MECHANICAL FIXATION OF TUFTED PILE LOOPS INTO THE PRIMARY BACKING BY USING THE PARAMETERS OF FABRIC WEAVE DESIGN

Application of Newly Developed Yarn Tension Compensation Device for Tufting of Technical Yarns

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Abstract: *Tufting technology is commonly used exclusively for the production of textile floor coverings. With the e-Jerker, the TFI - Institut für Bodenbeläge an der RWTH-Aachen e.V. has developed a yarn storage element that can be parametrised and retrofitted to existing tufting machines, which allows the processing of low-stretch and high-strength pile yarns. In the future, this will enable tufting producers to offer completely new products for innovative applications in the field of technical textiles. A tufted textile is particularly suitable for applications where insulating, shielding or absorbing properties are required due to its three-dimensional pile structure. However, since the latex coatings traditionally used for securing the tufted backing are out of the question for technical applications in which high temperatures have to be considered, heat-resistant alternatives are required. In the current research project "High-Performance Tufting Structures", two alternatives were evaluated with regard to their suitability. On one hand, woven primary backing materials were developed which, in combination with the needled pile yarns, achieve the highest possible pile binding forces. This should allow the omission of coatings entirely, if necessary. On the other hand, temperature-resistant formulations for back coatings based on PU and silicone were also developed. The investigations focused on the use of glass yarns for both the primary backings and the pile yarns. In general, it can be said that both the feasibility of production and the acoustic and thermal properties of a tufted technical textile open up new application possibilities.*

Keywords: *Tufting, primary backing, technical textiles, weave design, heat-resistant coating, glass yarn.*

1 INTRODUCTION

Tufting technology is a process for the production of textile surfaces characterised by high productivity. It has been conventionally used for decades to produce textile floor coverings. A tufted product is created by needling pile yarns into a textile base material (non-woven or woven), thus creating a 3-dimensional textile with a pile-surface. In order to produce a stable and usable product, it is necessary to secure the pile to the backing using a back coating. This prevents the pile yarns from coming loose during use. Depending on the machine type and fineness, the tufted 3D structure can be very variable in terms of pile height and ranges from a few millimetres to several centimetres. Correspondingly, the overall density can also be adjusted. 85% of the yarns used to produce tufted floor coverings are synthetic bulked continuous filament yarns (possessing inherent elasticity) made from polyamide, polyester or polypropylene [1]. As only elastic pile yarns can be processed, tufting is limited to the product group of floor coverings.

Expanding the range of usable materials for tufted textiles, with their broad range of possible constructions, unlocks potential applications for technical tuftings. Due to its open pile surface, a tufted surface structure is particularly suitable for applications where insulating, shielding or absorbing properties are required. This, in combination with the use of heat-resistant materials for pile yarns and backings, allows manufacturing of tufted structures that have both high acoustic absorption and thermally shielding effects at the same time. However, since the synthetic latex coatings usually used to strengthen tufted floor coverings are thermally unstable, the only option is not to use a coating at all or, alternatively, to use temperature-resistant formulations.

Both options were investigated in the pre-competitive research project "High-Performance Tufting Structures". The absence of a backside coating to firmly bind the needled pile yarns to the primary backing means that the yarns need to be mechanically anchored in the primary backing with sufficient stability to ensure safe product use. In this project, fabrics for the primary backing were structurally optimized to exhibit the best possible pile clamping forces. For possible applications in which the pile clamping forces achievable in this way are not sufficient or a backside coating is desired, corresponding coating tests with temperature-resistant formulations were carried out.

2 WOVEN PRIMARY BACKINGS

As explained earlier, a core issue within this project is the production of a heat-resistant “primary backing”, i.e. a base fabric suitable for the tufting process. Glass fibres are the best option for a high-temperature-resistant base material for this purpose, as well as being a very economical option.

Pre-trials on different weave constructions using polyester-yarn showed that a tight construction (maximum weft density at high warp densities) as well as the use of texturized weft yarns have a major influence on the retention of tufted yarn in the finished product. Furthermore, warp backed weaves and multi-layer construction showed positive effects regarding the resulting tuft withdrawal forces [2].

The main challenge for the transfer of these results is the production of a stable and relatively tight fabric in warp-backed and double- or multi-layer construction in order to replicate the positive results of the pre-trials.

2.1 Materials and machinery

All trials were executed on a rapier loom (Dornier HTV8/S20). This machine has two warp beams (for increased flexibility regarding warp densities) and 16 shafts (+2 shafts for selvedge production).

Table 1 Materials used in pre-trials vs. experiments with glass yarn

	Code	PES-trials [2]	Glass-trials
Warp / Weft1	Y1	PES 1100dtex 200f Z60	Vetrotex EC11 204 Z28 T63C H8
Weft 2	Y2	PES 1400dtex bulked	Vetrotex ECO11 T220 T10C (voluminized)
Weft 3	Y3	PES 1400dtex air-texturized	Vetrotex ECT9 T370 T10C (air-jet texturized)
Pile Yarn	YP	HKO Thermo-E-Glass Yarn texturized ET6-300 tex x2 z100 TS	

All yarns were selected for their similarities regarding diameter and structure - however, this proved impossible (Y1, Y2, Table 1) due to the availability of certain glass yarn grades. All glass-trials were executed at a warp density of 22 ends/cm and utilized only 8 shafts.

2.2 Test Methods

On tufted samples the force needed to draw out one tuft is measured according to ISO 4919.

2.3 Experimental

Through intensive experimentation in the pre-trials [2] single layer and warp-backed weave constructions could already be eliminated from the main trials with glass yarn. Furthermore, it was found that one weave construction (weave 1, Figure 1) could not be woven with glass yarns, even if the results with PES were hopeful. This is due to the uneven distribution of interlacing points between warp yarns leading to slippage between threads and a high occurrence of warp breaks.

All weaves (Figure 1) are based on plain fabrics, with weaves 1 and 2 representing weft-backed constructions, weave 3 as a double layer fabric made up of plain weaves and weave 4 as a combination of both (one layer is a regular plain weave and one layer is weft-backed weave 2). All weaves were woven in various combinations of the threads listed in 2.1. Table 2 shows the full list of finished fabrics.

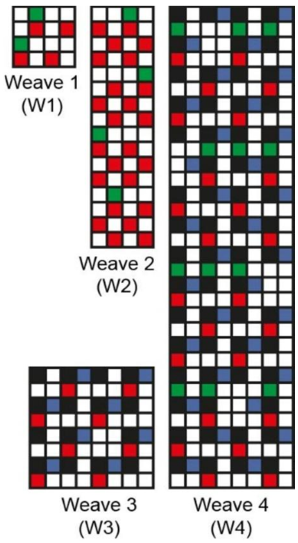

Figure 1 Weaves used in glass-trials

Table 2 List of weave / yarn combinations tested

Code	Max. weft density	
	Glass trials	PES-trials
W2_Y12	8	20
W2_Y13	7	-
W2_Y2	8	16
W2_Y3	6	-
W2_Y23	6	-
W3_Y12	11	14
W3_Y13	10	-
W3_Y2	11	14
W3_Y3	10	14
W3_Y23	10	-
W4_Y12	10	20
W4_Y2	10	20
W4_Y3	9	18

2.4 Results

Compared to the pre-trials on PES, where weft densities of up to 20 picks/cm were achieved for the same weaves, it can be seen that glass fabrics needed a lower density to be weavable, even if theoretical maximum densities should have been closer (Table 2). Nevertheless, these glass fabrics have good slippage resistance and were tufted. The respective tuft withdrawal forces are shown in Figure 2, with the grey line representing the tuft withdrawal force achieved by conventional tufting of bulked continuous filaments in non-woven primary backings.

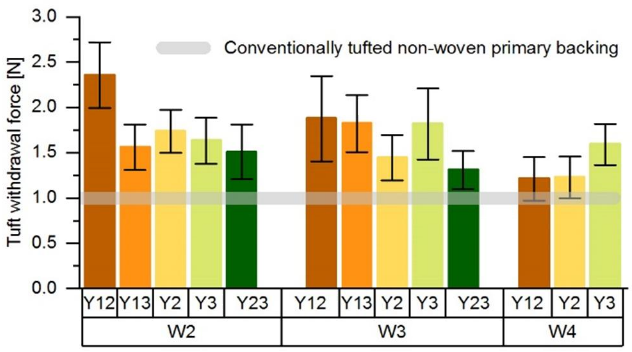

Figure 2 Tuft withdrawal forces of glass trials

2.5 Discussion

While the pre-trials gave some indication that choice of yarn and weave have a major influence on tuft retention, the glass trials do not follow these trends, as is shown in Figure 2. Furthermore, the tuft withdrawal forces do not show any relation to conventional fabric parameters such as thickness, areal weight or air permeability. Weave 4 shows remarkably low tuft withdrawal forces. However, weave W12_Y12 achieved a high tuft withdrawal force of 2.35 N, further confirming the conclusion from the pre-trials that weft-backed weaves result in high tuft withdrawal forces. This fabric will be used in further experiments. All primary backings surpass the tuft withdrawal force of conventional (raw, uncoated) tufted non-woven primary backings, thereby making it clear, that these textiles are stable enough to be manufactured into finished products.

3 TUFTING PROCESS

During tufting, many needles simultaneously stab through the primary backing at tufting cycles of up to 2000 stitches/min. The primary backing is transported by a set distance (stitch length) between each complete needle stroke. Below the primary backing, the pile yarns pierced by the tufting needles are transferred to hooks and formed into yarn loops. In the production of cut pile fabrics, the yarn loops held on the hooks are additionally cut open by knives arranged on the side of the hooks (Figure 3) [3].

A tuft cycle corresponds to a complete, vertical stroke of the needles from the top to the bottom dead center and back to the starting position. When the needle passes through the primary backing and the pile yarn is deposited on the hook, temporary deflections of the yarn feeding mechanism cause yarn consumption to vary over time. However, the vertical displacement of a standard jerker bar (horizontal perforated strip for yarn guidance), which is mechanically coupled to the lifting movement of the needles, does not permit any adjustable yarn storage. Instead, the elasticity of the yarns compensates for the difference between yarn demand and yarn supply.

3.1 Use of e-Jerker

In a previous project by the TFI-Institut für Bodensysteme an der RWTH Aachen e.V., a new yarn storage element was developed which, contrary to the method of operation described above, guarantees a programmable lateral yarn displacement and thus an optimised feeding of the pile yarns to the needles at any time during the tuft cycle [4]. The individual displacement of the pile yarns is effected by a servomotor drive of the e-Jerker. This was used in the project described in this paper in order to enable the use of glass fibres, which are non-elastic.

The programming of the e-Jerker is carried out for each new pile yarn individually to customize processing. For this purpose the variation in yarn feed tension during a single tuft is measured over several tufting cycles using a laser sensor that makes it possible to correlate yarn demand at a given point in the tuft cycle with the corresponding position of the needle.

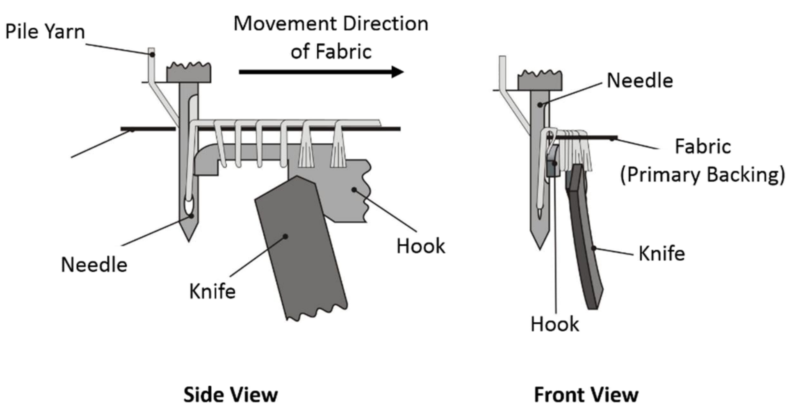

Figure 3 Tufting mechanism for pile fabrics

The motion profile is logged continuously, producing a typical curve which reflects the yarn requirement of this pile yarn for a tuft cycle (Figure 4). The angular positions shown in Figure 4 correspond to the following needle positions during a tuft cycle:

- 0° or 360° Needle at top dead center
- 90° Needle eye at the level of the primary backing
- 90° - 180° Needle to bottom dead center
- 180° - 270° Transfer of the loop to hook

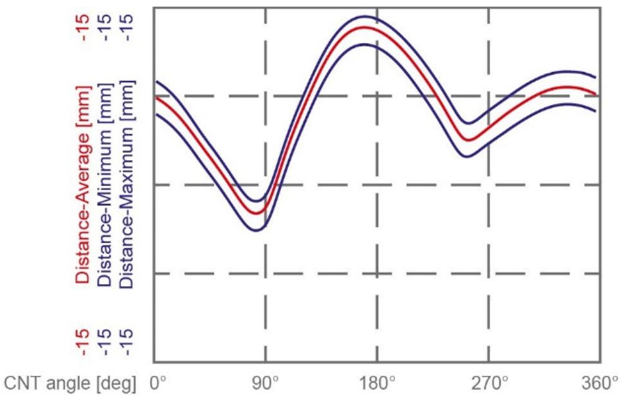

Figure 4 Typical yarn displacement during tufting cycle

The simultaneous video-assisted observation of the tufting tools then allows a precise analysis of any errors or inadequacies during yarn transfer or take-up between needles and hooks. This way it can be decided whether more or less yarn should be delivered from the needles to the hooks at any given time to ensure optimum pile loop formation at all points in the tuft cycle. The adjustment is made by changing splines in the recorded movement curve at those points where errors or inadequacies have been observed in relation to the position of the tufting tools. A motion curve manipulated in this way can then be read into the servomotor control of the e-Jerker as a yarn-specific reference curve.

3.2 Materials and machinery

In the manner described above, mainly glass yarns were measured and their processability in combination with the developed glass fabrics tested. In addition, further tests have shown that low-stretch pile yarns made of aramide, basalt or steel fibres can also be tufted by programming the yarn storage behaviour using the e-Jerker. In addition to the pile yarns mentioned above and the glass fabrics that were investigated in detail, the feasibility of using high-strength aramid fabrics as primary backings for tuftings could also be confirmed. In order to achieve different material finenesses and surface characteristics, test goods were produced on tufting machines of different designs. Cutting and looping machines with machine gauges of 1/10 inch and 1/8 inch were used.

4 HEAT-RESISTANT COATINGS

As the goal of a tuft withdrawal force higher than 7N cannot be reached by weave construction alone, a coating with comparable heat resistance is necessary for sufficient tuft retention. The main demands are avoidance of halogenated flame-retardants, improved mechanical stability of the glass fibre fabric after direct contact to flames, limited smoke emission and good coating behavior.

4.1 Materials

In order to achieve different draping behaviors, two different matrix-systems were considered: Polyurethane dispersions for a stiffer fabric and 2K-silicone for a softer drape. The flame retardants tested are shown in Table 3.

4.2 Test method

In order to test the coating resistance against direct contact to flames, testing according to ISO 15025 was considered, but no differences regarding coating performance were observed. Therefore a non-standardized method utilizing a Bunsen-burner and an infrared camera was developed (Figure 5).

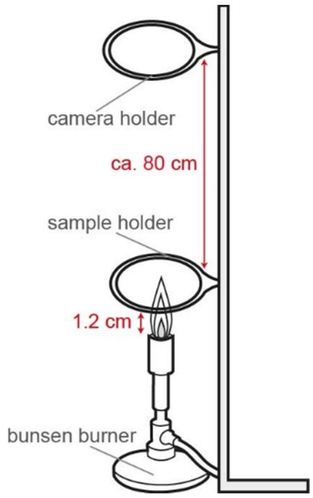

Figure 5 Test set-up for burn tests

The main criteria are burning behavior, smoke generation and fibre damage after burning. The infra-red videos can be used supplementally to gain more information on heat dissipation, especially in tufted fabrics. The camera used is a FLIR ONE thermal imaging camera. Figure 4 shows a sketch of the test set-up. The textile is placed coated side down on the sample holder and exposed to the flame for 12 seconds. The time and distance to the flame was set so that an uncoated fabric shows distinct signs of melting and a high degree of fibre damage, making it possible to observe the influence of the coatin

4.3 Experimental

The following recipes were tested and evaluated for the criteria listed below:

Table 3 Coating formulations (% of dry weight) using different matrix materials, coating and burning behavior

Sample no.	2a	2b	2c	3a	3b	4a	4b	5a	5b	5c	6a	6b	6c
PU1	x			x		x		x	x	x			
PU2		x			x								
2K-silicone			x				x				x	x	x
Ammonium polyphosphate (APP)	15	15	15	15	15	15	15	15	15	15	15	7.5	7.5
Aluminium-pigment	5	5	5	5	5	2.5	2.5	5	5	2	2.5	2.5	2.5
Dipentaerithriol	5	5	5	5	5	5	5	5	5	5	5	2.5	2.5
Melamine						5	5	5	5	5	5	2.5	2.5
Aluminiumtrihydrate (ATH)								7.5	7.5	7.5	7.5	7.5	7.5
Vermiculite (dispersion)				7	7								
Bentonite									1	1			1
Coating	+/-	+	-	+/-	+/-	+/-	-	--	-	+/-	--	+/-	+/-
Burning	+	+/-	+/-	-	+	+/-	+/-	--	+/-	--	No test	+/-	+/-
Smoke	-	-	-	+/-	+	+/-	-	--	-	--		+/-	+/-
Fabric damage	--	+	++	+	+	+/-	++	+/-	+/-	-		+	++

4.4 Results

It can be seen that in general coating behavior proved a bigger problem for the silicone-based recipes (Table 3), as for this product it is not possible to influence viscosity. Regarding smoke generation, silicone formulations in general produced smokier outcomes with little influence of the flame retardant combination used. However, while all PU-based samples are stiff, silicone-coatings retain their drapeability.

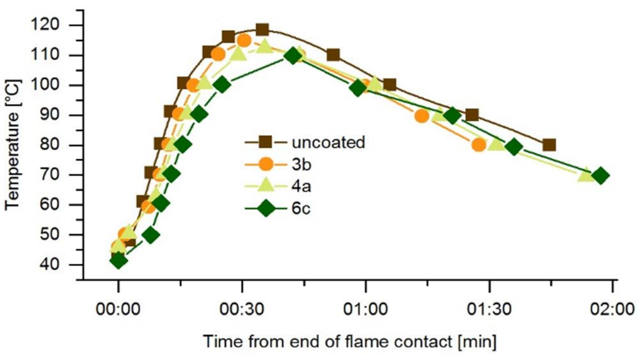

Figure 6 Effect of coating on surface temperature

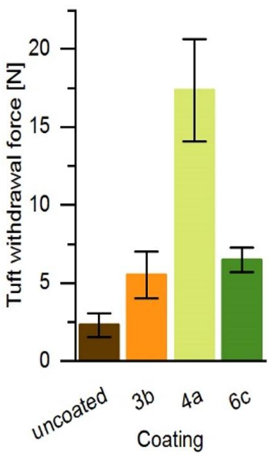

Figure 7 Tuft withdrawal force after coating

Formulations 3b, 4a and 6c were further evaluated for their coating behavior on tufted sample W2_Y12. The results of the infra-red camera reading are shown in Figure 6. Figure 7 shows the improvement of tuft withdrawal force that can be achieved with each formulation.

4.5 Discussion

Regarding coating performance it was found that certain coating formulas can achieve a good stability against open flames in regard to burning behavior as well as fibre damage. This subjective rating is corroborated by the measurements using an infra-red camera (Figure 6). It can be seen, that the surface of coated textiles does not get as hot as an uncoated sample, presumably due to the cooling and insulating effect achieved by flame retardants as well as heat reflection from the aluminium-pigment. However, on tufted samples there are big differences between the coatings tested regarding tuft withdrawal force after coating, so that a compromise needs to be made between good drapability and high tuft retention. The goal of a tuft withdrawal force >7N could only be achieved using a PU-based coating.

5 ACOUSTIC PROPERTIES

In order to check the acoustic properties, samples were tested using an impedance tube in accordance with EN ISO 10534-2. The sound absorption coefficient serves as a measure for the improvement of acoustics in a room. Samples tufted with the reference pile yarn (YP) on three different glass fabrics were compared. The coatings, regardless of matrix material, compared to the corresponding uncoated fabrics. All measurements show sound absorption levels similar to or slightly better than those of tufted floor coverings. Since the selected test products are constructions similar to those of tufted floor coverings, it can be concluded that the materials used for primary backings and pile yarns have no significant influence on the sound absorption coefficient. A comparison of the coated variants with the uncoated references does not show a uniform picture or a significant difference. Further tests with constructive modifications (pile height, pile density) for further improvement of acoustic properties are planned.

6 CONCLUSION AND OUTLOOK

It could be shown during this project that it is possible to produce primary backings for tufted textiles from glass yarns. The tuft withdrawal forces achieved using weft-backed weave constructions are higher than those of conventional (uncoated) tufted fabrics, allowing for further processing. Further, it was proven that tufting with glass yarn in the pile is feasible. The benefit of the retrofittable e-Jerker for the production of tuftings from technical yarns is evident in practical use. Furthermore, coatings developed for direct contact with flames improve heat-stability as well as mechanical properties of the tufted fabrics, allowing for a broad spectrum of applications. Lastly, the sound absorbing qualities of a tufted glass fabric were investigated and it could be shown that neither yarn material nor coating change the good acoustic properties known from conventional floor coverings.

In conclusion, both the feasibility of production as well as the acoustic and thermal properties of a tufted technical textile open possibilities for new applications. The fields currently considered for potential industrialization are lightweight building materials for passive fire safety as well as acoustic insulation for industrial machinery.

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