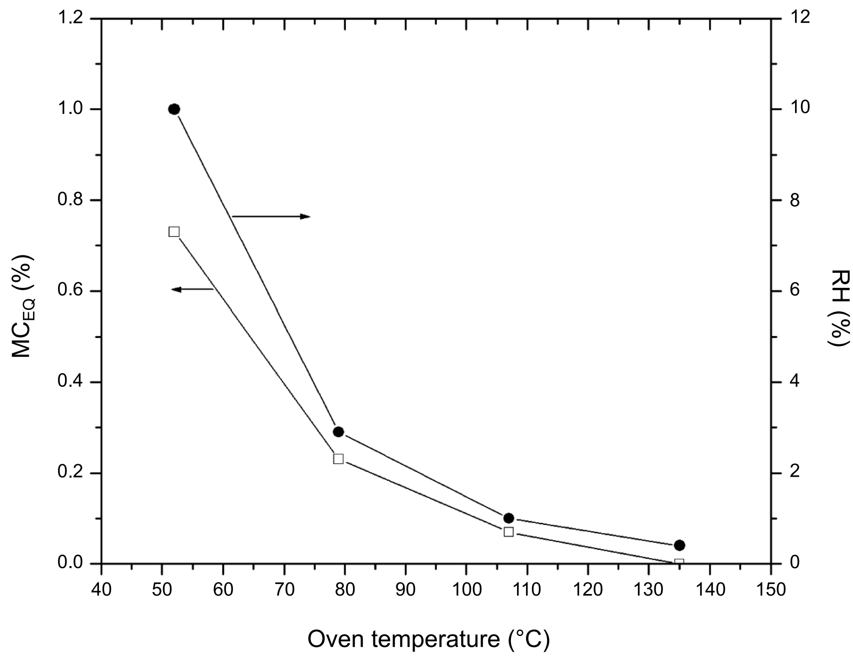

Figure 5. RH in the oven and MC$_{EQ}$ of latex-backed carpet versus oven temperature.

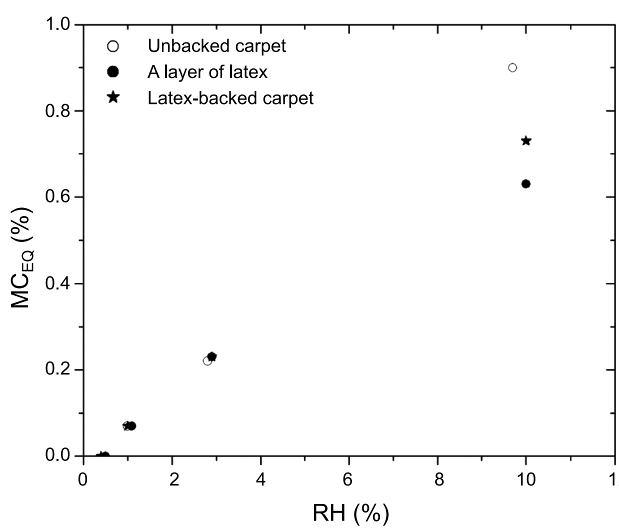

Figure 6. MC$_{EQ}$ of unbacked carpet, a layer of latex, and latex-backed carpet as a function of RH.

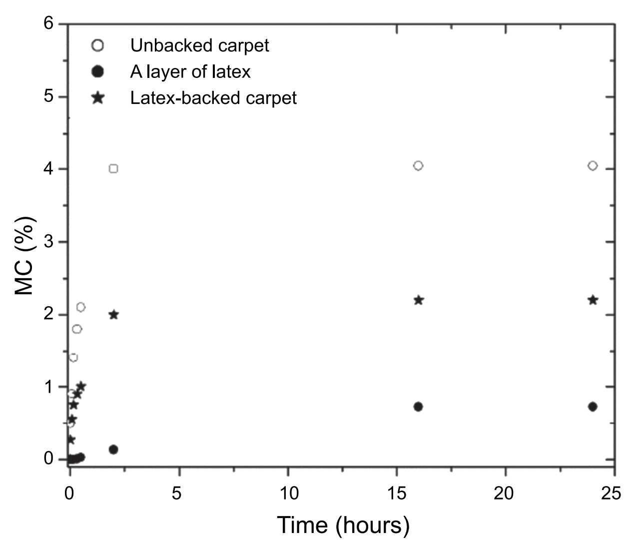

Figure 7. MC of unbacked carpet, a layer of latex, and latex-backed carpet as a function of conditioning time in a standard testing laboratory.

very fast in the first 30 minutes and began to level off at about 2.0% after about two hours, but continued to rise slowly and reached an equilibrium value of about 2.2% after several hours. The results indicate that much of the moisture regained by latex-backed carpet after drying is in the face yarns.

Effect of drying parameters

The variations of TB, measured directly following drying, with MC and latex temperature, both measured just before the latex-backed carpet was removed from the oven, are shown in Figure 8. TB increased as MC decreased for all oven curing temperatures. There was no clear correlation of TB with latex temperature; however, the sample having the highest TB was the sample having the highest latex temperature (119°C) which was also at the lowest value of MC. Thus, it appears that low MC is required to obtain high TB, but once low MC is obtained, TB is improved by increasing latex temperature.

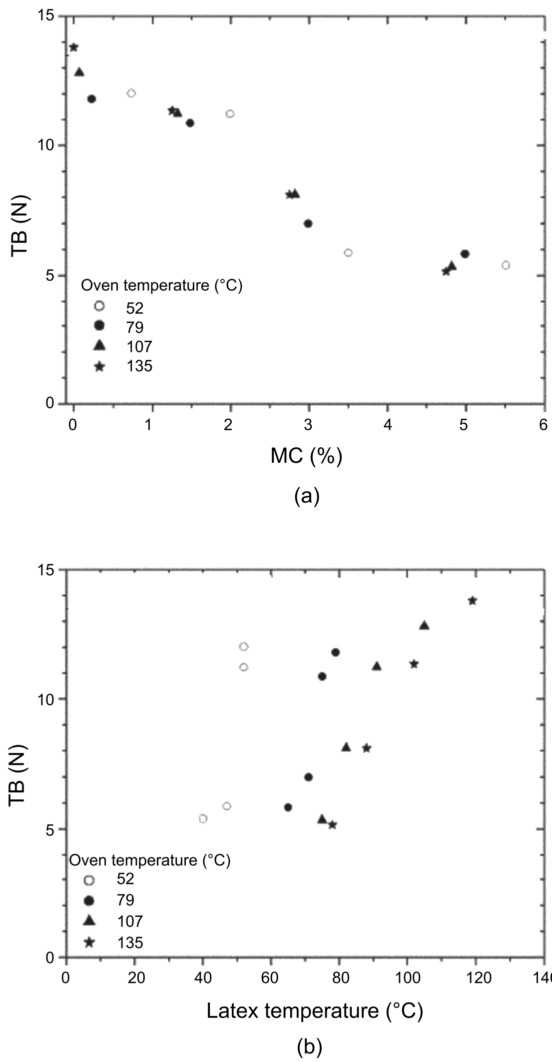

Figure 8. Tuft bind (TB) of latex-backed carpet measured directly following drying: (a) TB as a function of MC measured in the oven at the end of drying and (b) TB as a function of latex temperature measured in the oven at the end of drying.

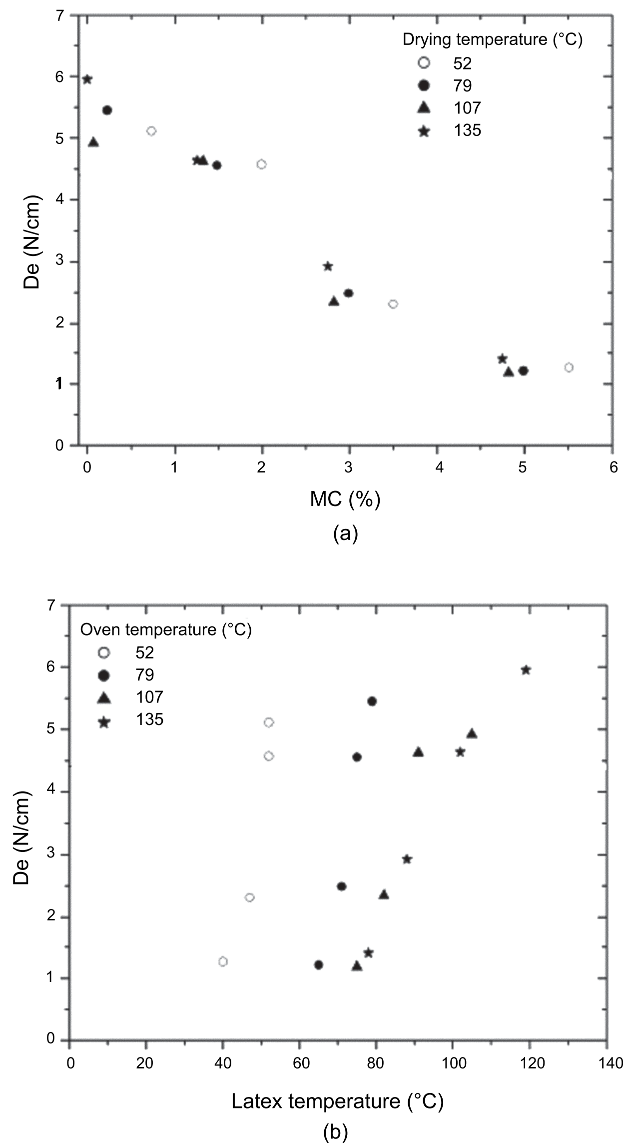

Figure 9. Delamination strength (De) of latex-backed carpet measured directly following drying: (a) De as a function of MC measured in the oven at the end of drying and (b) De as a function of latex temperature measured in the oven at the end of drying.

The variations of De, measured directly following drying, with MC and latex temperature, both measured before the latex-backed carpet was removed from the oven, are shown in Figure 9. De increased as MC was decreased for all oven temperatures. There was no clear correlation of De with latex temperature; however, similar to the results for TB, the highest value of De occurred at the highest latex temperature of 119°C which was also at the lowest value of MC.

Effect of conditioning

The effects of conditioning the samples for 24 hours in a standard testing laboratory ((65 ± 2)% RH and (21 ± 1.1)°C) were studied. MC of the conditioned sample versus MC of the sample measured in the oven at the end of the drying is shown in Figure 10. MC_A shown in the figure was obtained from the moisture absorption tests discussed earlier (Figure 7). The drier samples absorbed moisture while the samples with higher starting MC lost moisture. However, the samples that were absorbing moisture had lower MC after conditioning than those loosing moisture.

In Figure 11, the mechanical properties of the conditioned samples are compared with those measured directly following drying. With conditioning, TB and De either increased or stayed at the same value with

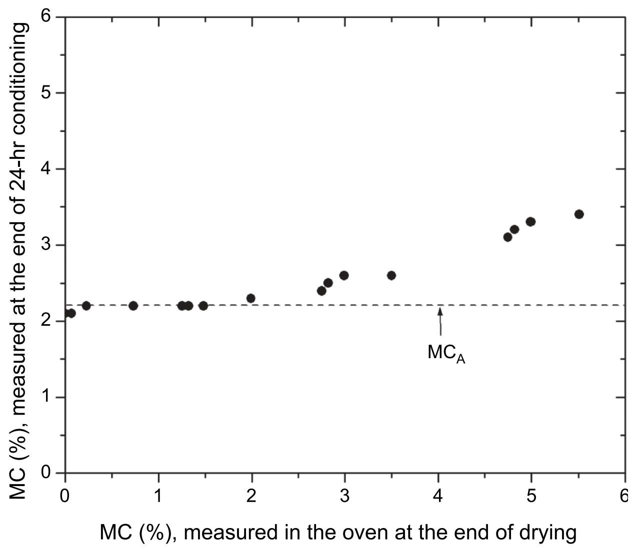

Figure 10. MC of the conditioned sample versus MC of the sample measured in the oven at the end of the drying test. Note: MC_A is the equilibrium MC reached by an initially totally dry sample after conditioning in the standard testing laboratory (see Figure 7).

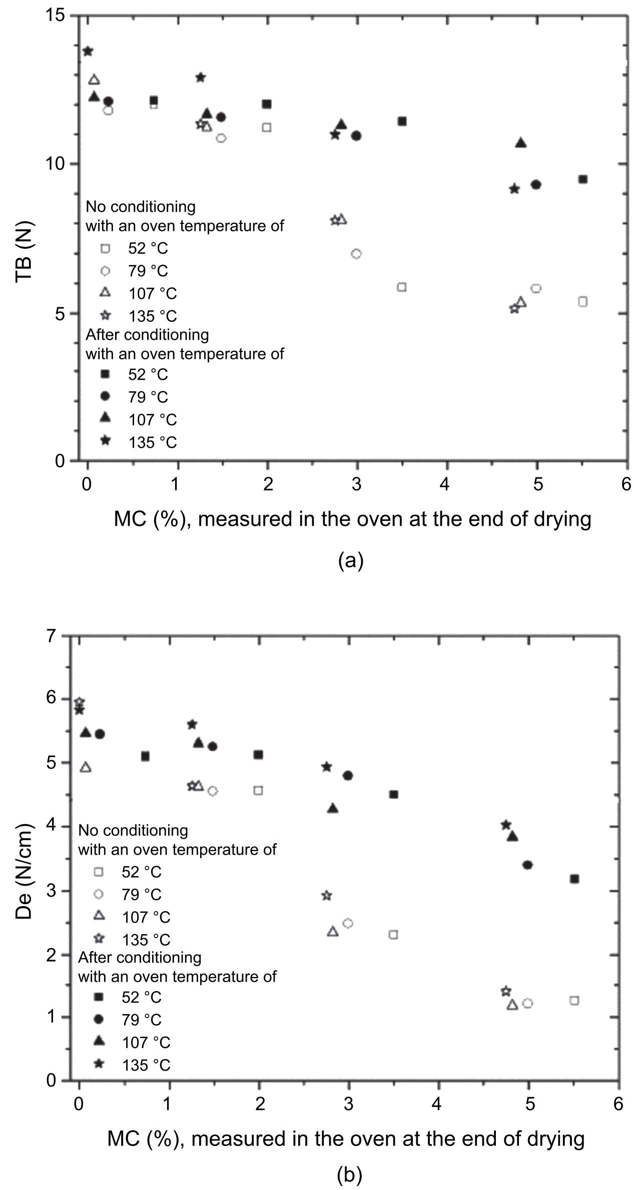

Figure 11. Effects of conditioning on mechanical properties of latex-backed carpet as a function of MC measured in the oven at the end of drying test: (a) tuft bind and (b) delamination strength.

only one exception where TB decreased slightly. Samples with the lower initial mechanical properties showed larger increases while there was little change for the sample with the highest initial mechanical properties.

In Figure 12, the mechanical properties versus MC_L (lowest MC experienced by sample in either drying or conditioning) are shown. Both TB and De clearly correlate closely with MC_L.

Latex temperature

In Figure 8(b), no clear correlation of TB with latex temperature was seen; however, the highest TB was achieved at the highest latex temperature (119°C). To further study the role of latex temperature in developing TB and De, samples were dried to low MC, but at low temperature, by using a vacuum dryer. The samples were first dried in the convection oven at a temperature of 79°C until MC reached equilibrium. Then the sample was dried in a vacuum oven at a temperature of 79°C for 24 hours. The decrease in MC in the vacuum oven was similar to the loss found in the desorption tests when a sample was first dried to equilibrium at 79°C, subsequently dried further at 107°C, and then 135°C until equilibrium was reached. MC of the vacuum dried sample was similar to that of the sample dried in the convection oven at 135°C. With vacuum drying with the sample at 79°C, TB and De increased from 11.8 to 13.0 N and 5.4 to 5.7 N/cm, respectively. However, they were lower than the values (13.8 N and 6.0 N/cm, respectively) for samples dried at an oven temperature of 135°C and latex temperature of 119°C at the end of drying.

Latex film formation is described in several studies (Brown, 1956; Dillon et al., 1951; Vanderhoff, 1977) as a transformation of a colloidal dispersion into a polymer film. Initially latex spheres move freely in the water without touching each other. As water is removed during the drying process, the motion of the spheres is restricted, and eventually the particles are forced together by surface tension to the point where the double layer repulsion is overcome. As water continues to be removed, the spheres are progressively forced

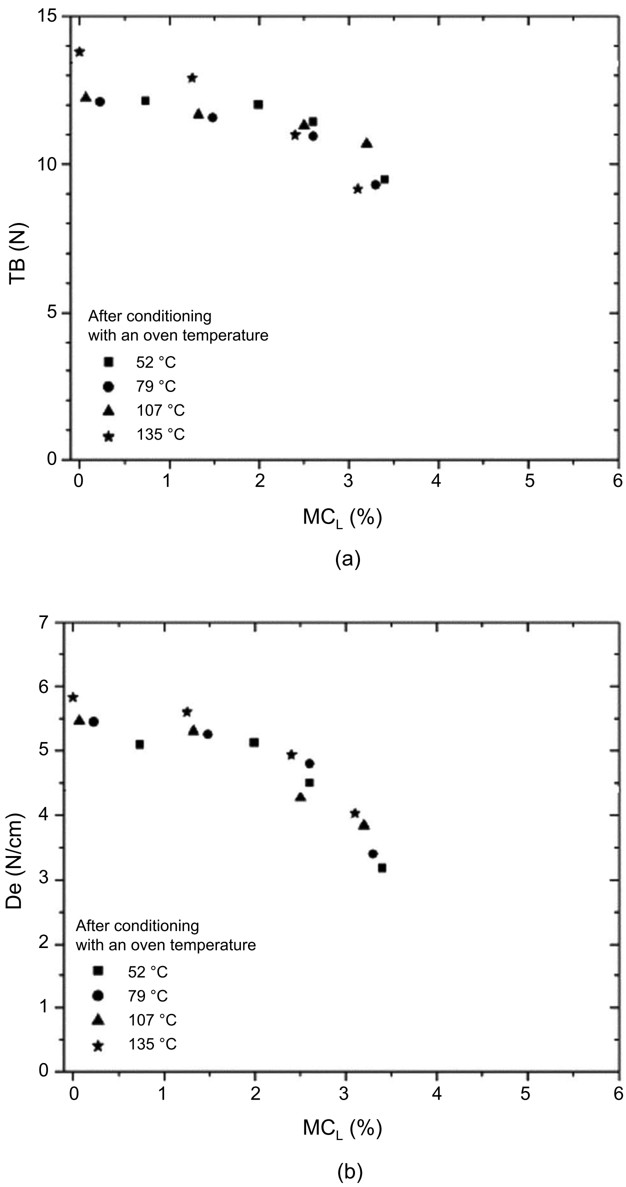

Figure 12. Mechanical properties of latex-backed carpet as a function of MC_L: (a) tuft bind and (b) delamination strength. MC_L is the lowest MC experienced by sample in either drying or conditioning.

together, forming a continuous film. It is conjectured that once MC is very low, raising the latex temperature increases molecular motion of the polymer molecules in the latex and promotes further consolidation of the polymer film. As result, mechanical properties improve.

The conclusions drawn in this paper were based on tests using cut-pile, nylon 6,6 carpet. Carpet produced from other fibers such as polyethylene terephthalate (PET) may have a different affinity for latex. Thus, a fiber such as PET may not be run in the backcoating tenter at the same curing conditions as nylon 6,6. Any yellowing effect associated with high oven temperature would be compensated for by longer residence times at lower temperatures.

Conclusions

The effects of drying parameters and conditioning on mechanical properties of latex-backed carpet were investigated. Lowering MC was necessary to develop mechanical properties; however, the highest value of TB and De occurred at the highest latex temperature of 119°C, indicating that raising latex temperature can improve mechanical properties if MC is sufficiently low.

Conditioning of the samples for 24 hours can increase the mechanical properties of the samples, but the effect depends on the initial value of MC. The samples with higher initial MC showed larger increases in mechanical properties after conditioning. Mechanical properties are clearly correlated with MC_L.

Acknowledgements

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