FINAL REPORT

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DEVELOPMENT OF A PROCESS FOR CONTINUOUS DYEING OF PET CARPET AND MACHNOZZLE PRE-STEAMING IN NYLON CARPET FINISHING

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Executive Summary

The carpet industry has for many years wished to convert the coloration of residential polyethylene terephthalate (PET) carpet from batch processes (i.e., becks) to continuous processes. Benefits of converting this important segment of carpet production from batch to continuous processes are many, assuming that the run volumes are of critical, large size. However, on typical pad (or slot apply)-nip-steam-wash continuous carpet dye lines, process speed is very low due to the extremely long dwell times required in the steamer to fix the dyes. Thus the productivity of continuous lines for the coloration of residential polyester carpet is low. Earlier work conducted in continuous dyeing of heavy-weight, commercial nylon carpet showed that a Machnozzle® slot steam device can rapidly bring the saturated carpet temperature after dye application (typically 350-400% wet pickup of liquor) to the desired 150-190°F range, thus reducing the required time in the steamer.

The first objective of the reported research was to determine if the insertion of a slot steamer system (Machnozzle) into a pilot polyester carpet continuous line just after the disperse dye pad and before the main steamer could reduce the required dwell time in the steamer, and consequently increase process speed. A second objective of the work was to evaluate the effect of Machnozzle pre-steaming on carpet finishing (combined stain repellency/stain block application). One of the tasks of the finishing research was to determine if pre-steaming the carpet after the application of finishing chemicals (stain repellency/stain block) and before steaming in an atmospheric steamer would increase the level of fluorine incorporation into the carpet. The fluoropolymer (FP) stain repellency agents are very expensive, and the current pad/steam commercial process results in only ~85% incorporation of the FP finish. Another was to better understand how thermal treatment affected the incorporation of finishing chemicals into the carpet structure.

PET dyeing experiments were conducted to determine the effect of several Machnozzle parameters on required dyeing time and color values (CIE L^*, a^* and b^*) of the face and back of the dyed carpets of dyed PET carpet. Preheating using the Machnozzle steam slot applicator did not improve the PET dyeing fixation rate for dyeing light-weight PET to medium-shade. This finding is different from the results for dyeing heavy weight nylon carpet where significant decreases in dwell time in the atmospheric steamer were required. The difference is explained by the fact that PET is much more difficult to dye than nylon and the weight of the PET sample was much lower. The dwell time required for dyes to migrate into the PET carpet structure is long compared to the heat up time in the steamer. Consequently the effect of rapidly heating the PET carpet did not significantly impact steaming time in the atmospheric steamer. Another reason that the Machnozzle did not have a significant effect on required steaming time in the atmospheric steamer is the very low yarn face weight (20 oz/yd^2) of the PET carpet. The Machnozzle steam slot applicator can shorten the heating time from 90 second (in atmospheric steamer) to 1~2 second for heavy-weight carpet (65 oz/yd^2), but only from 15 seconds to 1~2 second for light-weight carpet. In the current project, the supplied PET carpet had a low pile

weight of 20 oz/yd^2, and thus the steam slot applicator did not provide a large advantage over the atmospheric steamer alone in rapid heating of the structure.

Finishing tests without pre-steaming were first conducted to determine the required steaming time for complete fixation of finishing agents in the atmospheric steamer. Then tests for six combinations of Machnozzle operational parameters were conducted where the carpet with finish applied was preheated with the Machnozzle and then steamed in the atmospheric steamer for times varying from 0 to 60 seconds. Three tests were conducted to evaluate the incorporation of finish into the carpet. The fluorine content of carpet pile fiber and water drop penetration tests were used as indicators of how well the fluoropolymer is operating. The stainblock test was used as an indicator of how well the stain block polymer component of the finish formulation is operating. For the samples steamed less than 60 second in the atmospheric steamer, the fluorine content was lower than the acceptable value. However, increase in steaming time longer than 60 seconds did not have a significant effect on fluorine content, indicating that the steaming time of 60 seconds currently used is sufficient to reach an acceptable value of fluorine content. Pre-steaming with the Machnozzle without steaming in the atmospheric steamer was sufficient to incorporate the fluorocarbon stain repellency agent into the carpet structure. However, steaming in the atmospheric steamer following pre-steaming with the Machnozzle did not increase the fluorine content in the fiber above that for Machnozzle preheating only. Thus, the results indicate that pre-steaming the carpet after the application of the finishing chemicals (stain repellency/stain block) and before steaming in an atmospheric steamer will not increase the level of fluorine incorporation into the carpet. Samples pre-steamed using the Machnozzle gave superior stainblock ratings to that for steaming of 60 seconds in the atmospheric steamer only. The samples treated with the Machnozzle had a much better uniformity of stain blocking performance than those treated in the atmospheric steamer only.

Research Objectives

One objective of the research was to determine if the insertion of a slot steamer system (Machnozzle) into a pilot continuous line just after the dye pad and before the main steamer could reduce the required dwell time in the steamer, and consequently increase process speed. The project used a similar approach to that used for Machnozzle-assisted dyeing of heavy weight Nylon 6,6 carpet; however, PET's structure is different from that of Nylon 6,6, and it is much more difficult to dye. The effects of incorporation of the Machnozzle on the required box steaming times of light weight PET carpet at various dye loadings (light, medium and dark shades) were evaluated. Dye utilization and fixation with the developed process line versus the conventional line were compared and the potential effects on process speed were evaluated.

A second objective of the work was to evaluate the effect of Machnozzle pre-steaming on carpet finishing (combined stain repellency/stain block application). One of the tasks of the finishing research was to determine if pre-steaming the carpet after the application of the finishing chemicals (stain repellency/stain block) and before steaming in an atmospheric steamer would increase the level of fluorine incorporation into the carpet. This is important because these finishing agents are very expensive. Another was to better understand how thermal treatment affects the incorporation of finishing chemicals into the carpet structure.

Experimental

Materials

Polyester Dyeing Tests - Light-weight, tufted PET polyester carpet (pile yarn weight 20 oz/yd^2, greige), disperse dyes and auxiliary chemicals were provided by Mohawk Industries, Inc., as well as the dye formulation (Table I). They represent a typical polyester carpet and color shade for a continuous dyeing process.

Table I. Dyeing formula for polyester (PET) carpet.

Disperse Dyes/Chemicals		Concentration (g/L)
Dyes	Blue 56/77	0.2735
	Red CDS	0.3463
	Yellow BG	0.4098
Chemicals	Arrolev 2186R (carrier)	2.5
	DAD (wetter)	0.85
	Chelate	0.7
	Buffer SAC (pH control)	1.0

Nylon Finishing Tests –Materials (see Table II), including nylon 6 carpet (pile weight of 38 oz/ yd^2), finishing chemicals and formulation were provided by Mohawk Industries, Inc. The formula used in the industrial process is prepared for net wet pickup of 100%; however, the water residual left in the carpet from the previous washing and extraction steps after dyeing is ~40-50%, so the actual total wet pickup at the finishing step is ~150%. Thus, in our lab tests, we added 50% water to the formula, and wet pickup was controlled to be ~150%. Thus the actual chemical pickup in our lab tests was the same as that in the industrial process.

Table II. Finishing formula for nylon carpet (pile weight of 38 oz/yd^2).

Chemicals	Concentration (g/L)
System 404 acid	2 - 3 (adjust amount to get pH of 2.0 - 2.2)
Epsom salt (40% liq.)	21
Arrofoam 2309A	*4 (If padding instead of foaming, omit it)*
3M's PM 1400	5.5
3M's FC 700	37.5

Experimental Setup

The experimental setup (located at Georgia Power Company's Technology Center) for the PET dyeing test and nylon finishing tests was built is shown schematically in Fig. 1. Steam was provided by a boiler (Chromalox CES 60) controlled using a pressure transducer (Omega PX-4200), a proportional-integral-derivative (PID) controller (Chromalox 2104), and a silicon-controlled rectifier (SCR) (Chromalox MaxPac II). A ball valve was used to adjust the steam flow rate to a 16-inch-wide Machnozzle slot steam applicator (Brugman Machinefabrik BV, Holland) and box steamer (Mid-South Metalworks, Dalton, Georgia). Steam flow rates were measured using a vortex steam flow meter (OMEGA FV-500B). A conveyer belt with adjustable speed was utilized to obtain different dwell times under the preheating device. Metal shims with various thicknesses were used to adjust the steam slot opening width.

Experimental Procedures

Test procedures for PET dyeing and nylon finishing tests were similar; however, some test parameters were different: the total wet pickup of PET dyeing was 400% while the total wet pickup of nylon finishing was 150%; and steaming time for PET dyeing was much longer than that for nylon finishing. The main process steps are briefly described next. A roll of carpet was cut into 12 inch by 12 inch test samples. The individual carpet sample was weighed, soaked in 2L of chemical (dye or finish) solution for 30 seconds, and then passed through a set of squeeze

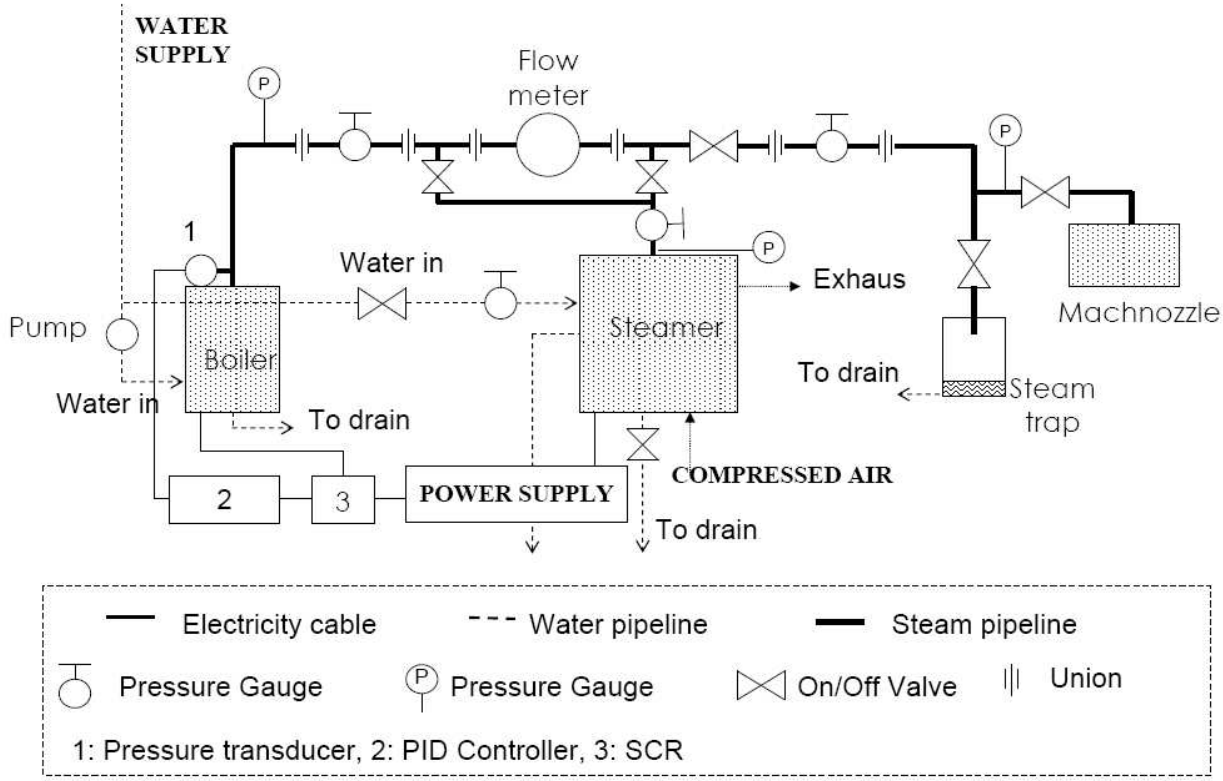

FIG. 1. Schematic of experimental setup

rollers two or three times to give wet pick-up of ~400% (in the range of 390-410%) for PET dyeing and ~ 150% (in the range of 140-160%) for nylon finishing. The required steaming time for tested samples receiving no pre-heating was first determined and used as a basis for evaluating the effect of steam slot preheating. Then tests on samples preheated using the Machnozzle slot steam applicator were conducted. The wetted sample was preheated by passing the face of the padded carpet at various proximities to and underneath the slot steam applicator (slot length of 12 inches), followed by steaming in an atmospheric box steamer. Samples were steamed over a range of times. After pre-heating, samples were placed in the atmospheric batch steamer for a range of dwell times. The dyed PET carpet sample was then washed in cold water; for nylon finishing, simple spay washing was used and in some cases the samples were dried directly without washing. Excess water was removed by vacuuming until the wet pick-up reached approximately 100%. The sample was then dried using a tumble home dryer (at a maximum temperature of about 160°F) and conditioned for at least four hours in a standard testing laboratory (70°F and 65% RH) before further measurements were made to evaluate the dyeing or finishing effects. All tests were replicated at least three times.

For the PET dyeing test, color measurements were made to evaluate the dye pickup of the dyed PET carpet. For the nylon finishing test, three measurements were conducted, including fluorine content (FP specific), water bead drop test (FP specific), and red dye stain (stain blocker polymer specific). The first two measurements were used for evaluating fixation of the stain repellency

FP agent, and the last one was used for evaluating the fixation and effectiveness of the stain blocker agent during the finishing process.

Operational Parameters of Steam Slot Applicator

To determine optimum process conditions for the slot steam applicator, several operational parameters (including flow rate, slot opening, and belt speed) for the steam slot applicator were varied for the PET dyeing and nylon finishing tests. First, we calculated the theoretical amount of steam needed for the carpet sample to reach a temperature of 211°F. These were 0.1 lbs for the PET samples and 0.08 lbs for nylon samples. Then, the steam flow rate, slot opening and belt speed were adjusted to obtain identical steam amounts applied on the samples for different steam jetting speeds. Base on previous studies, the flow rate to the steamer was selected as 60 lb/hr since a higher value does not increase the heating rate significantly. Machnozzle mounting location, i.e., separation distances from the pile tips to the slot, was set as zero. For our previous study, this location gave the highest heating efficiency.

Measurement Methods

Color measurement - Dye fixation was evaluated by measuring the CIE L^*, a^* and b^* color values of the face and back of the dyed carpets using a Hunterlab Reflectometer Ultrascan XE. Five different locations on each sample were selected and measured. L^* represents the darkness-lightness of the shade ($L^* = 0$ indicates black and $L^* = 100$ indicates pure white), a^* represents the shade position between red and green (negative value indicates green while positive value indicates red), and b* represents the shade position between yellow and blue (negative value indicates blue and positive value indicates yellow). The standard reference samples, which were not exposed to MN pre-steaming, were prepared by varying the steaming times in the atmospheric steamer until dye utilization and fixation for each shade was optimized. Color differences (Del E^*) were calculated to represent the relative extent of dye fixation and shade development between the reference (steamer only) and MN pre-heated samples:

$$Del\ E^* = \sqrt{\left(L^* - L_r^*\right)^2 + \left(a^* - a_r^*\right)^2 + \left(b^* - b_r^*\right)^2} \qquad \text{Eq. 1}$$

$L^*a^*b^*$ and $L_r^*a_r^*b_r^*$ are the color values of MN pre-heated test samples and steamer-only reference samples, respectively.

Evaluation of nylon finishing - Three tests were conducted to evaluate the incorporation of finish into the carpet. Brief descriptions of these follow:

Fluorine content of carpet pile fiber – The amount of the fluorocarbon stain repellency agent present on carpet pile fibers was determined by measuring the fluorine on fibers. The tests, which are based on AATCC 189 [1], were conducted by Mohawk Industries, Inc. A typical value for finished nylon carpet is 305 ± 38 ppm.

Water drop penetration test [2] - A 1% solution of direct Red 80 dye in distilled water was prepared to be used as the drop medium. The red dye was used to provide contrast between the water drop and the nylon carpet sample. Drops of the colored solution (approximately 50 μL) were placed from a height of 1 cm onto the surface of the carpet sample. Photographs were taken at time intervals of 1, 10 and 60 minutes. Drops on a more hydrophobic surface (higher fluorine content) exhibited a nearly spherical shape and required a longer time to penetrate into the carpet.

Stainblock test [2] – This test is based on AATCC Test Method 175 -2003. The carpet specimen was immersed 1 cm in double-strength, cherry-flavored Kool-Aid® solution at 60 °C for 60 seconds, rinsed in cold water and dried by line dry. The stain repellency of test samples was rated by using the AATCC Red 40 Stain Score – a grade of 10 is no stain and 1 is stained severely.

Results and Discussion

Part I: PET Dyeing Tests

PET dye fixation in atmospheric steamer (without Machnozzle preheating)

Dyeing tests without pre-steaming were first conducted to determine the required steaming time for complete dye utilization and fixation in the atmospheric steamer. The color differences measured on the carpet face and back are shown as a function of steaming time. The color differences (Del E^*) were based on the samples dyed at steaming times of 10 min. serving as the "standard." Test results showed that ΔE was sufficiently small for times greater than 10 min. Thus these samples were selected as "steamer only" reference samples.

Table III. Steaming time vs. color difference (the "standard" is the sample with a steaming time of 10 min).

Steaming Time* (min)	Face				Back			
	L	a	b	Del E	L	a	b	Del E
6	35.23	10.30	9.35	1.51	44.54	8.49	9.01	1.34
8	34.75	10.43	9.62	1.03	43.95	8.60	9.08	0.77
10	33.73	10.38	9.51	0.00	43.22	8.42	9.21	0.00
12	33.45	10.49	9.48	(-)0.31	43.12	8.52	9.07	(-) 0.20
20	32.72	10.41	9.51	(-)1.02	42.43	8.20	8.96	(-) 0.86

* In the atmospheric steamer

PET dyeing fixation in atmospheric steamer after Machnozzle preheating

Base on our previous study [3], we started our preheating tests using the parameter combination: slot opening of 6 mils, steam flow rate of 29 lb/hr and belt speed of 4 ft/min. The test results are shown in Table IV. Compared with the "standard" samples of 10 min. steaming time only, Machnozzle preheating did not significantly increase the dye fixation speed. The higher values of L* indicates a lighter shade on the face and back than the standard, and the color differences Del E* between the reference samples and the MN pre-heated samples were >1.0 on the front and >0.5 at eight minutes of steaming time post-Machnozzle (the critical value indicating a significant color difference detectable by the eye between two samples is Del E* ~1.0). Based on these results, the next tests were conducted using a higher steam jetting speed.

Table IV. PET dyeing with Machnozzle (MN) pre-steaming (flow rate of 29 lb/hr, belt speed of 4 ft/min, slot opening of 6 mils, and steam jetting speed of 113 m/s).

	Steaming Time* (min)	Face				Back			
		L	a	b	ΔE	L	a	b	ΔE
Steaming only	10	34.45	10.78	9.59	0.00	42.68	8.32	8.65	0.00
MN pre-steaming	2	38.43	8.84	9.45	4.43	46.00	7.30	8.31	3.50
MN pre-steaming	4	37.46	10.01	9.63	3.10	44.23	7.95	8.67	1.60
MN pre-steaming	6	36.75	9.98	9.83	2.44	43.10	8.30	8.62	0.43
MN pre-steaming	8	36.16	10.26	9.73	1.79	42.94	8.54	8.72	0.35

* In the atmospheric steamer

In Table V, test results are summarized for a steam flow rate of 51 lb/hr, belt speed of 7 ft/min, and slot opening of 6.0 mils. Under these conditions, the steam jetting speed was about 198 m/s. Lighter (worse) color shade on the carpet face and darker (better) shade on the carpet back were obtained. These results indicated that the steam was blowing dye liquor to the back of the light-weight polyester carpet sample. Thus, for our next tests, we decreased the steaming jetting speed to reduce this effect.

The Machnozzle operational parameters were next adjusted to obtain a steaming jetting speed of 80 m/s. Test results are given in Table VI. However, the color differences Del E* were still higher than the critical value of ~1.0 on the face of the carpet, even at the eight minute steaming time post-MN.

In an effort to get acceptable results using the Machnozzle, the steam speed was then reduced to 57 m/s. The slot opening was increased to 12 mils, and the steam flow rate and belt speed were held at the same values as in the previous tests. The results are given in Table VII. The color differences were smaller than those in the previous test. This was interpreted to indicate that a lower jetting speed reduces the amount of dye liquor blown off and/or through the light-weight

Table V. PET dyeing with Machnozzle pre-steaming (flow rate of 51 lb/hr, belt speed of 7 ft/min, slot opening of 6.0 mils, and steam jetting speed of 198 m/s).

	Steaming Time* (min)	Face				Back			
		L	a	b	ΔE	L	a	b	ΔE
Steaming only	10	33.05	11.20	9.01	0.00	42.18	8.76	8.63	0.00
MN pre-steaming	2	37.14	8.94	9.42	4.69	44.97	7.89	8.36	2.93
MN pre-Steaming	4	36.05	9.90	9.83	3.37	42.82	8.49	8.75	0.70
MN pre-Steaming	6	35.12	10.31	9.57	2.32	41.52	8.75	8.74	(-)0.68
MN pre-Steaming	8	34.63	10.13	9.84	2.08	41.50	8.73	8.79	(-)0.70

* In the atmospheric steamer

Table VI. PET dyeing with Machnozzle pre-steaming (flow rate of 29 lb/hr, belt speed of 4 ft/min, slot opening of 8.5 mils, and steam jetting speed of 80 m/s).

	Steaming Time* (min)	Face				Back			
		L	a	b	ΔE	L	a	b	ΔE
Steaming only	10	33.07	10.61	9.37	0.00	42.76	8.72	8.44	0.00
MN pre-steaming	2	38.61	9.03	9.30	5.76	46.57	7.65	8.37	3.96
MN pre-steaming	4	38.43	9.84	9.59	5.42	44.20	8.15	8.47	1.55
MN pre-steaming	6	36.37	10.42	9.38	3.31	43.01	8.53	8.54	0.33
MN pre-steaming	8	35.56	10.66	9.35	2.50	42.85	8.65	8.49	0.13

* In the atmospheric steamer

Table VII. PET dyeing with Machnozzle pre-steaming (flow rate of 29 lb/hr, belt speed of 4 ft/min, slot opening of 12 mils, and steam jetting speed of 57 m/s).

	Steaming Time* (min)	Face				Back			
		L	a	b	ΔE	L	a	b	ΔE
Steaming only	10	32.73	10.48	9.68	0.00	42.26	8.68	8.83	0.00
MN pre-steaming	2	36.83	8.28	10.19	4.68	45.61	7.48	8.78	3.56
MN pre-steaming	4	34.97	9.40	9.84	2.49	44.28	8.18	9.01	2.09
MN pre-steaming	6	34.65	10.11	9.66	1.96	43.24	8.68	8.90	0.98
MN pre-steaming	8	33.74	10.56	9.55	1.02	42.88	8.81	8.86	0.64

* In the atmospheric steamer

carpet structure. However, the color difference of the face of the eight minute, post-MN steamed carpet barely met the targeted ~1.00 Del E* value with a one unit higher L* value, although the back of the sample carpet matched the standard in both Del E* and L* values. With the conclusion that dye liquor was still being blown to the back and/or through the light-weight carpet, the jetting speed was further decreased for the next test.

The steam jetting speed was reduced to 42 m/s by increasing the slot opening to 16 mils and holding the steam flow rate and belt speed at the same values as in the previous tests. Under these conditions, color values did not improve (see Table VIII), e.g., color differences on the carpet face were much higher than the target value of ~1.0 and the L* value of the sample was two units higher than that of the standard. Again, however, the shade on the back of the carpet matched that of the standard in both Del E* and L* values at the eight minute post-MN steaming time.

The jetting uniformity of the steam slot applicator at a lower flow rate was not optimum, so we next doubled the steam flow rate and increased the belt speed to 8 ft/min, which maintained the amount of steam applied per sample. Tests results are shown in Table IX. Color differences and L* values increased at the face increased compared to those in Table VIII, indicating a poorer dyeing correlation, although again the shade at the back of the carpet matched that of the standard at the eight minute post-MN steaming time.

Table VIII. PET dyeing with Machnozzle pre-steaming (flow rate of 29 lb/hr, belt speed of 4 ft/min, slot opening of 16 mils, and steam jetting speed of 42 m/s).

	Steaming Time* (min)	Face				Back			
		L	a	b	ΔE	L	a	b	ΔE
Steaming only	10	32.62	10.34	9.42	0.00	42.14	8.39	8.52	0.00
MN pre-steaming	2	37.06	8.41	9.14	4.85	45.38	7.47	8.39	3.37
MN pre-steaming	4	35.73	9.33	9.40	3.27	43.46	8.19	8.53	1.33
MN pre-steaming	6	34.45	9.91	9.16	1.90	42.69	8.44	8.59	0.55
MN pre-steaming	8	34.39	9.88	9.39	1.83	41.92	8.51	8.60	-0.27

*In the atmospheric steamer

Table IX. PET dyeing with Machnozzle pre-steaming (flow rate of 58 lb/hr, belt speed of 8 ft/min, and slot opening of 16 mils, and steam jetting speed of 84 m/s).

	Steaming Time* (min)	Face				Back			
		L	a	b	ΔE	L	a	b	ΔE
Steaming only	10	33.79	10.37	9.19	0.00	43.56	8.57	8.71	0.00
MN pre-steaming	2	37.46	8.24	9.28	4.24	46.18	7.42	8.51	2.87
MN pre-steaming	4	36.87	9.37	9.43	3.24	44.51	8.14	8.68	1.05
MN pre-steaming	6	36.17	9.87	9.43	2.45	43.29	8.60	8.80	-0.28
MN pre-steaming	8	36.36	10.05	9.35	2.59	42.90	8.67	8.79	-0.67

* In the atmospheric steamer

Conclusions for Part I: PET Dyeing Tests

Preheating using the Machnozzle steam slot applicator did not significantly improve the dyeing fixation rate for coloration of light-weight PET to a medium shade, most specifically the face of the carpet. This finding is different from the results for dyeing heavy weight nylon carpet where significant decreases in dwell time in the atmospheric steamer were observed with the Machnozzle steamer inserted in-line. The difference can explained by the fact that PET is much more difficult to dye than nylon and that the face weight of the PET sample was much lower than that of the previously-studied nylon carpet. The dwell time required for dyes to migrate into the PET carpet structure is long compared to the heat up time in the steamer. Consequently the effect of rapidly heating the PET carpet did not significantly impact steaming time in the atmospheric steamer. Another reason that the Machnozzle did not have a significant effect on required steaming time in the atmospheric steamer is the very low yarn face weight (20 oz/yd^2) of the PET carpet. Base on our previous study on heating process of carpet samples, the Machnozzle steam slot applicator can shorten the heating time from 90 second (in atmospheric steamer) to 1~2 second for heavy-weight carpet (65 oz/yd^2), but only from 15 seconds to 1~2 second for light-weight carpet. In our current project, the PET carpet had a low pile weight of 20 oz/yd^2 and thus the steam slot applicator does not provide a significant advantage over atmospheric steaming alone in rapid heating.

The experimental results indicate that for some operating conditions, the Machnozzle moves the dye liquor from the tips of the face yarns in the light-weight polyester carpet towards the primary backing and/or blows the dye solution out of the carpet. This problem was not encountered with the previously-researched heavy weight nylon carpet. This is believed to be associated with the very low weight of the face yarns and the much more open construction of the polyester carpet.

The question of whether Machnozzle line inclusion could decrease the required steaming time in the continuous, dark-shade coloration of heavy-weight (60-70 oz/yd2) polyester carpet, much of which is now processed by the industry on batch exhaust jet dyeing machines, was not addressed in this project.

Part II: Nylon Finishing Tests

Finishing tests without pre-steaming were first conducted to determine the required steaming time for complete fixation of finishing agents in the atmospheric steamer. Then tests for six combinations of Machnozzle operational parameters were conducted where the carpet with finish applied was preheated with the Machnozzle and then steamed in the atmospheric steamer for times varying from 0 to 60 seconds.

Three tests were conducted to evaluate the incorporation of finish into the carpet. The fluorine content of carpet pile fiber and water drop penetration tests were used as indicators of how well the fluoropolymer is operating. The fluorine content test is a standard tests conducted by our industry partner, and the expected value ranges from 267 to 343 ppm. The water drop test is also an indicator of how well the fluoropolymer stain repellent is operating. A drop (approximately 50 μL) of 1% solution of Direct Red 80 dye in deionized water is released at a height of 1 cm onto the surface of the carpet sample. Observations are made and photos are taken at time intervals of 1, 10 and 60 minutes and qualitatively evaluated.

The stainblock test was used as an indicator of how well the stain block polymer component of the finish formulation is operating. The carpet specimen was immersed 1 cm in double-strength, cherry-flavored Kool-Aid® solution at 60 °C for 60 seconds, rinsed in cold water and dried by line dry. The stain repellency of test samples was rated by using the AATCC Red 40 Stain Score where a grade of 10 is no stain and 1 is stained severely.

In Table X, the results of the fluorine content and stainblock (stain repellency) tests for steaming in the atmospheric steamer are given. For unfinished carpet, fluorine content is 0% and stain repellency rating is 0. In Table X, samples with a steaming time of zero were dried in the tumble dryer directly without steaming in the atmospheric steamer, spray washing, and vacuuming. For the samples steamed less than 60 seconds, which is the time used by our industry partner, the fluorine content was lower than the acceptable value. However, increase in steaming time longer than 60 seconds did not have a significant effect on fluorine content, indicating that the steaming time of 60 seconds currently used is sufficient to reach an acceptable value of fluorine content.

The stainblock tests ratings for all finished samples was superior to that of the unfinished carpet. However, the stain repellency of finished nylon samples decreased with steaming time in the atmospheric steamer.

The water drop test indicated that the fluoropolymer stain repellent is operating well. Drops had a nice spherical-cap shape on the finished nylon samples, but penetrated into unfinished carpet quickly (< 1 min).

Table X. Fluorine content and stain repellency of finished nylon samples in the atmospheric steamer only.

Steaming time (sec)	Wet pickup* (%)	Fluorine content (%)	Stain repellency (grade)
0	154	136	7
30	155	197	6
60	155	325	6
120	152	342	5

*Target wet pickup of 150%.

In Table XI, the results of the fluorine content and stainblock (stain repellency) tests for the six combinations of Machnozzle operational parameters are given. Samples with a steaming time of zero were dried in the tumble dryer directly after passing through the steam slot applicator and without steaming in the atmospheric steamer, spray washing and vacuuming. The results of the fluorine content test indicate that preheating with Machnozzle without steaming in the atmospheric steamer is sufficient to incorporate the fluorocarbon stain repellency agent into the carpet structure. This is true for all six combinations of Machnozzle operational parameters. Similar values of fluorine content were obtained for the Machnozzle preheating only to those for steaming only in the atmospheric steamer for 60 seconds. However, steaming in the atmospheric steamer following pre-steaming with the Machnozzle did not increase the fluorine content in the fiber above that for Machnozzle preheating only. Thus, the results indicate that pre-steaming the carpet after the application of the finishing chemicals (stain repellency/stain block) and before steaming in an atmospheric steamer will not increase the level of fluorine incorporation into the carpet.

The water drop penetration test results indicate that there is no significant difference in drop penetration into carpet among samples steamed in the steamer only and those pre-steamed using the Machnozzle for the six combinations of operational parameters.

Samples pre-steamed using the Machnozzle gave superior stainblock ratings (mostly 8 for five Machnozzle operational parameters) to a rating of 6 for steaming of 60 seconds in the atmospheric steamer only. The exception was for the operational condition giving the highest steam jetting speed. The results indicate that a low steam jetting speed is preferred for better stain repellency performance of the nylon finishing process.

A significant advantage associate with using the Machnozzle lies in the uniformity of the stain block polymer component of the finish formulation present on the carpet pile fiber. The samples

treated with the Machnozzle had a much better uniformity of stain blocking performance than those treated in the atmospheric steamer only.

Table XI. Fluorine content and stain resistance of finished nylon samples with Machnozzle preheating followed by steaming in the atmospheric steamer.

MN operational parameters	Steaming time (sec)	Wet pickup* (%)	Fluorine content (%)	Stain repellency (grade)
6 mils[a] 34lb/hr[b] 12 ft/min[c]	0	152	358	8
	15	154	263	8
	30	154	297	8
	60	156	323	8
6 mils 67 lb/hr 6 ft/min	0	156	317	8
	15	153	231	7
	30	156	255	8
	60	156	324	8
6 mils 90 lb/hr 16 ft/min	0	154	324	7
	15	153	221	7
	30	154	268	7
	60	149	296	6
12 mils 34 lb/hr 6 ft/min	0	157	314	7
	15	159	264	8
	30	153	287	8
	60	153	310	7
12 mils 67 lb/hr 12 ft/min	0	157	286	8
	15	157	281	8
	30	155	294	8
	60	159	328	7
12 mils 90 lb/hr 16 ft/min	0	153	319	8
	15	152	254	8
	30	149	262	8
	60	154	298	7

* Target wet pickup of 150%
a. Slot opening width
b. Steam flow rate
c. Conveyor belt speed

Conclusions for Part I: Nylon Finishing Tests

For the samples steamed less than 60 second in the atmospheric steamer only for less than 60 seconds, the fluorine content was lower than the acceptable value. However, increase in steaming time longer than 60 seconds did not have a significant effect on fluorine content, indicating that the steaming time of 60 seconds currently used is sufficient to reach an acceptable value of fluorine content. Pre-steaming with the Machnozzle without steaming in the atmospheric steamer was sufficient to incorporate the fluorocarbon stain repellency agent into the carpet structure. This was true for all six combinations of Machnozzle operational parameters. However, the test results indicate pre-steaming the carpet after the application of the finishing chemicals (stain repellency/stain block) and before steaming in an atmospheric steamer will not increase the level of fluorine incorporation into the carpet. Samples pre-steamed using the Machnozzle gave superior stainblock ratings to that for steaming of 60 seconds in the atmospheric steamer only. The samples treated with the Machnozzle had a much better uniformity of stain blocking performance than those treated in the atmospheric steamer only.

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