Creation and Application of 3D Nonwoven Structures

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3D, the abbreviation for “three dimensional”, describe objects that have volume and may be measured and described using three distinctive directions.

Three dimensional products have been a known entity for many years. Making a three dimensional structure (molding) has been well developed with the use of many different substrates and application but these tend to be distinctly formed applications i.e. head liners and ABC automotive panels. There have been embossed woven, knits and nonwoven substrates. Embossing is a process of imparting a shallow design. This is typically applied to paper and used to impart a decorative pattern.

Today’s topic on three dimensional nonwoven structures will target a very definitive type of structure. One where the deep molding is exemplified in the fabric not just the form of the end use application. As per the definition of dimension, we will be discussing space and characterizing space with width, height, or length. What is unique about these three dimensional products?

The three dimensional products discussed today will be referred to as deep molded. We will define deep molding; look at how the products are made, and how the technology enhances the substrates. Then we will take a look at how the features and benefits created by the 3D structures enhance the end use applications.

Creating 3D structures

Patents have been written covering the deep molding of knit and woven substrates and have been known for years. These were primarily high denier monofilaments. The advancement in this technology pertains to nonwoven. The basis of the current patent filing takes the process into the next dimension using fabrics with finer denier fibers. Specifically, denier sizes of less than 100 microns.

In the simplest terms, the process involves taking a planar fabric and transforming it to have dimension. The molds and geometries take many different forms, but we typically categorize them into one of two categories, male/female or inter-digitated configurations. The male/female molds will be flat on one side and have protruding domes on the other produced using two male molds. The inter-digitated pattern will have the same appearance from both sides of the product.
The height of the dome can range between 1-50mm and the width of the dome up to 100mm. The process involves the application of heat, pressure and time to create the deep molded substrate. The molding process can be achieved through platen presses, or a calendar molding process.

The selection of a nonwoven substrate does have some critical requirements. The fiber content must have a relatively high percentage of thermoplastic materials. The fibers can be in filament or staple form, with each producing their own unique properties. The array of fibers successfully deep molded is broad and includes polyester, polyamide, polypropylene, polyolefin’s and more. These can be sheath/core, tri-lobal, segmented pie or any of the component fiber constructions.

The ideally formed substrate would be a nonwoven fleece made of randomized thermoplastic fibers. The more randomized the fiber orientation the better. The process elongates the fibers when exposed to the correct temperatures. As a result, it is important to use fibers that have not been fully drawn. This will allow the fiber to form to the desired pattern without
producing holes in the fabric. This also ensures better performance and maintenance of the domes over the life of the products. Crimped fibers also aid in producing well formed domes structures.

Not all nonwovens can be molded.

Draw ratios of up to 200% can be achieved in some fabrics. The draw ratio is the area of the molded substrate over the area of the unmolded substrate. The draw ratio is dependent upon fiber size, fabric weight, mold pattern and the fabric formation.

The temperatures required to obtain a stable mold will vary depending upon the fibers being molded but must fall between the fiber’s glass transition point and the melt point of the fiber. This process enables us to retain a textile hand, and maintain the original functionality of the fabric.

If stiffness (more resistance to compression) is a requirement, this can be imparted with larger diameter fibers.

Stiffness
Dome size and weight also impacts the stiffness of the ultimate product.

This chart illustrates that compression stress increases significantly when the mold pattern is increased from $\frac{1}{4}$” to $\frac{3}{8}$” (M/F mold). Weight also plays a role but not as significantly.

Multiple substrates can be used to build a composite providing the essential performance requirements. When two of the same substrates are married, the compression performance increases significantly. Nesting the substrates verses stacking the substrates also provides changes the compression performance.
Applications

A logical application for this type of product is in place of foam. A comparison between deep molded products and foam tells a very interesting story.

- The deep molded substrate can have up to 75 times greater air permeability than foam.
- It is roughly ½ the weight of foam while still maintaining the same compression level.
- It is less flammable than urethane foams.
- Recyclable
- 1000 time the tear strength.

This technology offers a rebirth to many products. The process will enhance the performance of the end use application in addition to increasing its value. Certain qualities become inherent in deep molded substrates because of the geometries. By creating space, air circulation is increased. This, in turn, introduces the ability to manage heat and moisture. This is appealing for medical application such bedding and wound care.

The increased surface area improves moisture and particle pickup in industrial and household products. This can mean the life for the product is extended or the manufacturer doesn’t have to sell as large of the product to get the job done.
With a more rigid substrate, the product can deflect the force of impact; very appealing for products such as bullet proof vests. The protective garment is also more comfortable because it sits off the body, allowing greater air flow.

Space also provides the opportunity to insert circuitry. Automotive seating has become very sophisticated, requiring a lot of circuitry to be imbedded in the seat. The deep molded product not only makes this process easier but improves the comfort and functionality of the product.

There are many other applications where the deep molded products provide important performance and aesthetics characteristic. Some are noted below including:

- Outdoor equipment
- Filtration
- Acoustical applications
- Construction
- Clothing

The list is very lengthy and is only limited by the imagination.

This technology has created and will continue to create tremendous opportunities for the nonwoven market. With the right combination of polymers, fiber, construction and mold geometries, the possibilities are never ending.

The research performed to support this paper and for the development of the technology is a collaborative effort of the University of North Carolina and Freudenberg North America. I wanted to acknowledge some key individuals who enabled this process to become reality.

- Dr. Behnam Pourdeyhimi, Associate Dean of Textiles @ NCSU, inventor of this nonwoven technology.
- Mr. Walter Schwarz, President of Freudenberg Nonwovens North America for having the vision to support this endeavor.
- Dr Walter Chappas, General Manager of Novolon Dimensional Fabrics for his enthusiasm and spirit to create a business out of this technology.
Creation and Application of 3D Nonwoven Structures

Novolon™ Dimensional Fabrics
There are other 3D structures.

- Most of the known 3D structures are made to fit a space and form specific to the application, (headliners, automotive carpets)
- There is little to no recovery after elongation.
- Honeycomb structure made from knits and woven materials are not possible with nonwovens.
- Embossing provides a shallow dimension. Attaining structures with any depth results in punctures in the substrate.
Monofilament

Substrates

Nonwoven

microfiber

Spunbond
Typical Geometries

- Top View
- Side View - Male/Female
- Side View - Inter-digitated
Basic mold patterns

Interdigitated

Dome heights range up to 50mm
Dome widths up to
The creation of a 3D structure

Planar Fabric (thermoplastic component)
+ Heat (between glass transition and melt point)
+ Pressure (mechanical deformation)

+ Time

= 3D substrate
The process

- Male/Female Mold
- Planar Substrate
- Formed product
- Heating
- Molding
- Cooling
- Continuous
- Formed product

Platen Substrate
How is it done?

- If molded independently, the use of thermoplastic fibers that have not been fully drawn, produces the best results.
- Nonwovens made from fibers of any size can be deep molded.
- Ideally, the structure is isotropic, with $f_p$ between $-\frac{1}{2}$ and $\frac{1}{2}$.
- The presence of crimp improves the mold-ability.
- Composite substrates can be designed to provide the ultimate performance characteristics.
Nonwoven Substrate Requirements

- Most nonwovens cannot be molded

- Ability to be drawn locally and globally as much as 200 to 300 %. This requires partially oriented fibers.

- Structure must be somewhat isotropic. High anisotropy ratio leads to holes in the structure.
Dome Compression

![Graph showing relative stiffness vs. total denier for different categories of textiles and industrial fabrics.]

- **Relative Stiffness** ranges from $10^{-7}$ to $10^0$.
- **Total Denier** ranges from 1 to 10,000.

- **Categories**:
  - **Textiles**
  - **Industrial Fabrics**
  - **Deep Molded Novolen**
Effect of mold pattern

Compression stress

Substrates

1/8" Inter-digitated
1/4" MF
3/8" MF

EV80  EV100  EV130  EV170
Spunbond 180g
Variation of Substrates

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<th>EV130</th>
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Compression stress (lbs/in²)
Compression Properties 180gm spunbond

![Graph showing PSI values for Single Layer, Nested, and Dome-to-dome configurations.]

- Single Layer
- Nested
- Dome-to-dome

Images of nested and dome-to-dome configurations.
Advantages over Foam

- 75X greater air permeability
- Absorbs < 1% as much water
- Weighs roughly 1/2 as much - at same compression level
- Much less flammability than urethane foam.
- Recyclable
- 1000 times tear strength

- Deep molded product can be more expensive than foam depending on the substrate.
- Foam can be produced by almost anyone, almost anywhere.
- Foam can be made into shapes.
- Foam can be produced in almost any thickness
General Advantages of Deep Molded Structures

- **Light weight** (often less than half the weight of competitive materials)
- Greatly enhanced **thermal comfort** in garment applications.
- Good **resilience and crush resistance**
- Very open structures leading to high air and water permeability and quick drying
- **Aesthetic** advantages
  - Extreme **versatility** such that the material can be engineered for a very wide range of applications.
  - In specific cases, it can improve **tensile strength**.
  - Ability to maintain a textile hand.
Markets for Novolon Deep Molded Structures

- **Acoustic**
  - building panels
  - entertainment equipment
  - automotive

- **Filtration** media

- **Cushioning and bedding**
  - furniture
  - infant mattresses
  - office & transportation seating

- **Medical**
  - seating and bedding
  - orthopedic cast padding
Markets for Novolon Deep Molded Structures

• Outdoor equipment

• Apparel
  high performance fashion

• Transportation
  insulation/noise abatement spacers

Concrete reinforcement
Markets for Molded Structures

- Concrete reinforcement
- Wipes
  - household
  - food industry
  - commercial
- Transportation
  - insulation/noise abatement
  - spacers
- Apparel, outdoor equipment
  - high performance
  - fashion
- Acoustic
  - building panels
  - entertainment equipment
- Filtration media
- Cushioning and bedding
  - furniture
  - mattresses
  - office & transportation seating
- Medical
  - seating and bedding
  - orthopedic cast padding
World of Possibilities

**Fabric**
Evolon, Spunbond, Composites
Lightweight knits & wovens

**Fiber**
Diameter, Tensile Properties

**Geometry**
Shape, Height, Diameter, Wave Form

**Polymer**
PP, PET, Nylon, Other
Thank you

• Dr. Behnam Pourdeyhimi, Associate Dean of Textiles NC State University

• Mr. Walter Schwarz, President of Freudenberg Nonwovens NA

• Dr. Walter Chappas, General Manager of Novolon Dimensional Fabrics