Advanced textiles for intimate apparel

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1.1 Fibers and yarns

Cotton, silk, rayon, nylon, polyester, and spandex are common types of fibers currently used in intimate apparel. However, new types of fibers offer new possibilities to intimate apparel designers. Their important properties include (1) performance and versatility, (2) moisture management and coolness, and (3) sustainability. Fibers and yarns that possess these properties are discussed in the following sections.

1.1.1 Performance and versatility

Intimate apparel products should be versatile; for instance, they should have easy-care properties, be light weight, be comfortable, provide freedom of movement, be durable, and even have antibacterial or antiodor properties. Major fiber manufacturers such as Nylstar, Invista, Toray, and Lenzing have launched different types of fibers that are versatile and suitable for use in intimate apparel.

1.1.1.1 Nylstar S.A.

The Meryl® product line by Nylstar offers different types of polyamide microfibers for bodywear, sportswear, intimates, swimwear, and cosmetics. Four common types of fabrics offered by Meryl® intimates include Nateo, Sublime, Satiné, and Elite.

Meryl® Nateo is an air-textured polyamide yarn with a round cross section. It has easy-care properties, a natural look and feel, quick-drying properties, and resistance to abrasion (Meryl® Nateo). Underwear made from Meryl® Nateo may incorporate Meryl® Skinlife gussets, which can provide antimicrobial protection to the wearer. The special handling and silky touch of Meryl® Sublime is particularly good for intimate apparel (Fig. 1.1).

This fiber, made with very fine filaments, can offer multifilament comfort, freshness, lightness, a silky touch, and no pilling. Meryl® Sublime provides a unique softness as well as ultra-breathability because it is a fully drawn yarn and its thickness is only 0.45 dtex/filament (Meryl® Sublime). Meryl® Satiné has a trilobal cross section designed to reflect light and give a shiny luster (Meryl® Satiné). Meryl® Elite is another option that can be spun into fine or superfine yarn (see Fig. 1.2). It is ultralight, smooth, naturally elastic, and durable, and has a high resistance to abrasion, thus making this microfiber favorable for use in the hosiery market (Meryl® Elite).
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1.1.1.2 Invista

Invista offers Lycra®, Coolmax®, Tactel®, and Corudura® for spinning yarns with the necessary stretch properties that contribute to the wearer’s comfort. Intimate apparel with Lycra® can provide a stretchable and form fit because of its shape retention properties (Varghese and Thilagavathi, 2014). In 2012 Invista developed the Lycra® Xtra Fine fiber, with 33 dtex or less for knitted and woven fabric; the maximum fabric weight of knits is 120 g/m² and that of woven fabrics is 90 g/m² (Lycra Extra Fine Collection Fiber Branding Requirements, 2012).

Sports bras are designed to control excessive breast motion and reduce breast pain during vigorous activities (Yip and Yu, 2006). The selection of the most appropriate materials for sports bras is extremely important. The Lycra® SPORT fabric is engineered and designed to support athletes and active individuals in their sporting activities. To meet the qualification standards, Invista conducted an in-depth analysis of over 50 garments from leading active wear and outdoor apparel companies. The property requirements include elongation, fit, and recovery power. The results showed that the Lycra® fiber delivers stretch and recovery power designed to help athletes move and perform at their best (Lycra Sport). The markets for active wear and sportswear have evolved and developed to meet modern sports and fitness needs. Invista’s SUPPLEX® fabric provides the feel of cotton by using finer, multiple nylon filaments, which are 26–36% softer than those used in standard nylon fabrics (see Fig. 1.3). It is claimed that SUPPLEX® fabric is breathable, holds the garment shape, dries faster.

Figure 1.1 Meryl Sublime microfibers.

Figure 1.2 Properties of Meryl® Elite microfilaments.

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than cotton, and retains its color (SUPPLEX® Fabric brand certification requirements; SUPPLEX® Fabric).

### 1.1.1.3 Toray

Toray has newly developed single yarns with nanometer-diameter fibers. This yarn comprises 1.4 million or more single nanofibers in a yarn of 44 dtex. Because the surface area of a yarn comprising nanofibers is much larger than that composed of conventional fibers, it exhibits excellent softness and moisture absorption (Toray Industries Inc.). Fig. 1.4 shows nanofiber bundles before and after water absorption.

TOREX™ QUUP™ from Toray is a continuous nylon filament made from polyamide mixed with highly absorbent polyvinylpyrrolidone (Taiwan Textile Federation, 2007). It can be used together with traditional polyamide filaments. The TOREX® QUUP® FARRILLO filaments have a triangular, hollow shape (Fig. 1.5) with a highly moisture-absorptive property that is about double that of conventional filaments.
When compared with traditional nylon filaments, it weighs 20% less. QUUP is widely used in intimate apparel, sportswear, and stockings (Toray Industries Inc., 2014). For example, Wacoal Japan has adopted this fiber in their functional slim-up pants (Taiwan Textile Research Institute, 2013).

1.1.1.4 Lenzing

Lenzing’s innovative strength lies in wood-based cellulose fibers, especially Lenzing Modal® and TENCEL®. Lenzing Modal® is mainly extracted from beech wood (Fig. 1.6). Softness is the key factor in choosing materials for intimate apparel. The low fiber rigidity and cross section of Lenzing Modal® make the fiber very soft in a natural way. Measurements of the softness factor using the Kawabata evaluation system showed that Lenzing Modal® is twice as soft as cotton (Lenzing, 2014). MicroModal® AIR (0.8 dtex) has the softest handfeel when compared with MicroModal® (1 dtex), Lenzing Modal® (1.3 dtex), and cotton fibers (Lenzing, 2014).
In China, Bellevue™ silk yarn has been created with a special structure. Elastane is incorporated and trapped within the silk filament, so that only the silk comes into contact with the skin. The yarn combines the natural properties of silk (comfort, heat regulation, antibacterial, and ultraviolet protection) with a very high level of 4-way elasticity. Bellevue silk yarn is capable of withstanding high temperatures and can therefore be used for the inner surface of bras, in knits, and in lace or woven fabrics.

1.2 Moisture management and coolness

Moisture management has a significant influence on the human perception of moisture sensation (Hu et al., 2005). Moisture in clothing has been widely acknowledged as one of the fundamental factors that affect discomfort during wear (Li, 2005). Liquid absorption and transport properties are important for intimate apparel to be comfortable; moisture and heat should be transmitted from the body to the environment in the form of sensible and insensible perspiration to regulate thermal insulation caused by moisture buildup (Hu et al., 2005). Sensible perspiration drips off the skin to exert a cooling effect, whereas insensible perspiration evaporates before it is perceived as moisture on the skin. Cotton fabrics are traditionally used as underwear materials because of their high moisture regain to maintain body warmth. However, cotton fabrics cannot rapidly evaporate sweat and therefore result in a feeling of stickiness. Synthetic fibers demonstrate an advantageous dry-fit function: perspiration can be rapidly expelled from the fabric during contact with the skin. New research and development endeavors that aim to improve moisture management and provide cool contact sensations are summarized in the following sections.

1.2.1 Moisture management

Liu et al. (2014) have conducted extensive research work in moisture management. In their recent work, a responsive fabric material based on thermoresponsive poly(N-isopropyl acrylamide) (PNIPAM) was grafted onto the surface of cotton fabrics to construct a smart hierarchical system. Thermoresponsive polymers originate under a low critical solution temperature (LCST), at which the polymers are converted from hydrophobic to hydrophilic (Nash et al., 2012; Xue et al., 2012). They are smart materials that undergo physical changes in response to external temperature stimuli. The smart system exhibits thermoregulation by responsively absorbing perspiration at different atmospheric temperatures. Liu et al. (2014) showed that at a chamber temperature of 25°C (a temperature below the LCST), the surface temperature of PNIPAM-modified fabric increased by approximately 2°C compared with that of an unmodified cotton fabric after 15 min. At 40°C (a temperature above the LCST), sweat drips off the skin to exert a cooling effect on the body. Modified fabrics that have superior hygroscopicity and a dry-fit function can cool down the body temperature. Fig. 1.7 shows a schematic diagram of the thermoregulation and moisture management processes of PNIPAM-grafted fabric.
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Fabrics made from freshFX® have a unique four-channel capillary cross section that provides a wicking property. This property not only helps to transfer moisture and allow quick drying but also has an exceptionally soft handfeel (Invista). Nike has developed a moisture management fabric by using a denier differential mechanism to facilitate the movement of sweat away from the wearer’s body. Basically, the fabric is engineered with two sides: a face layer and a back layer. Surface tension and capillary forces drive the moisture from the wearer’s skin to the back layer. Then the moisture moves from the back layer to the face layer (Hurd and Sokolowski, 2014).

1.2.2 Coolness

Because of global warming and power-saving trends, more and more people prefer to wear environmentally friendly clothes that use functional textiles. It is not difficult to find in stores clothing that features “sweat-absorbing” and “quick-drying” functions and a “cool contact sensation.” Triumph International Ltd. introduced the “Cool Sensation” collection in 2013. The idea behind the development of this new fabric, which can reduce the temperature of the body, was a double-face fabric that can transfer moisture from one side to the other. Similarly, Peach John also promoted the Coolish Bra in summer 2013, which uses Wincool® fabric.

According to Essick et al. (2010), soft and smooth materials are pleasant to the touch, and a cool feel allows the feeling of pleasant comfort to be maintained. The development of functional fibers with comfort has dramatically increased since the 2005 Cool Biz campaign in Japan (BBC, 2011). Several companies, such as Outlast Technologies Inc., Insilico, Kuraray, Teijin, Toyobo, Kurabo, and Mizuno, have launched different materials that provide a “cool” or “ice touch” effect. Selected types of fabrics suitable for intimate apparel are outlined here.
1.2.3 **Outlast**

The Outlast® technology utilizes phase-change materials (PCMs) that absorb, store, and release heat for optimal thermal comfort. PCMs are substances that absorb and release thermal energy during the process of melting and freezing. Outlast® PCMs can be located inside the fibers. The applications for these materials are for products that are worn next to or very close to the skin. For example, Outlast® viscose is soft, has a comfort similar to that of cotton or silk, is antistatic, and is easy to dye. It can therefore be used in underwear, shirts, dresses, sleepwear, work wear, and sportswear (Hartmann et al., 2009; Hartmann et al., 2012).

1.2.4 **Insilico**

Insilico has developed different types of microcapsules that can be applied to textiles. For example, ThermoBall® is a microcapsule product that contains PCM (Insilico) so that it absorbs heat as the surrounding temperature goes up and slowly releases heat as the temperature goes down. When the product is applied to clothing, the thermal-storage microcapsule causes a phase change resulting from the temperature change in the external environment and the skin, causing heat absorption or heat release. Such a mechanism is used to give cooling and warming effects to the body, and thereby the wearer feels fresh.

1.2.5 **Kuraray**

Ethylene vinyl alcohol (EVOH) fiber is a new material developed by Kuraray (Nanoka et al., 2014). Sophista™ is the brand name of the EVOH filament for garments. This fiber has a core-sheath structure that uses EVOH resin as a sheath and polyester as its core. The resin has a hydrophilic group (OH radical) (Ministry of Economy Trade and Industry, 2011). The properties of Sophista include moderate moisture absorbency and desorbency, thus giving a skin-friendly touch and providing an instantaneous cool feeling when in initial contact with the surface of the skin. However, the melting point of this fiber is around 170°C; therefore it may not be suitable for molding bra cup fabric.

1.2.6 **Teijin**

Teijin provides different types of materials with moisture management functions, such as Calculo® polyester yarn, Cool Shell®, Sweat Sensor®, Wellkey® hollow fiber, and Fibaliver®. Knitted fabric made with Fibaliver® changes the stitch density to improve air permeability when humidity is sensed. The stitches revert back to the original state when the fabric dries (Ministry of Economy Trade and Industry, 2011).

1.2.7 **Flycool**

The Taiwanese brand Flycool® uses mineral particles in its yarn with a special cross section that can manage moisture and provide a cool feel. The composition of the
Flycool® powder comprises minerals that release a cool feeling, such as malachite, glass, marble, iron ore, and gold, and materials that enable heat dissipation, such as graphite, aluminum, silicon, nitrogen, and boron (Method for processing double face fabric, 2012). These allow the Flycool® fabric to quickly dissipate heat.

### 1.2.8 All magic sports

Nano Coolness Fiber is a 100% polyester fiber patented by All Magic Sports. It provides a cool feeling, deodorizes, and is antistatic, quick drying, breathable, and comfortable. The Nano Coolness Fiber is layered with mica stone and is constructed by double-layering a silicone-oxygen tetrahedron with an aluminum octahedron. This substance has a high heat capacity, which means that more energy is required to heat this substance, thus resulting in a cool feeling. The patent also includes a cell shell structure combined with a multi-open-cell material to increase water absorption. According to All Magic Sports, the Nano Coolness Fiber has a cryogenic effect of 1.5–2°C (Method for processing double face fabric, 2012; All Magic Sports).

### 1.3 Sustainability

Because of the increasing number of ecological challenges, sustainability is a strategic initiative in 44% of the companies surveyed by Retail System Research (Wilson, 2008). Different innovative fibers that target increases in eco-friendliness and sustainability are being launched into the market, which the examples from the following companies illustrate.

Cotton Incorporated is driving and leading environmental improvements in the US and global cotton industry. As a result of a steady stream of scientific advances over the past 40 years in growing and processing cotton, as well as in manufacturing cotton products, the cotton industry has been reducing its environmental impacts (Cotton Incorporated, 2014). Famous lingerie brands also have their own collections that use cotton as the main material; for example, the Cotton Lingerie collection by Victoria’s Secret, the Eco Chic collection by Triumph, and the Eco-comfort line by Wacoal.

Of all organic fibres, organic cotton is one of the most popular. It is grown using methods and materials that have a low impact on the environment. A new initiative with the aim of accelerating the uptake of organic cotton has been launched with the support of retailers such as C&A, H&M, and Eileen Fisher, as well as Textile Exchange. The Organic Cotton Accelerator will work with “the entire supply chain” “to find and fund innovative ways to ensure the supply of organic cotton” (Bischif, 2014). It will therefore be no surprise if more and more lingerie brands create their own organic cotton collection in the coming years.

In terms of synthetic yarns, the Invista Apparel and Advanced Textiles business is committed to its own sustainability program, Planet Agenda, which focuses on three main objectives: minimizing its environmental footprint, offering competitive products that meet the needs of the apparel markets by using fewer resources and
enhancing the environmental performance of all fabrics, and protecting the health and safety of its workers (Shin, 2014). In 2014 Invista introduced a bio-derived spandex that can be used in a wide variety of apparel fabrics and garments. Lycra® T162R is a bio-derived spandex fiber that comprises approximately 70% by weight of a renewable source made from dextrose derived from corn.

Hyosung specializes in spandex, polyester, and nylon yarns. In the early 2000s, Hyosung developed techniques for recycling discarded nylon products into nylon filament yarns and introduced MIPAN® Regen™ (Hyosung, 2011). Hyosung creora® is a spandex filament that is widely used in different types of intimate apparel. The aim of Hyosung creora® eco-soft™ is to provide a soft feeling and whiter whiteness through its low-heat-settable properties. The manufacturers save on costs by reducing carbon dioxide emissions or improving productivity by increasing the stenter speed in the heat-setting process. Creora® easy scour™ is another product that enables effective dyeing and finishing with less water consumption (Shin, 2014).

Roica™ and Dorlastan™ are the trademarks of Asahi Kasei’s spandex/elastane fibers that can be dyed with acid or metal complex dyes. Dorlastan V550 is an eco-friendly spandex with a low silicon oil content (around 1–3%) compared with common spandex, which has a silicon content of 5% (Shin, 2014).

1.4 Fabrics

The requirement for fabrics used in intimate apparel is stretchability, and most preferable is four-way stretchability to enable the fitting of different shapes and sizes without the need for substantial modification of the garment pattern. Warp-knit fabrics are commonly used in intimate apparel, and spacer fabrics are becoming popular in the market. Therefore, these two categories are described in the following sections.

1.4.1 Warp-knit fabrics

Tricot, mirror satin, powernet, satinet, weftlock, tri-skin, jacquard, and simplex are common types of warp-knit fabrics used today in intimate apparel, shape wear, or swimwear. Tricot is the most widely produced warp-knitted fabric. The free-floating underlaps superimposed on the technical back contribute to a very pleasant touch. Mirror satin fabric has a very smooth and shiny surface on its technical back as a result of the long underlaps produced by the front guide bar. Mirror satin is a one-way stretch fabric and is comfortable to wear; however, it is a heavier fabric and there is a greater risk of snagging. Powernet and satinet are used for esthetic purposes and to improve the air permeability of intimate apparel.

However, most warp-knit fabrics, like tricot and powernet, have greater stretch in the warp direction, which provides only one-way stretch. Fabrics that offer substantial isotropic stretchability and an equal modulus in all directions are highly desirable. They can offer equal stretch in all directions to provide a balanced degree of compression, shaping, and comfort to the wearer.
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Waldman and Lazarus (2014) invented a fabric with equal moduli in multiple directions. The fabric was knitted on a machine that had three guide bars. The lapping diagram and chain notation of this fabric is shown in Fig. 1.8. Guide bar 1 is fully threaded with nylon yarns, guide bar 2 is fully threaded with spandex yarn with an inlay structure, and guide bar 3 is fully threaded with spandex yarn using a 1 × 1 tricot construction. The first, second, and third moduli of elasticity are within the same range of magnitudes of modulus of elasticity required to form an isotropic fabric.

Smooth edges have become popular in intimate apparel. The technique is to produce a warp-knit fabric with an edge portion by pulling out yarn. This forms an edge that does not require finishing. To form an edge portion by pulling out yarn, the edges of the upper and lower portions of the piece must be parallel. Otherwise, one side needs to be finished with a hem. In 2009 Wacoal developed a warp-knit fabric structure that comprises a nonelastic yarn arranged in a 1 × 1 tricot structure and an elastic yarn arranged in a looping structure (Fig. 1.9).

The fabric is cut at an angle of at least 3 degrees and at most 177 degrees with respect to the knitting direction (Fig. 1.10). The edge of the fabric piece therefore does not require hem-finishing when left as cut (Oya, 2009).

Various patents have been filed on the development of warp-knit fabric structures. For instance, Jin (2013) introduced a method for constructing a warp-knit fabric using polyester yarn for both the base and the surface yarns, which aims to improve the softness to the touch. The base yarn is a fully drawn polyester yarn (also known as a filament yarn), whereas the surface yarn is a drawn textured polyester yarn (Jin, 2013).

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Revolutional™ Slim is patented by Carvico. It is a warp-knitted fabric made from 71% polyamide microfiber and 29% elastane, which incorporates Nurel, a microencapsulated fiber rich in caffeine, vitamin E, retinol, fatty acids, aloe vera, and ultraviolet protection factor 50+ to provide an antioxidant effect. This lightweight fabric of only 155 g/m² can protect the skin, fight against free radicals, is effective in hydrating and moisturizing, and resists pilling. The combined actions of such active ingredients require regular use of the garment for no less than 8 h/day for 8 weeks. It is claimed

Figure 1.9 Fabric structure with an edge that does not require hem finishing.

Figure 1.10 Fabric that does not require hem finishing when left as cut.
that the fabric will help to reduce the “cottage cheese” appearance typical of cellulite on skin and remodel the body silhouette (Self Company Group Sp. J, 2014).

1.4.2 Spacer fabrics

Spacer fabrics are created by connecting two independently knitted fabrics with spacer yarns so that the fabrics have a three-dimensional appearance (Lehmann, 1994) (Fig. 1.11). In general, spacer fabrics are categorized by their knitted structure, which is either warp or weft knitted. In the production of warp-knitted spacer fabric, a double needle bar raschel machine is used (McCartney et al., 1999; Donaghy and Azuero, 1999). Tables 1.1 and 1.2 show several types of warp-knitted spacers with various thicknesses and their microscopic views. Weft-knitted spacer fabrics are produced using a double-jersey circular machine that has a rotatable needle cylinder and needle dial (Shepherd, 2004; Sytz, 2004; Willmer, 2005).

Spacer fabrics are extensively used in the production of three-dimensional materials by the technical textile sectors, which include automobile textiles such as car seat and dashboard covers; industrial textiles such as composites; medical textiles such as antidecubitus blankets; sports textiles; and foundation garments. As discussed in many previous studies, spacer fabrics have numerous advantages as a component material. Their breathability is high so that moisture can be released, thus reducing the possibility of skin maceration. Therefore, the level of comfort increases in comparison with other materials such as neoprene, foam, and laminate fabrics. It is light and has high stiffness- and strength-to-weight ratios (Yip and Ng, 2008; Li et al., 2009). In addition, because spacer fabrics are recyclable, they are considered to be an environmentally friendly textile material compared with polyurethane (PU) foam. Table 1.1 shows different types of warp-knitted
Table 1.1  Types of warp-knitted spacer fabrics

<table>
<thead>
<tr>
<th>Spacer</th>
<th>Fabric type</th>
<th>Material used</th>
<th>Thickness (mm)</th>
<th>Areal density (g/m²)</th>
<th>Bulk density (kg/m³)</th>
<th>Angle of spacer yarn (θ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Wale</td>
</tr>
<tr>
<td>Spacer 1</td>
<td>Warp-knitted</td>
<td>Polyester</td>
<td>1.03 ± 1.49</td>
<td>135.32 ± 2.16</td>
<td>131.29 ± 2.10</td>
<td>19.02°</td>
</tr>
<tr>
<td>Spacer 2</td>
<td>Warp-knitted</td>
<td>Polyester</td>
<td>1.76 ± 0.05</td>
<td>17.91 ± 1.70</td>
<td>98.09 ± 0.96</td>
<td>32.06°</td>
</tr>
<tr>
<td>Spacer 3</td>
<td>Warp-knitted</td>
<td>Polyester</td>
<td>2.19 ± 0.34</td>
<td>146.35 ± 1.83</td>
<td>66.77 ± 0.83</td>
<td>14.23°</td>
</tr>
<tr>
<td>Spacer 4</td>
<td>Warp-knitted</td>
<td>Polyester</td>
<td>2.29 ± 0.11</td>
<td>138.53 ± 2.52</td>
<td>47.65 ± 0.85</td>
<td>26.63°</td>
</tr>
<tr>
<td>Spacer 5</td>
<td>Warp-knitted</td>
<td>Polyester</td>
<td>2.48 ± 0.16</td>
<td>199.04 ± 1.90</td>
<td>80.30 ± 0.77</td>
<td>34.25°</td>
</tr>
<tr>
<td>Spacer 6</td>
<td>Warp-knitted</td>
<td>Polyester</td>
<td>2.90 ± 0.10</td>
<td>241.29 ± 1.53</td>
<td>83.28 ± 0.54</td>
<td>27.71°</td>
</tr>
<tr>
<td>Spacer 7</td>
<td>Warp-knitted</td>
<td>Polyester</td>
<td>3.33 ± 0.08</td>
<td>242.24 ± 2.01</td>
<td>72.76 ± 0.60</td>
<td>40.21°</td>
</tr>
<tr>
<td></td>
<td>Spacer 1</td>
<td>Spacer 2</td>
<td>Spacer 3</td>
<td>Spacer 4</td>
<td>Spacer 5</td>
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<tr>
<td>Front view</td>
<td><img src="spacer1_front.png" alt="Image" /></td>
<td><img src="spacer2_front.png" alt="Image" /></td>
<td><img src="spacer3_front.png" alt="Image" /></td>
<td><img src="spacer4_front.png" alt="Image" /></td>
<td><img src="spacer5_front.png" alt="Image" /></td>
<td><img src="spacer6_front.png" alt="Image" /></td>
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<tr>
<td>Back view</td>
<td><img src="spacer1_back.png" alt="Image" /></td>
<td><img src="spacer2_back.png" alt="Image" /></td>
<td><img src="spacer3_back.png" alt="Image" /></td>
<td><img src="spacer4_back.png" alt="Image" /></td>
<td><img src="spacer5_back.png" alt="Image" /></td>
<td><img src="spacer6_back.png" alt="Image" /></td>
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<tr>
<td>Side view (coursewise)</td>
<td><img src="spacer1_course.png" alt="Image" /></td>
<td><img src="spacer2_course.png" alt="Image" /></td>
<td><img src="spacer3_course.png" alt="Image" /></td>
<td><img src="spacer4_course.png" alt="Image" /></td>
<td><img src="spacer5_course.png" alt="Image" /></td>
<td><img src="spacer6_course.png" alt="Image" /></td>
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<tr>
<td>Side view (walewise)</td>
<td><img src="spacer1_wale.png" alt="Image" /></td>
<td><img src="spacer2_wale.png" alt="Image" /></td>
<td><img src="spacer3_wale.png" alt="Image" /></td>
<td><img src="spacer4_wale.png" alt="Image" /></td>
<td><img src="spacer5_wale.png" alt="Image" /></td>
<td><img src="spacer6_wale.png" alt="Image" /></td>
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</table>
Spacer fabric, and Table 1.2 shows the microscopic view of seven types of spacer fabrics.

Spacer fabrics can also be used to replace PU foam because they have better heat and moisture exchange characteristics (Anon, 2001; Schmirmoff and Weinrich, 2006). Since spacer fabrics can be produced in a single process, the laminating and bonding processes are eliminated, which are otherwise necessary when producing conventional PU items such as PU molded cups (Donaghy and Azuero, 1999). Yip and Ng (2009) found that the optimal molding conditions and compressive strain of molded spacer fabrics are closely related to the material used for the spacer yarn, the linear density of the spacer yarn, and the elongation and recovery of the spacer fabric.

Spacer fabrics are currently used in many applications associated with intimate apparel, for example, molded bra cups (Kaye and Abbott, 2007), sports bras (Heath and Krueger, 2014), bra wings (Scheininger et al., 2011), wire casings (He, 2012), shoulder straps, and the backing of hook-and-eye closures. The advantages are (Sadhan, 2015):

• excellent compression elasticity and cushioning
• high breathability/air permeability
• high thermal insulation and temperature regulation
• good bending performance
• good draping
• adjustable vapor transport
• resistance to age
• sufficient surface and wash resistance
• low bulk density
• sterilization capabilities
• diverse surface design capabilities

1.5 Fabric finishing

Fabric finishing can be implemented through chemical or mechanical means. The use of nanotechnology in the textile industry has rapidly increased because it imposes unique and valuable properties. The use of nanotechnology allows textiles to be multifunctional and produces fabrics with special functions. In the following sections, finishings such as antibacterial, antiodor, and handfeel improvement are discussed.

1.5.1 Chemical finishing

1.5.1.1 Antimicrobial and antiodor properties

Different antimicrobial agents are already in use in textiles: primarily organosilicons, phenols, and quaternary ammonium salts. For instance, the Dow Chemical Company launched in 2012 SILVADUR™ antimicrobial, a revolutionary microbial control technology that provides long-lasting freshness and reliable protection against unwanted
bacteria that can cause unpleasant odors, decay, rot, and discoloration in textile fabrics (Grove, 2012). Other agents include silver nanoparticles, which have an extremely large relative surface area, thus increasing their contact with bacteria or fungi and vastly improving their bactericidal and fungicidal effectiveness (Patra and Gouda, 2013). McQueen et al. found that antiodor or antimicrobial textiles may not be really effective. Some antimicrobial textiles are far more effective at performing their advertised tasks in the laboratory than in testing on humans. In one experiment, a fabric was treated with a silver compound, which is marketed as preventing odor in clothing. Although the laboratory testing showed the antimicrobial activity, the treated fabrics did not have reduced odor or bacterial intensity during in vivo testing. Anything from sweat to proteins in the human body can disrupt the antimicrobial properties of a fabric. Therefore, it is important to test an antimicrobial or antiodor effect through in vivo testing rather than just using in vitro testing during textile product development (Betkowski, 2014).

1.5.1.2 Elastomeric finishes

Elastomeric finishes refer to elastic finishes achieved with silicone-based products (Betkowski, 2014). The main effect is to provide durable elasticity and recovery from deformation. Elastomeric finishes are frequently used in swimwear, lingerie, foundation garments, athletic wear, hosiery, and normal clothing. Some performance enhancements provided by elastomeric finishes include very soft handle, improved crease recovery, better ability to be sewn, higher resistance to abrasion, and some stain repellence (Schindler and Hauser, 2004a).

1.5.1.3 Softening finishes

Softening finishes can be used to achieve a soft hand, smoothness, more flexibility, and a better drape, which are important in intimate apparel. The perceived softness of a textile refers to its elasticity, compressibility, and smoothness (Kim and Vaughan, 1975; Schindler and Hauser, 2004b). Fabrics become stiffer after undergoing several finishing processes, which remove the natural oils and waxes of fibers. Softening finishes can be used to overcome this problem and even improve the original suppleness (Begum, 2012). Cationic softeners produce the best softness and are durable after laundering. However, cationic softeners attract grime, may cause yellowing upon exposure to high temperatures, and may affect the lightfastness of direct and reactive dyes. Anionic softeners are heat stable at normal textile processing temperatures and are compatible with other components of dye and bleach baths. Amphoteric softeners provide good softening and high antistatic effects, but have low permanence during washing. They also have fewer ecological problems than similar cationic products. Table 1.3 summarizes the important softener characteristics.

1.5.2 Mechanical finishing

The main fabrics used in intimate apparel, such as tricot and jersey, can also be treated by a mechanical finish to obtain a soft handfeel; for example, fabrics can be processed by wet sueding. Plurima machines from the Santex Group are used for this process
Table 1.3 Important softener characteristics (−, characteristic absent; +, characteristic present, rating from at least + to at most +++)

<table>
<thead>
<tr>
<th>Chemical type</th>
<th>Softness</th>
<th>Lubricity</th>
<th>Hydrophilicity</th>
<th>Substantivity</th>
<th>Stability to yellowing</th>
<th>Non-foaming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anionic</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>−</td>
<td>++</td>
<td>−</td>
</tr>
<tr>
<td>Cationic</td>
<td>+++</td>
<td>−</td>
<td>−</td>
<td>+++</td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>Amphoteric</td>
<td>++</td>
<td>−</td>
<td>+++</td>
<td>+</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>Nonionic ethoxylates</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>+</td>
<td>+++</td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Silicones</td>
<td>+++</td>
<td>+++</td>
<td>− to +</td>
<td>+++</td>
<td>+++ to +</td>
<td>++</td>
</tr>
</tbody>
</table>


Figure 1.12 The wet-sueding machine made by the Santex Group.

(Wet-sueding machine made by Santex Group). As shown in Fig. 1.12, two upper rollers press the fabric down onto the bottom rollers, and four bottom rollers with an abrasive surface rub the fabric’s surface. A water container is set below each spiral roller. When the roller rotates, it comes into contact with water and then with the
fabric. The addition of water helps to achieve an even suede effect. However, after washing several times, the stretch and recovery of suede fabric is reduced since the fabric is damaged during the wet-sueding process.

1.6 Conclusion

In this chapter, the latest developments in fibers, yarns, fabrics, and finishing processes being used in the manufacture of intimate apparel products have been discussed. It is important for designers and manufacturers to understand the intricate properties of various advanced textiles and how they can be used in intimate apparel. The new types of materials and developments are being introduced within three main categories: performance versatility, moisture management, and sustainability, which can add value to products. Different fabric structures provide various benefits to intimate apparel. For example, fabrics with isotropic stretchability and equal elastic moduli in all directions are highly desirable for use in lingerie, swimwear, and shaping garments because they provide a balanced amount of compression and the right amount of shape and comfort to the wearer. The use of nanotechnology allows textiles to be multifunctional and produces fabrics with special functions.

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