Principle for the development of textile specialty products using material design

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Many kinds of specialty textile products have been commercialized and their importance in textile industry is growing. In the development of textile specialty products, material designing of the products is one of the most important working components. But there has been almost no literature in which principle of development using material design for textile specialty products is systematically discussed. This paper reports a method of material design for the development of apparel specialty fabrics, which is a knowledge-based total system by differential way. Selective examples of knowledge data for material designing in terms of attributive items are presented with some examples of related specialty technologies.

Keywords: Apparel fabrics, Attributive items, Differential design, Material design, Textile specialty technologies

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1 Introduction

Textile specialty products can be defined as the products whose additional value based on their certain specialty effect and/or function can be recognized by the customers. In this paper, the textile products are limited to mainly apparel fabrics.

The amount of fiber consumption in the world is gradually growing due to the increase in its population and income per head in developing countries. Clothing is primarily used for the minimum requirement of physiological and social life. But with an increase in income, more sophisticated textile products having some specific values, like easy care, aesthetic effect, comfortability, safety, hygienic effect, have been more strongly demanded. Textile industry in some developing countries like China is now fast growing in producing mainly conventional products by mass-production. In most advanced countries, textile industry has highly oriented to produce technical textile products and high value-added products of apparel use. But globally competitive situation has made textile industry also in developing countries to have an interest in supplying such specialty products. In this situation, nowadays technologies for specialty textile products have become more important in textile industry.

In the development of apparel specialty fabrics, material designing of the products is one of the most important working components. There have been some systems for designing specific manufacturing conditions such as the necessary number of yarns for fabricating weave of a specified width. But material designing for the development of specialty apparel generally needs to include the whole process from conceptual design to manufacturing processing design. Neural network systems have been reported for predicting fabric properties based on fabric structures. But such system cannot be extensible to the region outside its original relational data. Hence, such a statistical tool is not useful for the creation of new specialty products.

In practice, material designing of apparel specialty fabrics is usually conducted by trial and error, based on personal knowledge and experience. Hence, the development of new specialty fabrics usually needs to spend much money and time for manufacturing of trial samples. Textile specialty products require some specific technologies in addition to the ordinary technologies for producing conventional products. On the other hand, R & D activities so far conducted in the world have accumulated a large amount of knowledge in textile science and technology. It is thought that such knowledge must be effectively used for the material designing of such specialty products. But there has been no literature in which principle for the development of apparel specialty fabrics using material designing is systematically discussed along this line.

This paper presents material design method for developing apparel specialty fabrics which is totally a knowledge-based system by differential way. Examples of knowledge data for the material
designing in selective attributive items are presented with some examples of related specialty technologies.

2 Method of Knowledge-based Material Design

2.1 Concept and Outline of Method

2.1.1 Total Material Design

Material design of apparel fabrics is the design whose object is ‘fabric as a material’. Contrary to this, in ‘colour/pattern design’, the objective is related with aesthetic effects based on colour/pattern. But it must be noted that there is a certain overlapped region where colour/pattern depends on material. The material design for developing new specialty apparel fabrics must contain all or most of the following design phases in a linear mode, as ‘total material design’:

- Conceptual design (CPD),
- Function/effect design (FED),
- Basic structural design (BSD),
- Basic manufacturing method design (BMD), and
- Detailed manufacturing method design (DMD)

Contrary to this, ‘partial design’ concerns only one or two of the above-mentioned design phases.

2.1.2 Differential Design

Differential design is defined as a kind of design in which at first, a suitable reference sample is selected in terms of conceptual design (CPD) and then the object of all the design works is reduced to be the difference between the product to be designed and the reference sample. The advantages of this differential design, in case the reference sample is suitably selected, are: (i) rather the qualitative knowledge can be effectively applied to quantitative estimation on the difference in the design works, and (ii) one can save all the structural parameters in the design works which have no relation to the difference.

This differential design is especially suitable for designing specialty fabrics of apparel use, in which the factors of specialty are additional to conventional fabric performance in most cases.

2.1.3 Knowledge-based Material Design System

This system is based on both the scientific & technological knowledge and the factual data of reference sample. The most prominent feature of scientific knowledge is that it has generally a certain universal applicability. In this sense, design based on knowledge is extensible and then can afford more creative design. The factual data are used in this system to increase the accuracy of design results.

2.2 Design Logics and Outline of their Procedures

Figure 1 schematically shows the frame of the designing system. In this system, the selection of reference sample must be done by a business strategy. At least the factual data of the reference sample and knowledge data base for the relationship between properties and structure, and cost estimation module must be incorporated in the system. The factual data can be obtained from the record of specification/manufacturing, or structure analysis/property measurements of the reference sample. In the system, all the design phases (CPD, FED, BSD, BMD and DMD) are situated in a linear mode as described below:

CPD is to conceptually state the features of the product in the form of difference from the reference sample selected. The features of the specialty are usually expressed by the conceptual terms related to fabric specialty performance/effect of attributive items under the condition of conceptual relative cost to the base of reference sample.

FED is to objectively characterize the performance/effect features in the form of difference from the reference sample under the condition of allowable relative cost. The characterization should be conducted by quantitatively specifying in terms of attributive items. It must be noted that the difference in these features must be sufficiently above the human discrimination limens.

BSD is to settle the product structure to realize FED in the form of difference from the reference sample. The product structure is represented by the structural parameters related to fiber, yarn, fabric and finishing process. The data base of knowledge on the relation between fabric property and structure must be fully utilized for conducting BSD.

BMD is to settle the basic manufacturing method in the form of difference from the reference sample. BMD includes the simple selection of some available materials and manufacturing methods. The data base of knowledge on the structure/property and manufacturing method must be effectively utilized for conducting BMD.

These knowledge data bases can be the bridge between material designing and the output of textile science/industry. Design works usually progress downward and the works on suitability judgment/checking go upward (Fig.1). The suitability...
judgment on the assumptive performance and cost resulted from BSD and BMD is conducted in comparison with FED. A judgment criterion has been proposed \(^3\) and the detailed design working procedures are also described. \(^3\)

An example of the design results is shown below for better understanding of this design system:

- **Reference sample**—worsted weave of black formal use, which the company is now commercially supplying.
- **CPD**—deeper black worsted weave than the reference sample, keeping soft hand and its production cost can be little higher.
- **FED**—\(L=11-12, \ B=0.09-0.11\) and cost increase<10\%, where \(L\) is the lightness in \(a, b\) and \(L\) chromaticity; and \(B\), the bending slope in KES system.
- **BSD**—very thin layer coated on fiber surface by a resin having low refractive index. Higher dye uptake and less flatness in fabric surface.
- **BMD**—fabric treatment by chlorine after dyeing and then resin coating as thin as possible. Pressure for pressing the fabric at finishing must be less than that for the references sample.

### 2.3 Attributive Specialty Items and their Relation to Specialty Technology

The knowledge data bases can be most effectively classified based on attributive specialty items. The author proposes the classification as shown in Fig. 2.

In the case of design example described above, it is a material design for worsted weave of black formal wear, which has very deep blackness. In this case, the specialty product technology has only one attributive specialty item as 'blackness' related to '1-2 colour developability' in the figure. But for example, if hollow fiber is adopted to realize lighter fabric, the fiber can give warmer fabric at the same time. Therefore, the specialty product technology of this case gives two kinds of specialties in attributive items. In this text, specialty product technology corresponding to the individual attributive specialty item is simply called as 'attributive technology'. Hence, usual technology of specialty product can include one or a plural of attributive technology.

### 3 Examples of Knowledge Data for Material Design

The knowledge data for material design in selective attributive specialty items are given below in a simply summarized form with some examples.

#### 3.1 Microclimate Comfortability

The comfortable ranges of microclimate at the surface of human skin under clothing are generally the temperature \(32\pm1\degree C\) and relative humidity 50\%10\%. Microclimate is determined by the balance of: (i) heat and perspiration exhausted from human skin, (ii) heat and sweat/moisture transfer at the place, (iii) ventilation effect of air at microclimate place. (iv)
Fig. 2—Classification of attributive specialty items

1 Visual aesthetic effect
- 1.1 Surface profile, fabric grain, fabric pattern, texture
- 1.2 Dyability and colour developability
- 1.3 Luster
- 1.4 Melange effect, fancy effect

2 Textile aesthetic effect
- 2.1 Compression
- 2.2 Friction
- 2.3 Bending

3 Microclimate comfortability
- 3.1 Warmness
- 3.2 Coolness
- 3.3 Reduction of sweaty humidity
- 3.4 Reduction of sweaty stickiness
- 3.5 Waterproof keeping lower moisture microclimate

4 Stretchiness
- 4.1 Stretchiness
- 4.2 Lightness
- 4.3 Slipability
- 4.4 Reduction of clinging

5 Easy care
- 5.1 Crease/wrinkle resistance
- 5.2 Washability, dimensional stability, dryability
- 5.3 Anti-pilling
- 5.4 Soil resistance
- 5.5 Moth proofing

6 Mechanical failure resistance
- 6.1 Tear resistance
- 6.2 Abrasion resistance
- 6.3 Snagging resistance
- 6.4 Seam slippage/breaking resistance

7 Hygienic, safety, environmental friendliness
- 7.1 Non-toxic, environmental friendliness
- 7.2 Skin care, UV guard
- 7.3 Healing effect
- 7.4 Antibacteria, smell proof
- 7.5 Deodorizing
- 7.6 Anti-staticity
- 7.7 Flame retardancy

8 Garment making-up capability
- 8.1 Silhouette formability
- 8.2 Sewability
- 8.3 Garment anti-defoaming

3.1.1 Warmness
The main factors for the reduction of heat transfer are:

(i) To keep larger amount of standing air within fabric

Technological means to achieve this are :

- to realize higher bulkiness using bulky fabric structure, bulky yarn or fiber raising.
- to make hollow part within yarn as hollow fiber or hollow yarn.

(ii) To reduce heat conduction through fiber within fabric

Technological mean to achieve this is :

- to use fiber having low thermal conductivity.

Table 1 shows the thermal conductivity \((k)\) for different fibers.

heat and moisture/sweat water transfer through fabric, (v) absorption with exothermal heat and desorption/vaporization with endothermal heat by the material of fabric, (vi) the effect of outside climate including sunlight and wind through fabric, and (vii) transient heat transfer between human skin and fabric due to their temperature difference.

The special attributive items can be ‘warmness’, ‘coolness’, ‘reduction of sweaty humidity’, ‘reduction of sweaty stickiness’ and ‘waterproof keeping lower moisture at microclimate’.

3.1.1 Warmness
The main factors for the reduction of heat transfer are:
Table I—Thermal conductivity (k) of different fibers

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Axial direction</th>
<th>Transverse direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>7.948</td>
<td>0.062</td>
</tr>
<tr>
<td>p-Aramid</td>
<td>4.334</td>
<td>0.104</td>
</tr>
<tr>
<td>Cotton</td>
<td>2.879</td>
<td>0.243</td>
</tr>
<tr>
<td>Linen</td>
<td>2.831</td>
<td>0.344</td>
</tr>
<tr>
<td>E-glass</td>
<td>2.250</td>
<td>0.509</td>
</tr>
<tr>
<td>Silk</td>
<td>1.492</td>
<td>0.118</td>
</tr>
<tr>
<td>Polyamid</td>
<td>1.433</td>
<td>0.171</td>
</tr>
<tr>
<td>Rayon</td>
<td>1.414</td>
<td>0.237</td>
</tr>
<tr>
<td>Polyester (filament)</td>
<td>1.257</td>
<td>0.157</td>
</tr>
<tr>
<td>Polyester (staple)</td>
<td>1.175</td>
<td>0.127</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>1.241</td>
<td>0.111</td>
</tr>
<tr>
<td>Acrylic</td>
<td>1.020</td>
<td>0.172</td>
</tr>
<tr>
<td>Wool</td>
<td>0.480</td>
<td>0.165</td>
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(iii) To interrupt heat radiation from fiber toward outside and/or to increase heat radiation from fiber toward human skin.

Technological means to achieve this are:
- to use fiber whose material has high capability of water/moisture absorption.

Acrylic acid fiber which is made by modifying acrylic fiber has been successfully commercialized for inner wears and sport wears by Toyobo (Eks™). Wool has high moisture absorption capability. Nihon Keori has developed the technology to enhance its moisture capability by adding hydrophilic material, which is named as Wellwarm™. Asahi Chemicals has commercialized a yarn composed of cupro fiber and acrylic fiber. Exothermal heat generated in cupro fiber and warm holding capability of acrylic fiber causes synergic effects.
- to fix material having high absorption capability to fabric surface by after-treatment.

(vii) To make use of exothermal heat generated by phase transition.

Technological means to achieve this are:
- to use fiber whose material has high capability of water/moisture absorption.

3.1.2 Coolness

The main factors for coolness are:
(i) To use effective transient heat transfer from human skin to fabric.

Technological means to achieve this are:
- to use fiber of material having high thermal conductivity value like cotton and linen as shown in Table 1.

(ii) To use fiber having high thermal conductivity value like cotton and linen as shown in Table 1.

(iii) To effectively interrupt sunlight.

Technological means to achieve this are:
- to use thick fabric with high cover factor.
- to use bi-component fiber whose core part contains high concentration of TiO₂.
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• to use fabric having metal layer by deposition or coating.

(iv) To effectively use endothermal heat of phase transition.

3.1.3 Reduction of Sweaty Humidity
The main factors for the reduction are:
(i) Diffusion within space toward outside.

*Technological mean to achieve this is:
• reduction of sweat within fabric having higher wicking ability and higher dryability.

(ii) Moisture absorption by fiber, etc.

*Technological mean to achieve this is:
• to use fiber or finishing agent having high absorption capability of moisture.

(iii) Moisture transfer toward outside by ventilation.

*Technological means to achieve this are:
• to use clothing having wide open end.
• to use fabric having high air permeability.

Use of fiber having reversible change between crimped (dry) and decrimped (wet) form has been successfully introduced. The fabric has high air permeability in moisture state and lower permeability in dry state. This reversible change in crimp by humidity has been realized by using side by side bi-component fiber composed of cellulose and triacetate by Mitsubishi-rayon (Ventcool™).

3.1.4 Reduction of Sweaty Stickiness
The main factors for the reduction are:
(i) Removal of liquid sweat toward outside.

*Technological mean to achieve this is:
• efficient transfer of liquid sweat by making use of capillary phenomena using hollow fiber with porous structure, fiber having sharp groove, and ultra-thin fiber.

(ii) Reduction of contact area with wetted fabric.

*Technological mean to achieve this is:
• to use fabric having crepe effect using untwisting torque in fabric caused by highly twisted yarn.

3.2 Wearing Comfortability
3.2.1 Stretchiness
The stretch amount of human skin by his movement can be related to the stretch amount of fabric as per the following equation:

\[
\text{(Stretch amount of fabric)} = \text{(Stretch amount of skin)} - \text{(Size allowance of clothing)} - \text{(Slippage amount between skin and fabric)}.
\]

When fabric on the curved surface of human body is stretched, the pressure is applied on the body by the tension of fabric stretch. If the fabric can be easily elongated, the pressure is lowered and then the body can move freely. But in some cases, power stretch is required for fabric to keep a certain level of pressure to support the body.

It must also be noted that the fabric having higher stretchability tends to more easily shows a certain amount of permanent deformation due to several reasons, such as high elongation by outer load, creep by self-weight of clothing and degradation of elastane fiber. Stretch of fabric is classified by the type of use, as shown below:

Comfort stretch—Fabric is elongated at comparatively small amount under comparatively small load at comfort stretch.

Power stretch—Fabric is elongated at large amount and the elongation gives human body feeling of moderate tightness by wearing.

(i) In the case of comfort stretch, it is desirable that fabric can easily be elongated to a certain small amount and resists to be elongated for higher loading in order to avoid the permanent deformation.

*Technological means to achieve this are:
• knitted fabrics made by suitable design of construction.
• fabrics made of textured yarn.
• weaves composed of core-spun yarn using elastane fiber.
• weaves made of bi-component fiber of side-by-side type.

PET filament of conjugate fiber with twisting (Z10™) was developed by Unitika and PTT filament of conjugate fiber by Toray.
• fabrics made by the combination of crimped fiber yarn and/or suitably twisted yarn and treatment of full relaxation process.

(ii) In case of power stretch.

*Technological mean to achieve this is:
• to use elastane fiber.

3.3 Easy care
3.3.1 Crease/Wrinkle Resistance
Crease/wrinkle is typically formed due to the mechanical pressing the folded fabric part by the action, such as sitting, and drying process after washing. Permanent strain of the fiber located at the
folded part corresponds to the local part of crease/wrinkle.

**Major technological means to increase crease/wrinkle resistance are:**

- to use fibers whose remained strain is small enough after recovery from the tensile stress relaxation for a certain period at 2-3% strain. Typical examples of such kinds of fibers are PET and wool at dry condition.
- to modify fibers so that their permanent strain becomes small enough. Its typical example is the combined treatments of liquid ammonium and resin finishing to cotton fabrics.

**Additional technological means for higher crease/wrinkle resistance are:**

- increase of fiber slip ability by applying softening agent for easing recovery against frictional constrain.
- selection of the fabric construction by which fiber strain caused by mechanical pressing and frictional constrain are decreased.
- increase in the freedom of fiber movement within fabrics by full relaxation finishing and/or weight reduction treatment to fabrics.

### 3.3.2 Washability, Dimensional Stability and Dryability

Advantages of water washing compared to solvent cleaning are feasible to cost saving, environmental friendliness and higher effectiveness for the removal of aqueous stain. On the other hand, the disadvantage of water washing is easy occurrence of shrinkage and deformation caused by its higher mechanical action. Washability, dimensional stability and dryability can be defined as:

- **Washability**—To be tolerable in shrinkage and deformation during water washing.
- **Dimensional stability**—To be resistant to shrinkage, deformation and wrinkle.
- **Dryability**—To be easily dried by atmospheric hanging.

(i) In the case of textile products made of animal fiber such as wool, felting and then shrinkage generally occur by the strong mechanical action of tumbling during water washing. Hence, the conventional animal fiber products show the lack of water washability.

**Technological means to solve this problem are:**

- to remove the step of scale of animal fiber by chemical or physical etching.
- to smooth the step by filling resin to the step.
- to depress mutual fiber movement by the increase of the constrain to fiber by applying resin binder and/or enhancing fiber swelling. It is reported that the plasma treatment causes the enhancement of fiber swelling.
- to incorporate some amount of synthetic fiber such as PET which resists mutual fiber movement and decreases the frequency of mutual fiber movement.

(ii) In the case of weave made of cellulose fiber such as rayon/cotton, the problem related to dimensional stability can often become problem. In water, this kind of fiber is so much swollen that intolerably high shrinkage occurs, because of the enlargement of yarn waviness due to fiber swelling.

**Technological means to solve this problem are:**

- sanforizing finishing.
- resin finishing.
- resin finishing with liquid ammonia treatment.
- treatment by high pressure steam.
- incorporation of some amount of PET fiber.
- curing for resin finishing after sewing gives higher quality of dimensional stability to clothing.

(iii) Dryability has become more important because of energy saving.

**Technological means to improve this property are:**

- to adopt hydrophobic fiber such as PET fiber.
- to select fabric construction which has open structure, higher surface area and lower water retention-ability.

### 3.3.3 Anti-pilling

Pills are formed by the generation of nucleus of small fuzzy fiber entanglement and then its growth through rubbing action to the surface of fabrics. Pilling tends to easily occur in the knitted fabrics composed of synthetic fibers such as PET and acrylic whose knot strength is high, because such fiber resists to be dropped off from the fabrics during pill growing process.

**Technological means to improve anti-pilling property are:**
to change in fabric construction so as to be less fuzzy.
• to increase constrain to the fiber pull-out from the fabrics.
• to select fiber whose knot strength is lower enough.
There are many commercialized specialty fibers for anti-pilling in PET and acrylic fibers.
• after-treatment on fabrics made of such a fiber to reduce its polymer molecular weight for lowering its knot strength.

3.4 Hygiene, Safety and Environmental Friendliness

3.4.1 Anti-bacteria/Smell Proof

Anti-bacteria/smell proof is to suppress bacteria and to prevent the smell resulted from bacteria multiplication.

Technological means for anti-bacteria/smell proof are:
• to incorporate specific zeolite, chemicals exhausting Ag or Cu ion.
• to incorporate titanium oxide photo-catalyst, organic silicone quad ammonium salt.
• to incorporate hetero-cyclic nitride-sulfur compound, chitin/chitosan. They are introduced into fiber or into finishing agent.
• Silver or copper metal plating can also be used.

3.4.2 Deodorizing

Deodorizing is to reduce substances of bad odor. The typical sources of bad odor can be mentioned as body odor, tobacco odor, odor of rotten materials, irritating odor from building materials and excreta odor. The typical substances of bad odor are: hydrogen sulfide, methyl mercaptan, acetaldehyde, ammonium, trimethylamine, and formaldehyde.

Technological means to solve these problems are:
• physical methods to remove bad odors using such deodorants as activated carbon, zeolite, silica-gel, and ceramic absorptive agents.
• chemical methods. e.g. oxidization/reduction by using photo-catalyst, enzyme, neutralization and ion-exchange.

Recently, the technology using titanium oxide as photo-catalyst has been significantly developed. Phthalocyanine-Fe derivative is a typical example of the above enzyme.
• There are also odor agents masking and/or offsetting bad odor.

There are several kinds of methods for applying these materials to fabrics, such as incorporation into fiber, incorporation into microcapsule as finishing agent and binding to fabrics with less reduction of their function.

4 Conclusions

The principle for the development of textile specialty products (mainly apparel specialty fabrics) using knowledge-based material design has been explained. Method of the material design has been described on the view points of its concept, design logic, design procedure and attributive specialty items. Some examples of knowledge data for material design for selected attributive items with some examples of related specialty technologies have also been presented. The author believes that if this kind of material design system is well established and is properly applied to the development of apparel specialty fabrics, the way using this kind of material design for the development will contribute to save much money and time for manufacturing many trial samples.

References
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