Acoustic Textiles: Beautiful and Demanding

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Introduction

On a smart speaker, the textile protects the speaker, orients users to the sound, allows great sound quality, and helps the device feel at home in their home. These user needs are translated into cosmetic, mechanical, manufacturing, and reliability requirements that ensure repeatable quality on each finished assembly. Designing and measuring textiles to ensure they meet these requirements is challenging and requires adjusting the approaches used for more typical mechanical parts. This unique approach starts at the beginning of the textile manufacturing process.

Textiles are multi-level materials, and each level involves its own manufacturing process and contributes to the final material's physical properties. Making a textile similar to the ones we typically design starts with polyester terephthalate (PET) pellets and small amounts of additives (such as TiO_2). The raw material is extruded as a collection of individual filaments that are collected as yarns and drawn while warm to increase tenacity.[1] Yarn batches are tested for their characteristic material properties to establish a quality control record. Circular knit fabric is produced from this yarn that is then scoured, and finally heat set, thus setting its final mechanical properties. For quality control, sections of textile rolls are tested per dye lot to understand the mechanical and reliability performance of the textile. These rolls are shipped to a converter/assembly supplier, where they are cut into swatches and assembled to the plastic components that shape the textile and allow connection to the final product (Fig. 1).

With mechanical parts, one must measure their key dimensions or properties before assembly to ensure that they will fit together and function properly. Unlike many mechanical parts, measuring a textile's physical properties is often destructive, and thus we rarely measure the actual swatches prior to assembly. However, system-level performance, such as acoustic or sub-assembly wrapping performance, is measured on those swatches after assembly. This begs the question "how do you perform validation to ensure that the assembled swatches meet the functional requirements?" It is a balance between characterizing the material, understanding material-level variation (within a roll and within a dye lot), and designing system level tolerances.

Design Methodology

Characterize the Textile

Characterizing the textile means quantifying it according to the critical attributes that will allow it to meet the cosmetic, mechanical, manufacturing or reliability requirements for the final assembled product. For each attribute, we run characterization tests to measure how the textile responds. One example of a

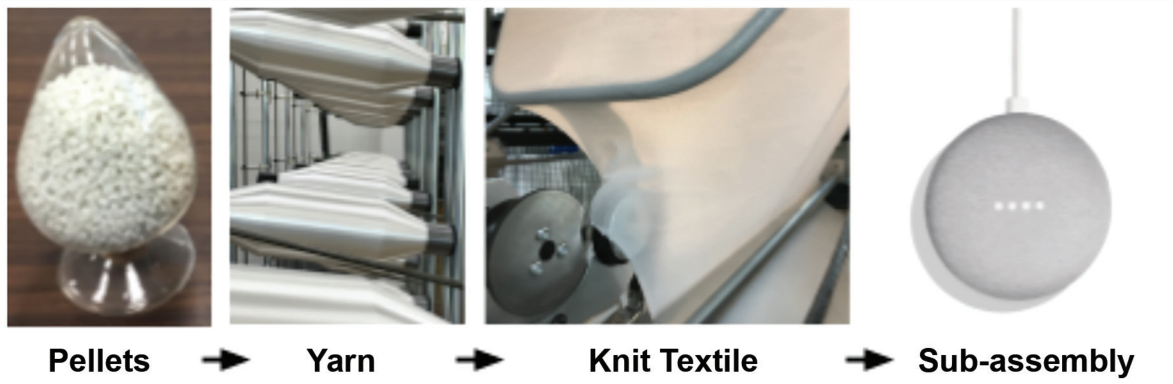

Fig. 1. Textile flow process.

textile characterization test is uniaxial elongation. It is used by product design and manufacturing engineers to understand the force-elongation relationship of the textile, allowing us to determine how far to stretch the textile during assembly. However, this test is destructive in that it permanently stretches out the textile sample that is measured. When qualifying a new testing procedure, it is standard to perform a Gauge Repeatability and Reproducibility test (GR&R) with a number of test methods.[†] This relies on being able to test the same piece of material repeatedly. Since a single uniaxial test permanently stretches out the sample, typical GR&R is not possible, so we implemented a three-step approach. First, we test a large population of textile to determine the population statistics for the textile's elongation at a specified force. Second, we select elastomers that exhibit elongations that match the lower and upper ends of our textile population. These elastomer swatches can be tested multiple times, so we are able to run a traditional GR&R test with them. Then, because we have both outgoing quality control (at the textile supplier) and incoming quality control (at the assembly facility), we had both facilities run GR&R with the elastomers.

Once the GR&R results demonstrated that the elongation test fixtures and procedures at each site were acceptable, we directed them to run a correlation study by testing a fresh set of textile swatches. These textile swatches were cut from a single meter of textile (to minimize material variation) and randomly distributed between outgoing quality control (OQC) and incoming quality control (IQC). Results from the correlation study showed where it was necessary to apply an offset between OQC and IQC. This offset interprets the values at IQC into equivalent OQC values so that we do not have to grant frequent waivers for material that appears out-of-specification, but are really only shifted by a predictable testing bias due to equipment or operator. The offset also allows us to share the same textile specification document among all suppliers.

Understand Material Tolerances

The textile specification document records a unique description of the textile. This includes yarn diameters used—typically in denier—and knit structure, like the simple repeated loops of pantyhose or the spongy 3D mesh on backpack straps. In addition to the qualitative description, the specification documents nominal values and tolerances for critical measurements such as color, air permeability, and uniaxial testing values. Material-level tolerances need to account for both the variation introduced within a textile roll or dye lot (up to 20 rolls that are finished together) and the variation introduced between different dye lots.

To understand the level of granularity that we needed to focus on, we first had to validate that the variation of mechanical variables (such as air permeability and uniaxial testing values) across one roll and one dye lot were not large enough to significantly affect assembly or acoustic performance. We calculated that textile properties regularly vary by up to 20% within a ~60 meter roll and the variation is similar across a dye lot. A 90% confidence level would require testing the vast majority of all the rolls used for a program—not only unsupportable from a cost and labor perspective, but as the part design often changes from build-to-build during development, comparisons become less meaningful. Therefore, rather than taking a brute force approach to quantifying more of the textile material and thus the material that is built into products, we established a test frequency that gathers data across rolls in each dye lot that is representative of the plan-of-record mass production (MP) process. We also aim for textile and product designs that have a broad range of tolerance for material and assembly variance.

Initial recommendations for the tolerances to account for the variation between different dye lots come from process capability studies at the textile manufacturer. For example, the textile manufacturer may be able to guarantee a tolerance of ±0.05 mm on thickness in mass production, based on their experience producing similar textiles. However, consumer electronics validation builds often only require a few dye lots each, which means that over the course of validating a product design, we most likely do not get the full range of material that we can expect to receive in MP. Textile manufacturers also cannot guarantee that there will be rolls that represent the MP upper and lower bounds of all of our measured properties within the dye lots they provide for validation builds. To reduce risk, we therefore lock the textile specification to the upper and lower bounds that have been built into systems, demonstrated passing acoustic performance within our design limits, and passed a cosmetic review by our industrial design team.

Yet, this still includes an aspect of uncertainty, since the ratio of measured data points in a dye lot to the

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[†] ASTM, ISO, and AATCC sometimes provide standards that differ in implementation, and are therefore suited to different equipment or factory preferences. Where multiple standards are practical options, we find it useful to check GR&R for each and make our selection on that basis (or modify as necessary).

number of assemblies that are made and tested from textile swatches in that dye lot is quite small. Since some uncertainty about what has been validated must remain, it is critical to have the product designs work within the tested strengths of a textile material, within a margin, to increase system tolerance to material variability.

Design System Tolerances

To understand how to increase system tolerance through textile design, specifically around audio performance, we built prototypes of well-understood systems (i.e., products that were already in production, since we had a robust audio population to compare to) with a wide range of textiles. These textiles deviated from our production textiles in significant increments of yarn size, knit gauge, etc., yielding a range of mechanical properties. Audio results were measured on a full system; that is, the textile was assembled to its housing, which was assembled to the speaker module and additional housing components, the speaker was driven with a pure sine signal (swept across frequencies the user is expected to play), a microphone outside the system recorded the output, and this output was compared to the input signal. Clarity of sound was characterized with standard metrics such as frequency response and total harmonic distortion.[2] With these metrics available, we compared the means of the prototypes' audio results to mass production records to isolate which textiles were significant improvements over the production textile. We evaluated material properties for these textiles and found that only one of the properties we measure, air permeability, was a significant predictor for acoustic performance.[3] Based on prototype data from a wide range of products, we established a lower limit for air permeability for new textiles.

There are ways to design the product architecture that increase system tolerance, as well. Two important examples rely on understanding the textile's force-elongation behavior. Our design language uses textile to signify where sound emits from these devices, so the textile has always been over the speaker. This means that the textile must be permeable by design—a feature we quantified with the air permeability limit. Knit textiles provide high permeability, as well as high drapability, because they are formed of loops of yarn. Drapability is important to allow us to make curved, organic forms that sit harmoniously next to other home goods.

However, the loop structure of a knit means that it is much more elastic in one direction (the course direction) than the other (wale direction); knit textiles are highly anisotropic. Additionally, the stiffness of the textile is not constant, but depends on how far it has already been stretched; knit textiles display non-linear elasticity. This means that a textile stretched over an acoustic grille will interact less with the air moving through it than a textile that is unstretched. Additionally, unstretched textiles can drape into the grille holes, which is unsightly. Non-linear, anisotropic materials are complex to model and do not conform to the simplifications that allow analytical stress-strain calculations. However, it is possible to turn this complexity to favor excellent acoustic performance. As mentioned earlier, applying a strain to the textile during assembly increases its stiffness (decreasing its contribution to acoustic distortion), as well as opening up the knit loops (increasing air permeability), and has a beneficial impact on cosmetics for flat grilles. Therefore, we specify strain in our textile assembly process. Additionally, since the textile is anisotropic, aligning the long axis of a plastic grille opening with the stiffer direction of the knit (typically the wale) yields a "stiffer" textile across the hole, with no change to the textile itself or the total open area of the grille.

Conclusion

Designing a product incorporating a cosmetic textile that meets stringent performance requirements (such as audio) requires a tailored measurement and quality control approach, in combination with clever product design that uses the complexity of textile behavior to best effect. Soft goods designers and engineers must avoid bogging down in the relatively large variances inherent in textile mass production and find ways to limit measurement burden. We do so by ensuring that our equipment and procedures are highly reliable (independent of textile measurements), then measuring a relatively small, but distributed, sample of the textile production. On the other end of the spectrum, it is important to avoid oversimplifying the textile representation into a thin film or plate with completely homogenous properties. Designing features that take anisotropy into account and processes that apply strain to increase textile stiffness can buy acoustic margin for the system that accommodates the variation we have some uncertainty about.

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Authors

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