Fiber and Fabric Blend Technology

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Webinar Overview

Introduction

Fiber Components and Associated Characteristics

Fiber FR Characteristics
- Protection Mechanisms
- Inherent vs Treated

Fiber and Fabric Blend Characteristics
- Comfort
- Durability
- Launderability

Actual FR Fiber Blend Comparison

Summary
Introduction
Fiber-Fabric Blend Technology

Fiber – Filament Extrusion

Fiber Finishing

Fiber Manufacturing

Bales for Shipment

Final Staple Fiber

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Fiber-Fabric Blend Technology

Baled Fiber Opening
Blending

Carding – Sliver - Roving

Yarn Spinning

Fabric to Garment Manufacturing process

Cut and Sew

Fabric Finishing

Weaving or Knitting
Fiber Components and Characteristics
Aramids

Wilfred Sweeny (1926–2011), the DuPont scientist responsible for discoveries in the 1960’s leading to the first meta-aramids and Nomex®

Common Uses:
- Thermal protective gear and apparel
- Lightweight FR aerospace composites
- Electrical laminates - transformer cores

- Inherently flame resistant - No deterioration in flame resistance after repeated washing and normal use
- Excellent thermal properties
- Meta-aramids have excellent textile apparel properties
- Helps minimize break-open and maintains a stable, inert barrier between the fire or arc flash and skin
- Forms a tough, protective char when exposed to flame.
- Excellent durability – Resists abrasion, tears and shows good chemical resistance.
- Meta-aramid based fabrics are easy to launder, low laundry shrinkage and rarely need pressing - Excellent appearance retention.
Aramids

Para-aramid

The first Para–aramid – was invented by chemist Stephanie Kwolek while working for DuPont, eventually branded Kevlar®. Invented in 1960’s searching for a new lightweight strong fiber to use for light but strong tires

Common Uses:
- Bullet and shrapnel resistant armor
- Thermal protective gear
- Cut resistant gear
- High strength composites
- Tire cords, high strength rubber hose reinforcement

- Inherently flame resistant - No deterioration in flame resistance after repeated washing and normal use over time
- Excellent high tensile strength
- Helps reduce fabric shrinkage and minimize break-open and maintains a stable, inert barrier between the fire or arc flash event and skin
- Excellent durability - Resists abrasion and tears – Good chemical resistance
- Para-aramids, in high percentage fabric blends, are not the best apparel fabrics for hand (tactile qualities) and drape
Cotton

Cotton is a natural fiber grown, harvested, cleaned, scoured/bleached, and baled. Cotton is a cellulosic polymer, similar to wood pulp, but with a higher degree of polymerization and crystallization.

- Development of the cotton gin enabled inexpensive processing – Most widely used natural textile fiber for clothing
- High moisture affinity
- Excellent tactile properties or hand qualities
- Inexpensive
- Easily dyed, but can exhibit color fastness issues
- Wrinkling, shrinkage, and appearance retention issues from repeated laundering
- Durability issues compared to aramids and other synthetic fibers
- **Cotton is a flammable fiber**
Modacrylic

*Modacrylic - The generic name of a fiber that has a lower Acrylonitrile (35-85\%) level than ordinary acrylic fiber.*

- Fibers made with monomers of acrylonitrile and others - such as vinyl chloride or vinylidene chloride.
- Commercial production began in the late 1940's.

**Common Uses:**
- Protective clothing
- Upholstery, drapery and carpet industries
- Faux fur
- Wigs
- Plush toys market

- Synergistic protective effect with other fibers, FR and non-FR alike. Can blend (higher percentages) with some non-FR fibers to produce a flame resistant garment
- Inherently flame resistant - No deterioration in flame resistance after repeated washing and normal use
- Does not melt or drip
- Soft hand, good textile properties
- Has good dyeability for bright shades
- Quick drying
- Low abrasion resistance and durability in high percentage blends
Man-Made Cellulosic Fiber

Lyocell

*Type of rayon or cellulosic fiber made from dissolved wood pulp*
*Developed in 1970’s by American Enka.*

- Lyocell – Trade name
- Tencel® - Brand name
- Lenzing – Manufacturer

- Lyocell is a type of rayon, regenerated cellulosic fiber. Dissolved and spun wood pulp. Is a similar but chemically different process than viscose rayon.
- Man-Made cellulose
- Lyocell is more expensive to produce than commodity rayon or cotton.
- Acts as a natural insulator
- Excellent blend fiber with good tactile feel or hand
- Excellent moisture regain
- Lyocell has better durability characteristics than typical cotton.
- Positioned as a high end cellulosic fiber
- **Non-FR variants are flammable**
Nylon

Nylon is a designation for a family of synthetic polymers known generically as aliphatic polyamides, first produced on **February 28, 1935, by Dr. Wallace Carothers at DuPont's research facility at the DuPont Experimental Station.** Nylon was intended as a synthetic replacement for silk. Used in many different products after silk became scarce during World War II.

**Common Uses:**
- General apparel – durability and fabric strength requirement applications
- Carpet
- Tents, rope, backpacks
- Molded parts

- Nylon has good toughness and resistance to abrasion
- Good tensile strength
- Flexible with a low coefficient of friction
- Easy to launder, dries quickly and retains its shape
- **Nylon does melt and is flammable**

*Nylon is used in FR fabric blends to bolster durability and strength properties*
Carbon-Based Fibers

Carbon fiber is defined as a fiber containing high percentages of carbon

Carbon Fiber Manufacturing Process
Polyacrylonitrile (PAN), or other precursor, is heat treated in successive steps and in inert (oxygen free) atmospheres to remove non-carbon atoms and bond the resulting carbon chains. Processing temperatures up to 3,000°F are common.

Common Uses:
- High strength – Low weight composites
- Excellent flame resistant properties
- High Strength to weight ratio
- Electrical Conductivity
- Good tensile strength but low elongation and brittleness
- Poor abrasion properties
- Dark color
- High fiber manufacturing costs (energy usage)

Carbon fibers make weak textile garment fabrics and generally need to be blended with other fibers to help impart fabric durability.
Fiber FR Characteristics
**Fire and Combustion Fundamentals**

1. **Decomposition - Pyrolysis**
2. **Flammable and Non-Flammable Compounds**
3. **Oxygen Exposure**
4. **Oxidation - Combustion**
5. **Self-Sustaining Heat**

Combustion Process Can be Interrupted at the “Stop Sign” Points

**Fiber-Fabric Blend Technology**
Aramids

1. Aramids require high temperatures to decompose (pyrolyze). Char above 750°F
2. Decreased formation of flammable volatiles, increased production of chars and other non-flammable compounds

- Aramids, such as Nomex® and Kevlar®, are inherently flame-resistant, high-temperature resistant fibers that do not melt, drip, or generally support combustion in air.
- Meta-Aramid, such as Nomex®, is used a primary textile fiber due to its good subsequent fabric qualities
- Para-aramid, such as Kevlar®, helps to reduce fabric shrinkage and break-open in the presence of extreme heat and/or arc flash exposure

Meta aramid fibers, such as Nomex® expand during the thermal exposure and form a protective barrier

Varga, Ksenija et. al, Thermal and Sorption Study of Flame Resistant Fibers, Lenzinger Berichte 89, (2011), 50-59
Cotton and Treated Cotton

- Cotton decomposes gradually above 300°F and rapidly above 475°F.
- Fabrics with high percentage cotton blends need post treatment to impart flame retardant qualities.
- Proban® treatment – Cross-linked topical phosphorus based FR Treatment – technology developed in the late 1950’s.
- Activation of treatment is exothermic – Adding additional heat and energy to the event.

2. Treatment works by lowering the decomposition temperature of cotton; increasing chars and reducing flammable gasses and compounds.

3. Treatment activation results in increase water vapor and CO₂ during pyrolysis – oxygen displacement.
Modacrylic fibers decompose without igniting

3 Exposure to heat and flame release halogens – Oxygen displacement

4 Free-radical scavenging (binding) of the oxygen - Interfere with the oxidation/combustion

- Synergistic protective effect with other fibers, FR and non-FR alike. Can blend (high percentages) with non-FR cotton and man-made cellulosics to produce a flame resistant garment
- Inherent, self extinguishing and do not melt or drip
- Decomposition temperature - 525°F
Man-made Cellulosic Fiber

- Man-made cellulosics, such as Lyocell can be used in FR PPE fabric blends in non-FR and FR variants
- Non-FR variants can be used with blended Modacrylic for FR fabrics
- Decomposition temperatures ~ 500°F
- Lenzing FR® - Phosphorus and sulfur based flame retardant additives are incorporated throughout the cross section of the fiber, added to the polymer before extrusion
- Other FR additives can be used in man-made cellulosic fibers

**FR additives decompose at lower temperatures than the base fiber polymer forming a protective char over the fiber**

Lenzing FR® keeps shape after burning. A carbon layer is formed on the surface and prevents the fibers from further burning.

Carbon Fiber

1 Carbon fibers are inherently flame resistant

2 Decreased formation of flammable volatiles

- Though Carbon Fiber is constituted of carbon which is flammable, the fiber itself does not burn under typical ambient conditions
- If heated up higher than 750°F together with some fuel, the fiber slowly oxidizes but stops after the burning fuel is removed.

Carbon fiber in its nature is pre-oxidized

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Nylon is a thermo-plastic synthetic fiber. It is used in FR fiber/fabric blends at low percentages, the thermal characteristics can be managed. The decomposition temperature is 660°F. The melt temperatures are 428°F and 509°F for Nylon 6 and 6,6 respectively.
LOI – Limiting Oxygen Index

The limiting oxygen index (LOI):

The minimum concentration of oxygen, expressed as a percentage, that will support combustion of a small sample. A high index is indicative of a less easily ignited and less flammable material.

Cotton – NON-FR 18
FRT Cotton 28-32
Wool 25
Silk 23
Nylon 6 20-21 (melt temp 215 C)
Nylon 6,6 24-25 (melt temp 265 C)
Modacrylic 28-32
Nomex® 28
Kevlar 29
Lenzing FR® (lyocell) 28

Many variables associated with fabric combustion. LOI of an individual fiber may not be a good indicator of finished fabric thermal performance.
Types of Flame Resistant and Retardant Fabrics

**Inherent**
- Flame resistant properties are present in the chemistry of the fiber at the time of fiber production
- Fiber molecular structure does not support combustion
- Dyed Fabric does not require chemical treatments

**Inherent Blends**
- Synergistic effect of FR fibers with other FR and non-FR fibers
- Dyed fabric does not require chemical treatments

**Chemically Treated**
- After fabric is manufactured, it is flammable requiring chemical treatments to the fabric to impart flame retardant properties
Potential Issues for Flame Retardant FR-Treated Cotton Based Fabrics

Lost or Compromised Flame Retardant Properties Due to:
- Sensitivity to Chlorine-Containing Bleaches
- Premature Failure of Flame Retardant Finish (Mechanical)
- Ion-Exchange Effects in Hard Water (+ Peroxide Effects)
- Potential Thermal Hazard, Exothermic Reaction W/ Concentrated Bleach

Fabric weight variation & FR treatment uniformity can effect rate of loss.

FR Properties of Fabrics Made with Inherent Fibers and Blends

Using Inherent Fibers and Fabrics:
- FR Properties are not affected by the use of chlorine bleach
- No Ion Exchange effect
- No post-treated, FR chemical finish to wash or wear off

Key Considerations for All FR Fabrics
- Wash separately or with other like FR garments
- Hard water may combine with soap film to deposit flammable contaminants on fabric
- Fabric softeners or other additives (such as starch) may coat fibers and affect FR performance
- Soil and contaminants, especially petroleum based, can reduce FR performance
Types of Flame Resistant and Retardant Fabrics

**How do you know FR Protection is still there?**

**Degree of Assurance Can Be Dependent on Technology Choice**

- **Inherent and Blended Inherent Fabrics**
  - Flame resistant properties of the fabric itself unaffected by laundering
  - Improper laundering can increase burn injury – Contaminates, additives, etc.

- **FR Treated Fabrics**
  - Flame resistant properties of the fabric itself can be changed by laundering
  - Laundry history must be known
  - Improper laundering can increase burn injury – Contaminates, additives, etc.
  - The manufacturer’s quality of treatment application can impact performance

**FR Assurance Testing**

- **All FR Fabrics**
  - Non-destructive tests not available – Garment destruction discerning FR protection

**Fiber and Fiber Blend Choice Can Impact Care and Maintenance Needs**
Fiber and Fabric Blend Characteristics
4 primary ways our bodies release and regulate heat

**Radiation**
- Heat and energy from a warmer body “radiates” into a cooler atmosphere (think infrared)

**Convection**
- Lose heat through the movement of air around our body

**Conduction**
- Heat flows from your body through direct contact with a cooler object

**Evaporation**
- As the amount of heat being removed from the body decreases, sweat is created.
- As the sweat evaporates into the atmosphere, heat is removed and the body cools

Goal: Maximize moisture management and thermal comfort while minimizing any negative impact clothing has on how our bodies cool.

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Fiber and Fabric contribute to both dry and wet heat transfer

**Fabric Weight**
- Heat and energy from a warmer body “radiates” into a cooler atmosphere (think infrared)

**Airflow**
- Lose heat through the movement of air around our body

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**Dry Heat Transfer**

**Fabric Weight**
- Fabric weight has the highest influence on heat regulation and heat stress, per 3rd party study*

* North Carolina State University Textile Study

**Fibers and fiber blends with better thermal protective performance allow for lighter weight fabrics**
Fiber and Fabric contribute to both dry and wet heat transfer.

**Moisture Management**
- The fiber and fabric’s ability to move moisture from the skin, across and through the fabric to enable evaporation

**Drying Rate**
- The rate of evaporation from the fabric

**Wicking**
- Movement of moisture over a larger area across and to the surface of the fabric

**Water Vapor Permeability**
- The ability of water vapor to move away from the skin and through the fabric

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**Absorption and Moisture Wicking**

- High percentage fiber blends of cotton or cellulosics can give an initial feeling of comfort, but once saturated, feel heavy and trap heat
- Blends of natural and synthetic fibers with moisture wicking properties can have a synergistic comfort effect
Fiber-Fabric Blend Technology

**Break Strength – Grab Method**

Breaking Strength and Elongation of Textile Fabrics - ASTM D5034
- Force required to elongate or break a fabric sample
- Measures relative strength of a fabric

**Stronger and More Durable Fibers/Fabric Can Provide a Longer Service Life, and Reduce Replacement Costs.**

**Abrasion Resistance**

Taber Abrasion ASTM D3884
- Abrasive discs rubbing against a fabric with a known pressure
- Indication of a fabric’s relative resistance to wear through.

- Aramids increase fabric durability
- Carbon fibers in a fabric blend reduce durability
- Nylon increases durability and commonly used in conjunction with cotton or other weaker fibers

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Launderability

- Soils and Contamination - Release Properties
- Ease of Care - Special Instructions

- Shrinkage
- Color fastness

- Laundering Wear and Weakening
- Ease of Care – Special Instructions

Fiber and Fiber Blend Choices Directly Affect the Launderability Characteristics of the Garment
Actual Fiber Blend Comparison
When Considering PPE Choices, The Fiber and Fabric Determines Many of the Desirable Garment Characteristics
Nomex® MHP Coverall vs. FR Treated 88/12 Cotton/Nylon

Thermal Manikin before and during an ASTM F1930 exposure

Total 8 cal/cm² - 2.0 cal/cm²s heat flux @ 4 seconds
- 2.66 cal/cm²s heat flux @ 3 seconds
- 4.0 cal/cm²s heat flux @ 2 seconds
Predicted Burn Injury

NOMEX® MHP,
7 oz/yd²

- 4 seconds @ 2.0 cal/cm²s
- Total Exposure: 8.0 cal/cm²
- Predicted Burn Injury: 23.0%

88/12 FR Treated Cotton / Nylon,
7 oz/yd² (8 oz)

- 4 seconds @ 2.0 cal/cm²s
- Total Exposure: 8.0 cal/cm²
- Predicted Burn Injury: 69.7%
**Predicted Burn Injury Survivability**

**NOMEX® MHP, 7 oz/yd²**

- 4 seconds @ 2.0 cal/cm²s
- Total Exposure: 8.0 cal/cm²
- **Predicted Burn Injury: 23.0%**

**88/12 FR Treated Cotton / Nylon, 7 oz/yd² (8 oz)**

- 4 seconds @ 2.0 cal/cm²s
- Total Exposure: 8.0 cal/cm²
- **Predicted Burn Injury: 69.7%**
**Nomex® MHP is the overall winner on key comfort criteria while maintaining durability with Nomex® and Kevlar®**

**Best Scores For**
- **Softness:** Pleasant sensation to the touch
- **Smooth:** Low perception of harshness
- **Thinnest:** Low height of the samples perceived between fingers
- **Most drape:** Evaluates the falling of the material under its own weight
- **Most Supple:** Capacity of the fabric to slide between fingers without resistance
- **Least voluminous:** Perceived quantity of residual material after squeezing it on the hand
- **Crease recovery:** Capacity of the fabric to recover its initial shape
- **Least Noisy:** Hearing perception resulting from the friction of the material with itself.
**Moisture Regain %**

- Measures how much moisture is absorbed by a fabric from its surroundings.
- Fabrics which absorb moisture easier can be prone to slowly releasing (more water to dry).
- Goal is to find optimized fiber blends which transport **and** also effectively release moisture.

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**Drying Rate**

![Graph showing drying rate comparison between Nomex® MHP and FRTC 88/12.]

**Optimized Fiber Blends Can Balance Desirable Properties**
**Actual Fiber Blend Comparison**

**Break strength + Abrasion Resistance = Predicted Durability**

- **Nomex® MHP can provide better durability**

**Nomex® MHP** compared to FRTC 88/12:
- **60% Higher break strength after laundering**

**Break Strength (Warp + Fill)**
- 100X IL: Nomex® MHP = 238 lbs, FRTC 88/12 = 133 lbs
- 200X IL: Nomex® MHP = 185 lbs, FRTC 88/12 = 115 lbs

**Abrasion Resistance**
- 100X IL: Nomex® MHP = 862 cycles, FRTC 88/12 = 625 cycles
- 200X IL: Nomex® MHP = 430 cycles, FRTC 88/12 = 351 cycles
Low Shrinkage = Better Fit Retention

- 50+% less shrinkage after 25 washes (FRTC 88/12)
- 37% less shrinkage after 100 washes (FRTC 88/12)
- 48% less shrinkage after 200 washes (FRTC 88/12)

Color Fastness = Appearance Retention

- 20% less color loss after 25 washes (FRTC 88/12)
- 160% less color loss after 200 washes (FRTC 88/12)
DuPont Nomex® MHP Can Provide a Lower Life Cycle Cost

- Low shrinkage
- Better durability
- Excellent appearance retention

Saves Money Over Time

**TOTAL COST OF OWNERSHIP COMPARISON**

- FRTC 88/12: Initial Cost $65
- Nomex® MHP: Initial Cost $85

$17,500 *

Replacement Costs Can Be Significant

* Assumptions: 200 wearer program, 6 year model, 4 sets of PPE per employee

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Summary
Understanding Fiber and Fiber Blend Characteristics is important to make informed PPE decisions

Fiber and Fiber Blend Choice Dictate Thermal Protective Performance

Fiber and Fiber Blend Choice Can Affect Care and Maintenance Considerations

Fiber and Fiber Blend Choice Dictate Fabric Comfort and Durability

Important to Match the Fiber and Fiber Blend Choice to Your Assessed Hazards

**Fiber and Fiber Blend Characteristics Dictate Many of the Final Garment Properties**
Thank You
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