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Literature Cited

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ABSTRACT

Inter-ply, low-melt yarn insertion improves a carpet’s resistance to foot traffic, i.e., its resistance to matting. In addition, low-melt yarn insertion improves the individual tuft’s tip definition in untrafficked carpet and increases its body, i.e., gives it a better showroom appearance. Negatively, the same factors providing these benefits—better inter-ply cohesion and tuft integrity—also give the carpet a slightly harsher feel or hand.

Synthetic cut-pile carpets of moderate density don’t physically wear out. Instead, they tend to become less aesthetically pleasing (they “ugly out”) under foot traffic as individual plied tufts untwist, open, and entangle with filaments from adjacent tufts. As wear continues, the carpet’s appearance changes as its surface loses tuft-to-tuft, tip definition. Such a worn surface scatters light differently from adjacent, less worn surfaces, and consequently, the trafficked areas appear lighter than those areas less trafficked. This optical phenomenon is well documented [2], as are the various wear mechanisms of cut-pile carpet undergoing foot trafficking or the constant compression of heavy loading [5, 7, 12, 16].

The carpet industry realizes that wear performance, as defined by the resistance to appearance change in a carpet under wear, is important to the consumer. In 1992, Monsanto conducted market research that sampled retailers and recent and intended carpet purchasers. Their study identified four major areas of concern to these consumers: carpet performance (its resistance to appearance changes), carpet aesthetics (its initial appearance), carpet maintenance, and the buying process itself. In
1998, AlliedSignal researchers reported similar findings [5, 11]: the average U.S. carpet purchaser last purchased carpet 13.2 years ago, thought about the purchase for six months, and within a week shopped three stores and paid with cash. Issues most important to their buying decisions were color, durability, stain and soil protection, and price. Durability concerns were common to both studies. Today, according to Sam Allman of Mohawk [3], residential buyers shop 1.3 stores before making their decision. If you’re a carpet retailer, and not the first store visited with an aesthetically pleasing product, you’re in trouble.

Clearly, carpet performance, specifically appearance changes with wear, has been a major issue with consumers and remains so today. Equal or even higher in importance, though, is a carpet’s showroom appearance, where it gets one chance to make a good impression aesthetically (with its color, style, hand, tuft tip definition, and body), regardless of its ability to withstand wear. Buyers won’t see the impact of poor wear tendencies until long after the carpet has left the showroom.

More recently, in 2002, Solutia sponsored research to assess opinions of consumers who had purchased carpet for their homes within the past 18 months [4]. Again, performance under traffic was that property most desired—given adequate stain protection—even in a market today that generally prefers a softer hand. Consumers continue to feel that today’s carpet, while wearing better, still falls short in its ability to resist appearance changes when subjected to foot traffic. Both initial appearance and long-term performance remain critical to a carpet’s retail success in today’s market.

It’s clear to the carpet consumer, the carpet manufacturer, and the fiber producer that carpet performance lies at the heart of this multibillion-dollar business, but its initial appearance is also critical. As a consequence, the industry—both fiber producers and carpet manufacturers—has directed much of its research and development efforts at improving both carpet performance—defined by a carpet’s wearability, its resistance to staining and soiling, its uniformity of appearance, and its color fastness—and its initial showroom appearance. In this work, we report the results of Solutia’s efforts to improve the initial look and wearability of residential, cut-pile, nylon 66 carpets.

Factors Affecting a Carpet’s Initial Look and Appearance Loss with Foot Traffic

Many factors impact a carpet’s ability to resist changes in its appearance when subjected to wear; polymer type, filament size and shape, filament modulus, level of filament crimp, yarn bulk, yarn size, yarn modulus, yarn ply twist level, degree of twist set, carpet construction features, and the incorporation of minor blend components, e.g., high-shrinkage or low-melt materials that activate during the heat-setting operation. All, to some degree, impact a carpet’s ability to withstand foot traffic and appearance changes.

Polymer type ultimately determines yarn resiliency [10], i.e., a carpet’s ability to recover from bending after being stepped on or being placed under heavy load. Load recovery characteristics have been documented for several common polymers used in carpet manufacture, e.g., if a rating of 10 signifies perfect recovery, then 9.5 was the recovery rating for nylon 66, 9.0 for nylon 6, 5.0 for polyester, and 5.0 for polypropylene [14]. Similar findings are presented in Figure 2 of reference 5. These recovery deficiencies can be improved by increasing the tuft density, i.e., increasing the tuft-to-tuft support to limit bending.

Filament, yarn, and carpet construction factors can be manipulated to improve carpet wear performance. Wemy [13, 15] modeled the appearance retention (a measure of surface change in a carpet subjected to foot traffic) of 233 carpets (Vetterman drum worn) against a combination of filament features [size (5 to 22 denier-per-filament (dpf))] and shape (1.4 to 3.7 modification ratio (MR)), of yarn features [size (1160 to 1700 yarn denier), bulk level (10 to 40%), and twist level (3.5 to 7 turns per inch)], and of carpet features [pile height (0.49 to 1.0 inch) and carpet weight (25 to 70 oz/yd^2)]. All yarns were nylon 66, bulked, continuous filament (BCF) yarns heat set though a conventional Suberba chamber. Wearability—appearance change with wear—significantly improved with increased dpf (increased bending modulus), with decreased MR (increased filament-to-filament packing density), with increased yarn denier (increased tuft modulus), with decreased yarn bulk (decreased filament crimp and associated inter-tuft entanglement), with increased yarn twist (reduced endpoint openness via increased intra-ply friction within each tuft), and with increased carpet weight (increased tuft-to-tuft support).

Lowering the crimp level of individual filaments also improved the carpet’s resistance to wear for a series of nylon 66 carpets heat set in a commercial Susseen chamber [7]. This researcher demonstrated the trade off between setting crimp in the single filament at the draw-texturing stage and later setting twist in the yarn at the heat-setting stage of manufacture. A carpet’s resistance to wear improved when the degree of the first was reduced and the second enhanced.

Similarly, a carpet’s resistance to matting as characterized by appearance retention was improved by both decreasing yarn bulk and increasing plied-yarn twist [12]. Further, adding high-shrinkage filaments as a minor component of a staple blend also improved carpet body and its resistance to matting, e.g., 20% high-shrinkage (30%
Examples of selected test carpets were placed without an under-pad on a wooden floor, subjected to 20,000 foot traffics by contract walkers, and graded for matting using the procedure described in ASTM D2401. A single grader skilled in the technique assessed each carpet’s wear against seven matting (AR) standards that together define the range of wear experienced over several years of foot trafficking. An AR rating of one is characteristic of the original, untrafficked surface, an AR grade of two shows just perceptible loss of tuft definition, and an AR grade of seven indicates that essentially no tuft definition remains in the worn carpet.

Quad analysis measure of carpet wear, hand, and body: Quad analysis provides an efficient, paired-comparison approach to subjective property characterization. A typical test consists of sampling subgroups of four carpets systematically from a larger group and rank-ordering them from best to worst. Each large grouping (from four to sixteen carpets) has a unique quad experimental design—one partially balanced and incompletely blocked. Ten carpets, for example, require that thirty individual quads be inter-ranked through a series of paired comparisons. Summary rank scores are obtained for each carpet by adding their individual quad rank scores. The lower the overall rank score for a given carpet, the better that carpet ranks with respect to the property being evaluated. An adaptation, “quad-folding,” further simplifies the rating process to produce an order of preference. Details of both methods are provided in reference 8.

Carpet body, endpoint, and hand: A grader, skilled in the art, assessed the aesthetic differences between pairs of carpets similarly constructed except for the presence or absence of a low-melt, inserted yarn. Resistance to hand compression provided a measure of body, tuft tip distinctness assessed visually, a measure of endpoint, and resistance to surface deflection, assessed by sliding a hand across the carpet’s surface, a measure of hand. In each case, an inserted carpet was contrasted with one not inserted, but otherwise similarly constructed, using the following scale: ++ (+2, much better), +(1, slightly better), 0 (0, equivalent), −(−1, slightly worse), −(−2, much worse). Half grades between ratings are also possible, e.g., a +1/+ + (+1.5) fell between the much better and slightly better ranking.

Results and Discussion

Changes in carpet product lines are more often driven by style than fundamental technology change. In residential cut-pile carpets, for example, textured surfaces are preferred today versus the straight-set saxony of yesterday because a textured surface hides footprints. But fundamental technology, even in the carpet manu-

shrinkage) Acrilan® fibers blended with 80% nylon 66 fibers. The higher shrinkage, Acrilan filaments caused yarn ply twist to build during heat setting and thus improved the resultant carpet’s ability to resist foot traffic.

Blends that incorporate a lower melting material have also been used as a route to improve a carpet’s matting resistance by generating better intra-ply cohesion within tufts. Minami, Hisayuki, and Saki reported in Japanese patent SHO 52(1977)-18835 that such a blend construction reduced staple fiber loss and inhibited tuft opening in shag carpets [9]. Similarly, Bowers reported in World Organization patent WO99/14408 that such blends improved the wear resistance and resiliency of nylon 6 carpets [1].

Others have also described the dual benefits of crush resistance and twist retention gained by inserting polyethylene yarn (melt point 106–109°C) or blending it as a staple fiber as a minor component onto or into several kinds of higher melting base yarns or fibers, e.g., cotton, wool, polypropylene, nylon, polyester, and acrylic [6]. They detailed the benefits derived from including a lower melting nylon 6/66 copolymer (melt point ~174°C) as an inserted yarn onto nylon 6 base yarns (melt point 215–220°C) [5]. Such inserted nylon 6 carpet resisted appearance change under cyclic compression, better retained its original appearance, restricted tuft opening, and more effectively retained each tuft’s tip definition with wear. Unfortunately, the lower melting insert also stiffened the hand of the carpet and made it feel harsher.

Similar benefits were derived by inserting a heat activated, adhesive coated nylon 66 core yarn onto a singles nylon 66 yarn [8]. These inserted carpets wore better and had better initial tuft tip definition but exhibited less body than did comparably constructed carpets lacking the insert. Their property gains were comparable to those attained by increasing the level of twist from 5.0 × 5.0 tpi to 6.0 × 6.0 tpi (singles × ply twist).

Low-melt, continuous filament yarn (copolymamide), inserted as a small percentage component (<10%) onto a staple singles yarn made from higher melting fibers (nylon 66), twisted with an insert-free singles, then melted during the heat-set operation, improves a carpet’s appearance and resistance to wear by tack welding plies within each tuft (intra-tuft bonding). Such an inserted product also improves the carpet’s tuft tip definition, i.e., its initial showroom appearance. In the work reported here we document Solutia’s development of an inserted nylon 66 carpet marketed under the trade name of Wear Dated® Traffic Control® fibers.

Experimental

Carpet appearance retention assessment: Dual samples of selected test carpets were placed without an
facturing industry, remains important. Residential con-
sumers, for example, have long desired better wear per-
formance from their carpets, i.e., a carpet that resists
change in its appearance due to foot traffic, while the
carpet mill has desired a product that looks better in the
showroom. The traditional route to either improvement
has been to increase the level of ply twist, but this is
expensive because it slows the manufacturing process as
well, excessive twist produces a leaner look and a stiffer
feel, both undesirable in today’s market. Low-melt yarn
insertion provides a more economical, more aesthetically
pleasing avenue to improving a carpet’s wearability and
its untrafficked look.

**LOW-MELT POLYAMIDE INSERT YARN MELTS DURING HEAT SETTING**

Low-melt, polyamide yarn is spun in a high-speed
process from a proprietary resin, one much lower melting
than the base nylon 66 fiber. This low-melt yarn is
inserted at levels less than 10% by weight onto a nylon
66 singles yarn in one of several direct-insertion pro-
cesses that don’t add process steps to the standard staple
mill’s manufacturing process. This insertion prior to
twisting eventually places the low-melt yarn preferen-
tially between, instead of around, two yarn plies because
of the tension differences encountered at twisting be-
tween the small low-melt yarn and the larger nylon 66
singles. The twisted pair is processed through a conven-
tional Suessen or Superba heat setting chamber where
the low-melt yarn, preferentially located between yarn
plies, melts during heat setting, flows, and tacks the plies
together. The result is a yarn that has substantial inter-plly
bonding—tack points—within each carpet tuft, as evi-
dent in Figure 1.

This Suessen chamber’s bonding process doesn’t im-
 pact subsequent yarn properties: yarn bulk is 16.4% for
non-inserted yarn versus 16.0% for the inserted yarn
(95% confidence interval +/- 0.63 for n = 5), yarn
shrinkage 2.54 versus 2.50% (95% confidence interval
+/- 0.50), and yarn crimp 14.2 versus 13.9% (95%
confidence interval +/- 0.72). Obviously, body differ-
ences between carpets, inserted or not, arise from tuft
moduli differences and the resultant enhanced resistance
to compression, not from any impediment to bulking,
crimping, or shrinking caused by the melt tack points.

Singeing staple yarns that incorporate the low-melt
insert yarn significantly improves the worn appearance in
both loop and cut-pile carpet constructions. In a series of
each example, each involving sixteen head-to-head trials,
skilled graders were able to rank the combined treatment
of singeing and low-melt insertion consistently better
than either single treatment at the 0.000011151 (one
chance in 89,681) to 0.000000023 (one chance in
43,046,721) level of significance. Evidently, partial

**FIGURE 1. Low-melt insert yarn binds the tuft plies together.**
bonding occurs in the singeing flame as the inserted yarn passes through under tension, then further bonding occurs in the Suessen chamber where the inserted yarn is passed through coiled on a belt under no tension.

**LOW-MELT YARN INSERTED CARPETS RETAIN THEIR TUFT-TIP DEFINITION UNDER FOOT TRAFFIC**

Figure 2 shows both side and top views of inserted versus non-inserted carpet surfaces, both worn to 20,000 foot traffics—about a year’s wear for a family of four. From the side, the inserted tufts appear undamaged, showing little untwisting at the top, while those not inserted have flattened and opened. Their surface appearances are shown in the top view. Clearly the inserted surface better retains its tuft-to-tuft distinctness—its tufts’ tip definition—while the non-inserted carpet has begun to mat, i.e., to lose its surface tuft definition. Low-melt yarn insertion improves both a carpet’s resistance to appearance change under traffic and its initial untrafficked appearance, i.e., showroom appearance.

Over the three years of development, many categories of low-melt yarns were evaluated to assess their ability to improve carpet wear performance and influence initial appearance. Table I lists the comparative properties of four kinds of low-melt yarns (specifics are proprietary) that could be used with nylon 66 base fibers (three nylon copolymers of varying melt points and a functionalized polyethylene). The first was chosen to commercialize and as a result was evaluated more frequently. In sixty-seven contrasts of widely varying yarn and carpet constructions—each a head-to-head contrast of similar construction except for the presence or absence of a low-melt insert yarn—the AR rating improved by 1.25 on average, the endpoint by 1.08, and the body by 0.80, while the hand stiffened significantly by a 1.14 rating. Bear in mind that a one rating in any of these properties is easily perceived by the expert grader. The insert spun from copolymer C (+20 °C higher melting than copolymer A) produced similar results, though the trials were fewer, but both copolymer B (+55 °C higher melting than copolymer A) and the functionalized polyethylene inserts showed far less promise. Obviously, the low-melt insert match to the base material is critical. Under the conditions of heat setting (temperature, moisture level, and dwell time), the former must melt, flow, and then be able to bind with the base fiber’s surface or flow around it to encase the base fibers, i.e., to form a low-melt cage.

Typical results are presented in Figure 3 where various degrees of surface wear are contrasted for two carpets, one inserted with the copolymer A binder yarn and the other free of low-melt insert material. The inserted series...
TABLE I. Nylon 66 carpet properties derived from low-melt yarn insertion. Low-melt inserted carpets contrasted with controls lacking the insert yarns but made otherwise with the same yarn and carpet constructions.

<table>
<thead>
<tr>
<th>Carpet properties</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Func. PE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting temperature:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lowest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of contrasts:</td>
<td>67</td>
<td>7</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Appearance retention</td>
<td>-1.25 (+/- 0.14)*</td>
<td>-0.49</td>
<td>-1.50</td>
<td>-0.17</td>
</tr>
<tr>
<td>Hand</td>
<td>-1.14 (+/- 0.19)</td>
<td>-1.00</td>
<td>-1.00</td>
<td>-0.80</td>
</tr>
<tr>
<td>Body</td>
<td>+0.80 (+/- 0.18)</td>
<td>+0.36</td>
<td>+0.50</td>
<td>+0.50</td>
</tr>
<tr>
<td>Tuft-tip definition</td>
<td>+1.08 (+/- 0.40)</td>
<td>+0.75</td>
<td>+1.00</td>
<td>+0.10</td>
</tr>
</tbody>
</table>

*a* Worn carpet measure.  
*b* Unworn carpet measure.  
*c* 95% confidence intervals.  
Numerical grades were assigned to hand, body, and tuft-tip definition according to the following rating criteria: --(-2), - -/- (-1.5), - (-1), -/0 (-0.5), 0 (0), 0/+ (+0.5), + (+1), +/++ (+1.5), ++ (+2). Note: --/- means rating was judged worse than a - rating but not so bad as a - - rating. Interpretation: Items using insert A yarns were judged 1.25 AR units better able to resist appearance change under 20,000 foot traffics, harsher by a 1.14 ranking, having more body by an 0.80 ranking, and having better tuft-tip definition by a 1.08 ranking. Note: None of the confidence intervals overlapped zero, i.e., all property contrasts were significant at the 95% confidence level.

FIGURE 3. Carpet worn appearance improves with low-melt yarn insertion. The lower the ranking, the better the perceived property.

resists appearance change significantly better at each level of foot traffic as measured by either AR, an appearance change contrasting worn with unworn carpets, or the quad approach where worn surfaces are contrasted with one another instead of their untrafficked control. In fact, the inserted carpet’s surface worn to 20,000 traffics looks better than does the carpet lacking the insert worn to just 4000 traffics.

AMOUNT OF LOW-MELT YARN INSERT IMPACTS A CARPET’S RESISTANCE TO APPEARANCE CHANGE

Figure 4 highlights the influence that insert yarn size—low-melt material amount—has on a carpet’s ability to retain its appearance and tuft tip definition under wear, its initial tuft-tip definition, and its initial body. Each of three items (no insert, 60 denier insert yarn, 75 denier insert yarn) was replicated three times and their carpets worn to 20,000 foot traffics. As before, these worn carpets were rated for wear by AR and quad analysis, while their unworn counterparts were rated for body and endpoint. Once again, the carpets inserted with low-melt yarn resisted wear. There is no overlap between the three replicated items with respect to quad wear and little overlap in their AR ratings. The degree of change from each of their untrafficked surfaces is similar for the two inserted products, and both are better than the uninserted carpets. Tuft-tip definition, on the other hand, while...
segregating the inserted items from those not inserted, shows substantial overlap between the inserted items. The same holds true for body as indicated by the size of the markers and their overlap. Obviously, the initial showroom appearance of these inserted carpets does not suffer from 20% less low-melt material until those surfaces are trafficked.

**INCREASED PLY TWIST IMPROVES A CARPET’S RESISTANCE TO APPEARANCE CHANGE**

Twist has often been used to improve wear in cut-pile carpets [7, 8, 12, 13, 15]. To inhibit a tuft’s untwisting at its surface, one can increase the level of twist, then set it well during the heat-set operation. But twisting is a slow process that costs money; moreover, with a carpet constructed at low pile heights, it’s difficult to hold the few turns present in each tuft. The low-melt insert yarn offers a solution by binding the tuft’s plies to one another, i.e., by locking in the twist and prohibiting any untwisting. Figure 5 contrasts the untrafficked carpet tuft-tip definition with the trafficked appearance for a series of carpets differing in twist level, twist balance, and twist multiple (singles twist/cotton count)\(^{1/2}\). Three points are clear for this construction space: increasing twist and/or including insert yarn improves a carpet tuft’s tip definition, an inserted yarn requires less twist to reach the carpet tuft’s tip definition seen in a more highly twisted yarn lacking the insert, and increasing the twist in those items lacking the insert doesn’t improve wearability enough to match any of the inserted carpets. As mentioned before, a carpet’s showroom appearance can be more easily manipulated than improvements in its worn surface appearance.

**COMMERCIAL CONTRASTS IN CARPETS WITH AND WITHOUT THE LOW-MELT YARN INSERT**

Figure 6 contrasts several important commercial properties for low-melt inserted carpets with those lacking the insert: the tuft’s tip definition improves, floor performance improves, the degree of fuzzing and bearding for a staple product lessens (an improvement), hand is slightly harsher, body increases, mill processability is more complicated, texture quality—as defined by a grader’s assessment of a textured carpet’s surface—is slightly better, and the soiling resistance is equivalent. The only real negative is the slightly harsher hand, but in today’s market hand is very important. Note that we have not addressed measures of soiling, texture quality, mill processability, and degree of fuzzing and bearding here, but they are standard measures encountered in the manufacture of staple carpets.

Ten carpets constructed over a wide range of typical construction features (tuft denier, carpet weight, ply-twist level, tuft density, and pile height), as well as with differences in polymer type (nylon 6 and nylon 66) and heat-set method [Suessen stuffer box (Sue 5P) and Su-
FIGURE 5. Increasing twist improves resistance to wear and tuft tip definition but adds cost to the mill; low-melt inserted carpets require less twist. The lower the ranking, the higher the perceived property.


perba stuffer box (Sup SB), were purchased from local retail stores, then characterized for their initial tuft-tip definition and their resistance to appearance change with foot traffic. The results are presented in Figure 7. These ten represent a selection of textured residential styles available today from several carpet producers, carpets using fibers from three producers (Solutia, DuPont, and Honeywell): BCF and staple, inserted with a low-melt insert yarn (inter-ply bonding) and not, nylon 6 and nylon 66 base yarns, and an item blended with a low-melt binder yarn (intra-ply bonding). The construction features, which vary considerably, are detailed in the
FIGURE 7. Direct relationship between tuft tip definition and appearance with wear (nylon 66 uses copolymer A inserts and nylon 6 uses copolymer B inserts). The lower the ranking, the better the perceived property. PH is pile height, tpi is ply twist per inch. Sup SB is Superba stuffer bax, Sue SB is Susessen stuffer bax.

figure where worn carpet appearance is contrasted with unworn carpet tuft-tip definition. A lower ranking of either means better performance. Three levels of hand are indicated by marker size. Across this wide range of construction features, there is again the familiar relationship between these three properties: the better the initial tuft-tip definition in the untrafficked carpet, the better the carpet’s appearance resistance to wear (lower endpoint and contract walker rankings). Generally, too, the softer the hand of the product, the worse its resistance to wear. The better performing carpets with respect to wear resistance and initial tip definition (lower left corner) are inserted with a low-melt binder yarn (staple)—the very best in a loose construction (fewer tufts/in.²), which in turn improves hand—or are tightly constructed BCF (greater tufts/in.²) where tufts can support and stiffen one another.

One carpet, however, behaves quite differently. The nylon 6 staple item, one that incorporates a low-melt staple fiber in its staple blend, displays good initial tuft-tip definition but doesn’t hold up as well as the others to wear. This approach to binding favors intra-ply rather than inter-ply binding. It’s clear in this set and a variety of other head-to-head comparisons we’ve made that the latter is responsible for improved resistance to wear.

Conclusions

Over the years, consumers have desired better performance from their carpets, i.e., they would like them to better hold their appearance with wear, to resist staining and soiling, to have a uniform initial appearance, and to exhibit color fastness. Low-melt yarn insertion and the resultant inter-ply bonding improve a carpet’s ability to resist change in its appearance when subjected to foot trafficking. They also improve individual tufts’ tip definition in untrafficked carpet by tacking plies along the tuft’s shaft and the resultant carpet’s body level as these reinforced tufts stiffen the carpet to resist compression. On the negative side, low-melt yarn insertion leads to a slightly harsher hand, an effect that can be lessened by construction features. Another obvious conclusion: the softest carpets simply don’t wear very well.

Historically, increasing the level of ply twist has been the route most often used to improve carpet performance in these areas, but that route doesn’t compete well with low-melt yarn insertion either. Twist level could be in-
creased to achieve equivalent tuft-tip definition to otherwise similarly constructed inserted carpets, but an equivalent worn appearance could not be achieved by changes in twist.

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