Fiber Assembly Structure Engineering and Design Logic of Textile Products

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Abstract

The concept of FIBER ASSEMBLY STRUCTURE ENGINEERING (FASE) was proposed. It was situated as one of the four systems which compose TEXTILE ENGINEERING. The content of FASE was discussed in terms of the design logic of textile products.

The basic structure of the design logic was out-lined. Its basic design is composed of three kinds of designs; aesthetic effect/function design, basic structure design and basic manufacture design. The data bases which must be supplied for basic structure design as a scientific system were discussed.

1. Introduction

In the later period of 1970s, the tendency to maturity of fiber/textile business in advanced countries including Japan became significant. Since then fiber/textile manufacturers in these countries have made much effort to enter non-fiber business fields and to change their fiber business from conventional one to more technology oriented or value added one. In apparel use, several speciality fabrics having highly aesthetic effects and new hands have been realized by making use of their sophisticated technologies. Several technologies orienting to comfortability have been commercialized. Several systems by which information from demand side can be effectively transferred to supply side have been developed. In non-apparel use, synthetic fibers have been rapidly applied to several new technical end-uses in the fields of civil engineering, transportation, medical, agriculture etc. In these cases, synthetic fibers have been mostly applied through engineered designs and fabrication technologies to meet end-use requirements. Several high performance fibers such as carbon, aramid, polyester liquid crystal and ultra high molecular polyethylene fibers have been commercialized. Several functional fibers such as adsorptive fiber, ion-exchanging fiber, bio-compatible fiber and membrane hollow fiber have been realized. Thus textile technologies have much deepened and enlarged as compared with for example those of 20 years ago.

On the other hand, several kinds of fundamental sciences and engineering such as polymer chemistry, polymer physics, mechanical engineering, chemical engineering, human engineering and psychology supply their basic ways of thinking for textile engineering. It seems that it is rather impossible to establish a scientific system for textile engineering based on a certain common scientific way. These lead to the impression especially to students and young researchers that textile engineering is a disordered assembly of scientific knowledge relating to textile and thereby to the reduction of its scientific fascination for them. In these situations, it must be desirable to present a systematic approach to textile engineering by which it can cover the technological

progress mentioned above in the past and expected in the future, and by which they can feel a certain scientific fascination.

Nowadays, CAD is effectively used for designing several products. But it is scarcely used for textile products except designing visual appearance. It is thought that textile engineering must effectively contribute to develop CAD technology for textile products other than appearance design.

In this article, the concept of FIBER ASSEMBLY STRUCTURE ENGINEERING (FASE) is presented. The concept and the constitution of TEXTILE ENGINEERING is discussed in relation with FASE. The content of FASE is discussed in terms of the design logic of textile products. The scheme of design logic is outlined. The data bases which must be supplied for basic structure design as a scientific system are discussed.

2. The Concept of Fiber Assembly Structure Engineering (FASE) and its Situation in Textile Engineering

2.1 Textile engineering

The central core of what is called textile engineering in the past was composed of the analysis of textile processing. Now let us think about how a new textile engineering should be addressed to meet with the present requirements, i.e.;

- It can follow the recent and future enlargement and deepening of textile technology.
- It can systematically arrange all the kinds of studies accumulated up to now in the field of textile engineering and positively work for its future progress.
- It has a unique methodology and a theoretical system enough to give a scientific fascination to students and young researchers.

Returning to the starting point, the author thinks that 'technology' and 'engineering' should be defined as follows;

- Technology is a definite measure based on natural science and/or logics to realize a certain object.
- Engineering is a scientific knowledge system supplying a base for technology.

According to these definitions, 'textile engineering' can be defined as "the scientific knowledge system supplying a base for textile technology".

2.2 The concept of fiber assembly structure engineering (FASE)

Figure 1 shows the structural system by which aesthetic effect·function of textile products are determined. It is composed of two main factors. One is the configurational, assembling effect of fiber. Another is the material effect of fiber. The essential, configurational function of fiber can be summarized into the following four elements;

- i . high flexibility
- ii . large specific surface area
- iii. formability into textile (flexible, porous, stable) structure
- iv. axial (high) rigidity

In order to meet the object of use, an optimum performance/cost settlement of textile products must be realized. Designing of textile products must be carried out to accord this line. Fiber which has an optimum material function must be selected. At the same time, enough knowledge is necessary to attain the best configurational and assembling effect of fiber.

In this context, the author would like to propose the concept of 'Fiber Assembly Structure Engineering (FASE)'^[1,2]. It is defined as 'the scientific knowledge system for technology to realize the optimum configurational and assembling effect of fiber for fiber assembly structure products'.

2.3 The constitution of textile engineering and the situation of FASE

Textile Engineering must cover such a wide range of textile technology as described in Introduction. If so, it is

impossible to arrange the whole range of Textile Engineering as a system with a common methodology. Therefore, it may be better if it is divided into a few subsystems and each with a certain common methodology. In this case, the number of subsystem should be as least as possible and the methodology should have the largest individuality from others. From this point of view, the author would like to situate FASE as one of these subsystems as schematically illustrated in Fig.2. These subsystems overlap each other as shown in this figure. Fiber Processing Engineering, Dyeing Processing Engineering and designing and/or selection of optimum fiber are located in the region overlapped by FASE and Fiber Material Engineering. Extraction of properties of fiber assembly structure products relating to a specified end-use are located in both regions (A) and (B) shown in fig.2. Fig.3 schematically shows the relationship between FASE and Textile Human Engineering. When a human-being wears cloth, there appears an interface between human-being and cloth. Textile Human-being (Apparel) Engineering includes evaluations from the stand points of susceptibility effect, comfortability effect and designing/processing of apparels. On the other hand, FASE extracts the key textile properties for the interface and pursues how to realize that textile.

It must be noticed that FASE deeply overlaps with the other three subsystems and on the other hand, Fiber Material Engineering scarcely overlaps with both Textile Human Engineering and Textile Application Engineering. Fiber Material Engineering is related with the other two subsystems mainly through only FASE. In this sense, FASE can be regarded as the central core of Textile Engineering.

2.4 The basic character and the range of FASE

FASE concerns the assembling behaviors and the

Fig. 1 The structural system for aesthetic effect/function of textile products

Fig. 2 Four subsystems constituting textile engineering

Fig. 3 The relationship between FASE and textile human engineering

assembling effect of fiber whose configuration is fine and long. The basic scientific methodologies for the analysis of these phenomena are mainly mechanics and transport phenomena. In this sense, FASE is a kind of configurational, structural, phenomenological knowledge system. Of course, the designing of fiber needs the knowledge of polymer chemistry and polymer physics to some extent. In Fig.2, fundamental and academic applications are shown in relation with FASE and the other three subsystems. FASE which is defined above in relation with fiber assembly structure products may be extended to cover both Textile Human Engineering and Fiber Application Engineering, in a broad sense. But in order to keep rather clear character of FASE, it is better to

confine FASE in the region from where basic textile materials are supplied to the other two subsystems, as shown in Fig.2.

3. The Constitution of FASE and the Design Logic of Textile Products

3.1 The constitution of FASE and the classification of designing stages

From the view point of designing, FASE can be divided into four parts as shown in Fig.4. These are i design logic of textile product, ii design logic of textile manufacturing method, iii data base for textile product design and iv data base for textile processing. Concerning

Fig. 4 The constitution of FASE from view point of designing

textile product design, it can be divided into the following three parts, according to its stage: (a) aesthetic effect/function design, (b) basic structure design and (c) basic manufacture design, as shown in Fig.4. The contents for each design are described in Table 1. In apparel use and interior use, aesthetic, susceptibility effect occupies

an important role and on the contrary, it has a rather small role for industrial use.

3.2 The execution logic for designing textile products and its manufacturing methods

Figure 5 schematically shows the execution logical

Table 1 Three categories of textile product design

	contents	examples
(a) aesthetic effects/function design	<ul style="list-style-type: none"> design for the aesthetic effects of textile product design for the functions/performance of textile products 	<ul style="list-style-type: none"> design of fabric colour pattern and hand for apparel use settlement of filtration efficiency and pressure drop for air filter material
(b) basic structure design	design/settlement of constituent fiber assembly structure to realize (1)	design/selection of fiber material, configuration and the structure of yarn, fabric/textile products
(c) basic manufacturing design	selection of manufacturing method to realize (2)

Fig. 5 The execution logic for designing textile products and its manufacturing methods

procedure for designing textile products and its manufacturing methods. The basic design concept of the textile product planned is materialized into the form of aesthetic effect/function design (work step 1). The basic structure design to realize the content of the above aesthetic/function design is carried out in the next step. Here the information of the basic relationship between the structure of textile products and their aesthetic effect/function, and that of their possible structure are drawn from data base for basic structure design during the work (work step 2). Then the selection of manufacturing method to realize the basic structure thus designed is carried out. At this time, the work is done by referring design logic of textile manufacturing method (work step 3). Then we must consider the processability of the material for the textile manufacturing method thus selected. According to this consideration, the basic structure design concerning the material must be modified, if necessary.

Next step is detail designing for the processing of the method. This designing is carried out by referring data base for textile processing and data base of detail information for technological elements (work step 4). This detail informations usually belong to know-how owned by textile manufacturers. In practice, manufacturers tend to create new products to which the strong point of their own technologies are positively utilized. In this sense, the hints of idea for new products are often obtained through the route of the dotted line in the figure.

Design works for steps 1, 2 and 3 are usually complicated and troublesome. Especially in step 2, when we intend to change a certain specified structural parameter in order to change a certain item of performance, it often leads to change of other items at the same time. Therefore, this kind of work should make use

of CAD.

4. The Constitution of Data Base for Basic Structure Design

4.1 The outline of the data base for basic structure design

In order to carry out work efficiently in step 2, it is required that we can easily obtain necessary informations from the data base. So the data base must be clearly arranged to be accessed. There are by far many kinds of structures and also many kinds of properties in textile products. In this situation, the author thinks that it is convenient if the data base is divided into the following 5 systems as shown in Table 2. The systems a, b and c are related with the relationships between properties and structures. The system d concerns with the relationship between the susceptibility, sensibility and properties. The system e is the data base for presenting systematically the possible structures and structural items to be filled.

In ‘medium contacting system’, fiber assembly structure concerns the medium which transfer on/in it. In ‘matrix complex system’, the complex of matrix material and fibers works as a cooperative function. On the contrary, in ‘independent system’, fiber assembly structure works independently. It must be noticed that the categories for a or b and b or c system are the kind of phenomena related with properties, and are not the kind of products. For example, pilling phenomena of the specified clothing fabric belongs to ‘independent system’, but the micro-climate problem of the same fabric is categorized into ‘medium contacting system’. In Table 2, these three systems are listed in relation to the four configurational fiber functions.

The manufacturers have usually accumulated a large

Table 2 Five systems constituting data bases to carry-out design

	configurational fiber function used in each system				scientific method typically used for each system	examples of study object
	flexibility	surface	formability	axial rigidity		
a. independent system	○		○	○	mechanics of fiber assembly structure	bending of woven fabrics, compression of fiber mass, textile processing
b. medium contacting system	○	○	○		transport/separation phenomena	dust filtration, micro-climate dyeing process, carbon fiber electrode
c. matrix complex system		○	○	○	solid/flow mechanics of complex system	processing/character of FRP, FRC, tire
d. aesthetic, sensible effect system					relation between sensibility and properties	
e. fiber assembly structure system					geometrical/configurational analysis and check-list system	

amount of data of these relations concerning their products. Then they can utilize them and these 5 data base systems for the designing.

4.2 The data base of ‘independent system’

Typical examples of properties belonging to ‘independent system’ are described in Table 3. The core properties of ‘independent system’ are mechanical properties. The data base of ‘independent system’ is the information bank of the relations between these properties and the structures of fiber assembly products.

4.3 The data base of ‘medium contacting system’

Several phenomena in ‘medium contacting system’ are arranged by the classification of transport-phenomena with some practical examples in table 4. The data base of ‘medium contacting system’ must contain the informations of relations between the properties of these phenomena and the structures of fiber assembly products. Such practical phenomena as related with micro-climate must be analyzed at first into the elementary transport-phenomena constituting them. So the data base for this kind of analysis must be also necessary.

4.4 The data base of ‘matrix complex system’

Table 5 roughly shows the relationships between the structure/constituent of fiber reinforced plastics and their properties/cost. Only qualitative tendencies are expressed in this table. But of course, the data base of ‘matrix complex system’ must include detail, quantitative relationships which correspond to the relations mentioned

in Table 5.

4.5 The data base of ‘aesthetic/sensible effect system’

The designing of susceptibility (aesthetic), sensibility effect may be often expressed by susceptible, sensible words in aesthetic effect/function design. So it is often difficult to carry out directly the designing by these expressions. As shown in Fig.6, it must be reasonable to translate these expressions into the objective properties corresponding to them by making use of the data base of ‘aesthetic/sensible effect system’ which concerns relations between these expressions and properties, beforehand the execution of basic structure design. The terms of aesthetic, sensible effect contained in this system should be; hand, drape, luster, texture and colour as aesthetic factor, and psychological and physiological factors.

4.6 The data base of ‘fiber assembly structure system’

As described in 2.2, one of the configurational, functional features of fiber is high formability into textile (flexible, porous and stable) structures. By utilizing this feature, fibers are transformed through twisting or interlacing etc., then weaving or knitting etc. into higher dimensional textile structures.

In building, structures are constructed by tightly fixing junctions between beams. On the contrary, in textile structures, fibers are not fixed with each other as a rule. With a rather slight outer load, fibers slide with each other and this causes the flexibility of fiber assembly structures.

Table 3 Typical research categories belonging to independent system

property	detail
mechanical	<div> <div> elongation shear bending compression </div> <div> dynamic, creep, relaxation </div> </div> friction fatigue wearing tearing bursting
of practical use [mechanical-appearing and dimensional]	fluttering, swaying draping, dress appearance clogging shrinkage, puckering, deformation crease pilling
electrical	electro-static properties electro-conductivity
accoustic	accoustic vibration
optical	luster colour

Table 4 Several phenomena in 'Medium Contacting System' classified by the concept of transport phenomena

classification	transport mode of medium	transfer mode to fiber	example of practical phenomena
permeation by back-pressure	flow caused by back-pressure	friction (momentum transfer)	air permeation of fabric, drainage of geotextile
dust, alien substance filtration	flow caused by back-pressure	friction + interruption etc.	air filter, liquid filter cigarette filter
permeation + absorption etc.	flow caused by back-pressure	friction + mass transfer	adsorptive bed by activated carbon fiber
permeation + heat transfer	flow caused by back-pressure	friction + heat transfer	heating, drying of textile products
diffusion	transport by conc. gradient		sweat vapor transport
diffusion + absorption etc.	transport by conc. gradient	mass transfer	sweat vap. trans. thru. hydrophilic fiber layer
liquid transfer by contacting	transfer by surface tension	surface wet-out	urine trans. to diaper water trans. to towel
centrifugal dehydration	flow caused by inertia	friction + surface separation	dehydration by washing machine
wiping	mecha. separation + surface tension	friction + surface tension	glasses wiping
acoustic absorp., interruption	sound wave propagation	absorption of sound energy	sound depression by curtain, wall cloth
heat transfer	convection, conduct., radiation	energy transfer radiation emission	keeping of micro-climate temperature by wearing
drying	convection, radiation, desorption, flow	friction + energy & mass transfer	natural drying, drying with forced hot air

Table 5 The relationship between structure, component and properties, cost of composite materials

	strength/ modulus	impact strength	interlaminar strength	heat resistance	chemical stability	reliability	weight	material cost
species of matrix		○	◎	◎	◎	◎	◎	◎
species of fiber	◎	○		○	◎	◎	◎	◎
volume fraction of fiber	◎	○				○	◎	◎
orientation of fiber	◎	○				○	○	○
length of fiber	○	◎				○		
interface adhesive strength	○	○				○		

◎ close relation

○ some relation

Fig. 6 The role of the data base of 'Aesthetic/Sensible Effect System'

But even with a strong outer load, it can resist and keep its structure comparatively stable³⁾. In this sense, fiber assembly structure is unique and very interesting ones.

Table 6 summarizes outer configurational, structural classification of fiber assembly structures. The dimensional category accords with a kind of outer configurational classification. It is not made by theoretical base, but by rather convenient, intuitive base. 1.5-dimensional structure means that the whole outer shape is 1-dimensional, but consideration on its heterogeneous thickness structure is indispensable. 2.5 dimensional structure has also similar meaning as this. Fiber assembly structure products listed in the column of higher assembled structure in the table are only some examples among vast variety of products belonging to this category. Higher assembly structures are fabricated through such process as sewing, stitching, bonding and laminating. In matrix complex structures, their flexibility is decreased, but three dimensional shapability is increased.

The data base of ‘fiber assembly structure system’ must also includes the list of items to be settled concerning the structures of product, yarn and fiber in addition to the table.

5. Future Prospect of the Progress in the Technology for Textile Product Design

The textile product design has been mostly carried out by experts experience and intuition. It may be one of the ways for establishing the design technology to transfer the abilities of these experts into the CAD system as expert system. This kind expert system may be surely practical

way. But there must be essential weak points as follows;

- ① The range of textile products covered by the CAD is obliged to be fairly limited.
- ② The level of the CAD thus made is also limited by the ability of experts.
- ③ It is rather difficult to incorporate new successive technological progress flexibly and new results of research activities into this kind of CAD.

On the other hand, the design method so far described in this article is flexible and opened enough to be feasible to all the textile products in principle and it is free from such weak points mentioned above.

The design logic such as aesthetic effect/function design, basic structure design and basic manufacturing method is widely applicable to general industrial products themselves. But as far as the design objects are basic materials of textile products, the related data bases and CAD softwares directly bases on FASE.

In this article, basic manufacturing method for textile products are not discussed. There is also no discussion on CAD software for textile products. Concerning even the data base for basic structure design of textile products, this article only sketches its out-line. It is thought that these contents must be materialized hereafter by the cooperative work of related scientific and industrial experts.

6. Concluding Remarks

Ship-building engineering, aircraft engineering etc. are limited for constructing a specified kind of system. On the

Table 6 Fiber assembly structure products by a structural classification

Dimensional categories	Fiber assembly structure products
0-dimensional structure	assembly of fiber powder, assembly of chopped fiber, small piece of random fiber block
1-dimensional structure	tow, roving, yarn (mono-filament, multi-filament, spun yarn, complex yarn), slitted yarn, hollow fiber bundle
1.5-dimensional structure	rope, cable, braid
2-dimensional structure	web, UD-tape, woven fabric, knitted fabric, non-woven fabric (dry laid, spun bonded, spun-laced, melt brown), paper, burst fiber sheet, strand mat, net, lace, screen, fibril sheet expanded from film
2.5-dimensional structure	laminated fabric, double layer knitted sheet, double layer woven sheet, multi-layer interlock fabric, multi-axial laminated tape, coated fabric, blanket, carpet, pile weave, velvet weave, leather, thick fiber block
tublar structure	tublar weave, circular knit, braid, filament wound product, formed cylindrical filter
3-dimensional structure	3-dimensional weave, 3-dimensional knit, 3-dimensional braid, formed fiber block
shell structure	formed sheet, lay-uped prepreg, sprayed preform
higher assembled structure	apparel, socks, stocking, brassiere, diaper, wig, brush, writing brush, fastner, quilt, mattress, sheet honeycomb, hollow membrane module, pleated filter unit, membrane structures, parachute, car-interior, airbag, brake face, ballistic jacket, optical fiber cable, speaker cone, stitched 3-dimensional preform etc.
matrix complex structures, formed/molded structures	fiber reinforced composites with several matrices such as plastic, rubber, cement, metal, ceramics, soil and tar pitch, formed/molded structures from above composite materials

other hand, the object of Textile Engineering concerns very wide range of products, as suggested in Fig.2. In this sense, it may be rather wider than even those of civil engineering and construction engineering, because it is not limited by a certain kind of product. Electrical engineering is based on Maxwells electro-magnetic equation and mechanical engineering on Newton principles. On the other hand, FASE is not based on such a natural scientific principle, but on geometrical, configurational principle originated from fiber form. Its configurational features related with this principle can be summarized as four factors described in 2.2 in this article. From the view point of such a basic principle, FASE has a certain similarity with electrical engineering and mechanical engineering.

The period from 1940 to 1960 was the rising age of synthetic fiber technologies. 'Fiber Material Engineering' in Fig.2 strongly footlight appeared before the among these four subsystems during that period. However core technologies for Shingosen base on FASE. The core technologies for designing and manufacturing textile

products which are applied to several industrial usages and to comfortable clothes are main related with FASE. From these reasons, it can be said that a greater attention should be paid to the importance of FACE nowadays.

This article treats 'Textile Engineering' as the scientific knowledge system based on fiber geometrical/configurational principle, which is not a closed system confined to only traditional textile industry, but is a kind of open system to create vast variety of technological developments. This article aims to establish textile design technologies based on this scientific knowledge subsystem FASE.

Reference

- [1] T. Matsuo; J. Text. Mach. Soc. Japan, (Japanese ed.) **44**, P9 (1991)
- [2] T. Matsuo; The Report of Faculty of Textile Science, Kyoto Institute of Technology 17 1 (1993)
- [3] J. W. S. Hearle; Mechanics of Fiber Assemblies, p.2 (Sijthoff & Noordhoff International Publishers B.V.) (1980)