

CHAPTER: II

**REVIEW OF
LITERATURE
PERTAINING TO THE
PRESENT WORK**

2.1 Introduction:

Crimped fibers are not new; wool fibers have a pronounced crimp, and natural cotton fibers have numerous convolutions and crimps. Certain other natural fibers are crimped to a greater or lesser degree. This property of natural fiber enhances their spinnability, fullness of hand, warmth and preferable aesthetical properties in woven and knitted fabrics.

With the arrival of the yarns now called “synthetic”, the possibility of producing permanent or durable crimps and durable latent crimping power occurred to inventors working in the synthetic yarn fields. Invention of means of producing durable crimps followed. They have made possible the development and growth of the stretch and textured fiber industry. The increasing aesthetic appeal and utility of properly designed and manufactured stretch and textured fabrics and garments indicate that the industry is destined for many years of growth and expansion. Quick response to change, offering wide range of products, all and above that economical rate of production, become salient features for the researcher, looking forward for the growth and expansion of this industry.

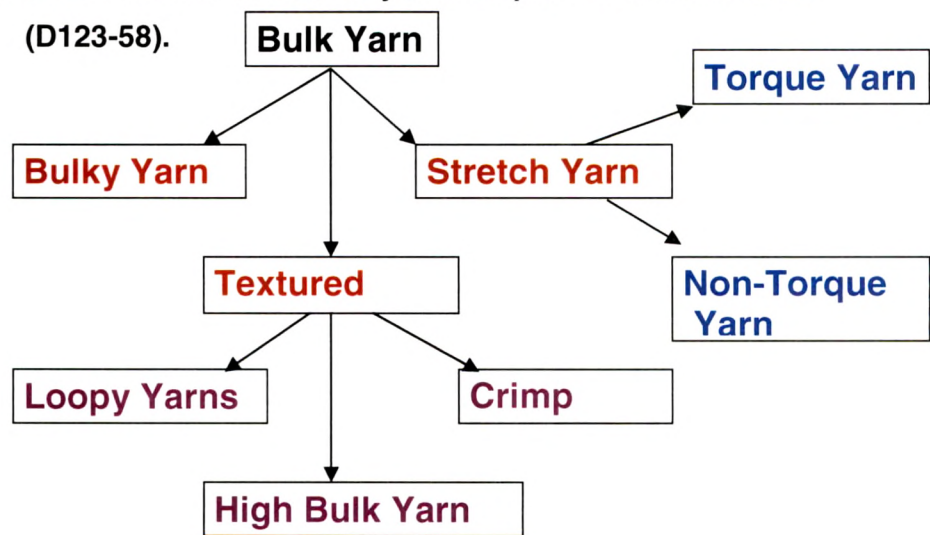
The concept of, “Mechanical texturising” developed is the research work done in this direction. It works on the theme of elimination of heat, steam and compressed air from the texturising process as well as post-treatments like mingling or plying before weaving. Thereby likely to allow considerable reduction in power-cost and respected labour compliment due to reduced machinery, maintenance and storage. Apart from that the structure of yarn so produced expectedly having closer resemblance with preferable

spun yarn structure. Combination of false-twist texturing as well as air jet texturing principles has been utilized in the production process. This has resulted in an out-put with an intermediate structure to those of commercial systems, adds up more favorable features in its account. Being purely a mechanical process makes it versatile in terms of raw material also.

2.2 Classification of Bulk Yarns

Texturing is the process for imparting bulkiness to the flat configuration of the synthetic filaments. Various textured yarns that have been prepared in different ways to have greater covering power or apparent volume, than that of equivalent yarn number and of the same basic material with normal twist are known as bulk yarns. The bulked yarns so obtained can be classified as per ASTM standards¹ (figure 2.1). There are three basic categories of bulk yarns, viz; 1) Bulky yarn, 2) Textured yarn and 3) Stretch yarn². Terms used for each category and subcategories in this classification are defined in section 2.2.1.

Figure 2.1 Classification of Bulk yarns as per ASTM standards (D123-58).



2.2.1. Definitions

Bulky Yarn: A generic term for yarns formed from inherently bulky fibers such as man-made fibers that are hollow along part or all of their length, or for yarns formed from fibers that cannot be packed closely because of their cross sectional shapes, fibre alignment, stiffness, resilience or natural crimp, or both.

Textured Yarn: A generic term for filament or spun yarns that have been given notably greater apparent volume than conventional yarn of similar fiber (filament) count and denier. The yarns have relatively low stretch. They are sufficiently stable to withstand normal yarn processing, including wet finishing and dyeing treatments, and conditions of use by ultimate consumer. The apparent increased volume is achieved through Physical, Chemical or Heat treatments, or a combination of these. As shown in fig. 2.1 they are further subdivided into three sub-groups, viz; a) Loopy yarn, b) High bulk yarn and c) Crimp yarn.

a) **Loopy Yarn:** Yarns essentially free from stretch, characterized by a randomly spaced and randomly sized loops along the fibers or filaments, e.g. Air jet textured yarn.

b) **High Bulk Yarn:** Yarns essentially free from stretch, characterized by high random crimp resumed by a fraction of fibers by shrinkage of remaining fibers, in general, have very low crimp, e.g. Producer Textured Thermoplastic Yarns.

c) **Crimp Yarn:** Thermoplastic textured yarns of this category are having relatively low elastic stretch (usually under 20 percent) and frequently characterized by high saw-tooth type crimp or curl, e.g. Stuffer box yarn, Gear crimping yarn, Edge crimping yarn. Whereas Non-Thermoplastic textured yarns with irregular crimp and relatively high elastic stretch but low power of contraction's tight crimp yarns in this category is produced by release of internal strains following immersion of fabric in water, or by chemical treatments.

Stretch Yarn: A generic term for thermoplastic filament or spun yarns having a high degree of potential elastic stretch and rapid recovery, and characterized by a high degree of yarn curl. It can be further subdivided into two categories, viz; a) Torque yarn and b) Non-Torque yarn.

a.) **Torque Yarn:** Stretch yarns that, when permitted to hang freely, rotate in the direction of the unrelieved torque resulting from previous deformation, e.g. False-twist textured yarn.

b) **Non-Torque Yarn:** Stretch yarns that have no tendency to rotate when permitted to hang freely, e.g. Plied False-twist textured yarns¹.

2.2.2 Texturing Methods:

Various texturing methods developed for the production of textured yarn [table 2.1(a-c)]. Depending on the media used for

setting up the deformed structure they can be well divided into three classes, viz; i) Methods dependent on heat-setting, ii) Mechanical methods and iii) other methods ^{2,3,4}.

Table 2.1 (a) Texturising Methods Dependent on heat- setting

Method	Yarn Character	Current status
Single heater, false-twist	High-stretch	Major use of nylon
Modified false-twist	High bulk, medium stretch	Obsolete for nylon
Set, double-heater, false twist	High-bulk, low stretch	Major use of polyester
Trapped twist texturising	Variant twist textured	Obsolete
Stuffer-box	High-bulk, medium stretch	Obsolete (Ban-Lon)
Edge-crimped	High-bulk, medium stretch	Obsolete (Agilon)
Knit-de-knit	Yarn crimp	Minor use
Hot-fluid jet (BCF)	High-bulk, Low stretch	Major use in carpet yarns
Impact texturising and moving cavity texturising	High-bulk, Low stretch	Variants of BCF, little used
Jet-tube (Fiber M)	High-bulk, Low stretch	No longer made

- *BCF (Bulked Continuous-Filament)*

Table 2.1 (b) Mechanical Texturising Methods

Method	Yarn Character	Current status
Air-jet	Projecting loops	Significant production
Wray's Mechanical Bulking	Projecting loops	No longer made

Table 2.1 (c) Other Texturising Methods

Method	Yarn Character	Current status
Bicomponent filaments	Fiber crimp	Revived interest
Differential shrinkage	High-bulk, Low stretch	Only staple fiber yarns
Gear-crimping	Fiber crimp	Staple fibers, obsolete

All of these methods seemed important at the time, but only the air jet texturising method and false-twist method found successful in the commercial market. They have captured the market owing to their versatility and quality. While Jet-screen texturising has found place only for the manufacture of coarse, BCF (Bulked Continuous-Filament) carpet yarns³.

Innovative concept of texturising, objective of present research work expectedly produce the intermediate structure to those of commercial successful systems. Therefore a brief summary of both the systems has been given in the forthcoming section.

2.2.2.1 Air-jet Texturising:

Air-jet textured yarns are produced from thermoplastic, cellulosic or non-organic filament yarns using a turbulent fluid, which is usually compressed air. Loops are formed on the surface of the filament yarn, giving it a voluminous character. Depending upon the material used the loop structure results in a yarn with characteristics, which resemble those of the conventional staple fiber product^{2, 4}.

Table 2.2 shows the range of end uses for which air-jet textured yarns are produced². Different types of yarns like single-end, parallel-

end, core-and-effect yarns and fancy yarns can be produced in air jet texturing. Air textured yarns have unique surface structure (fixed resilient loops of various configurations), greater bulk and results in fabrics having subdued lustre, warmer hand, good uniformity, better covering power, good resistance to pilling (equal or greater than spun yarns) and better insulation^{5, 6}.

The internal structure of the yarn is such that the tenacity and initial modulus is substantially reduced and a certain amount of instability is presenting the macro structure of the yarn. Provided the instability is not high, the extension at peak load is, generally, reduced. Hot water shrinkage of these yarns is also important from the point of view of processing of fabrics made from these yarns⁶.

Since, in air jet texturing, the load-bearing straight sections of filaments and the loops occur with frequencies which are associated with many processing parameters that can be controlled, a balance between bulk and strength, as needed in the final product can be easily achieved⁷.

In air jet texturing many parameters can be controlled, which permits the product variety. But the large-scale acceptance of this versatile yarn can be hindered due to following limitations:

Modern jets are claimed to texture yarns in the speed range of 350-750 m/min, depending on the choice of raw materials and process parameters. However better uniformity of the yarn, higher overfeed ratios and lower air-pressure often demand reduction of processing speeds⁸.

Tendency to "Cling" or "Velcro" (sticking/clinging of loops of yarn of top layer with the loops of yarn in the next bottom layer on the

package due to loopy structure) leads to unwinding problems, which can play havoc at both knitting and weaving^{9, 10, 11}.

On the high-speed shuttle less looms, due to higher frictional characteristics of the yarn, when used as weft, leading to uneven take-off from the package at high unwinding speeds. When it is used as warp especially on shuttle less looms, the adjacent ends in the shed hang up on one another and then interfere with the passage of a pick. This Velcro effect causes problems even in warping and slashing⁹.

Trials by DuPont¹² have shown significant yarn deformation when weaving without size, and this deformation, which is non-uniform, produces an undesirable streakiness in dyeing. It is believed that strain during shedding deforms the yarns.

The cost of air jet textured yarn is higher due to the high-energy cost of compressed air^{10,13}. Power required to produce compressed air is around 90% of the total power¹³.

The raw material cost for air jet textured yarn is also higher because for the same textured yarn denier, the feeder yarns for air jet are finer, which are generally expensive^{13,14}.

Table 2.2 Air-jet textured yarn properties and applications.

Property	Application	Remarks
Low friction character	Sewing thread	By means of protruding loops;
		• Cooler needle
		• Lower needle friction
		• Good cover
Spun yarn	Sports and leisurewear	• Mainly nylon and polyester
	Car seat cover	• From polyester POY
	Interior furnishing	• Mainly polypropylene
	Outerwear	• Mainly nylon with polyester
		• With raised surface
High friction	Skiwear, tablecloth	• Slip resistance
	Bed sheeting	
	Belts and straps	
	Luggage, rucksacks	
Dimensional stability	Tarpulin	
	Coated fabric	
	Tyre fabric chafer	
	Printed circuit	
Blended yarns	Composites comprising:	
	• Different fiber material	
	• Coarse and fine filaments	
	• Yarns with different properties	
	• Heather effects (spun-dyed)	
	• Combinations of these	
Structural effects	Curtains	• Variable texture
	Wall coverings	• Flame resistant i.e. glass fiber
Functional wear	Rain and sportswear	• microfilament
	Leisurewear Sports underwear	• double layer fabric from wicking yarns.

2.2.2.2 False-twist Texturising:

False twist texturising enhanced textile properties, both tensile and tactile, are given to spun, continuous filament partially oriented yarn (POY) by the simultaneous actions of drawing, heating and twisting the filament bundle. This subsequently is untwisted and then either collected directly on a bobbin after oil application known as "High elastic stretch yarns" or else subsequently heated under controlled partial relaxation and wound on a bobbin after oil application known as "Set yarn". Thus Hearle et al.³ have categorized false-twist textured yarn into two groups based on principle employed in the production process, viz; High elastic stretch yarns and "Set yarn".

By controlling four fundamental variables T^s : Tension, Twist, Time and Temperature, a wide variety of different textured yarn types can be made from partially oriented yarn (POY) feedstock. However these fundamental variables T^s also become barrier in increasing production-rate^{4,15}. As per Hearle et al.³, increased end break rate, excessive broken filaments, bulk variation, dye variation, intermingling faults, surging, tight spots are some common problems, encountered in the texturising plant, due to increased tension at higher speed, limits the achievable processing speed at 1100m/min. Higher rotational velocity of the yarn, due to twisting during texturising results in the compact yarn which has no air spaces in its center requires higher heater efficiency for heat stabilization, add up the product cost¹⁶.

The process requires heating and cooling of a thermoplastic yarn, then it must be taken into account that molecules do not change their structure instantly. Time required for the yarn to be successively

heated, cooled and twisted exceeds the elapsed time; certainly the results will vary from fiber to fiber ¹⁷. Use of certain fluids will result in more rapid transfer of heat to or from the yarn at high speeds. However any fluid that comes into direct contact with a yarn is going to wash off some of the applied lubricant together with monomer and other impurities. This opens up a new can of worms along with the increased cost of product³.

McIntosh¹⁸ has found that tension in the texturising zone increases with increase in draw ratio and also as the processing speed increases. He has suggested that the maximum tension compatible with good product mechanical quality should be used to ensure the most stable processing. It was also found that reducing the texturising zone length would allow a much wider choice of tensions. However, the bulk achieved is lower.

Wilson et al.¹⁹ have agreed that a higher texturising tension is needed to reduce instability. The disadvantage of using high tension is, of course, reduced bulk and an increase in the number of broken filaments. Instability can be reduced or completely eliminated by increasing draw ratio. This has disadvantages: crimp contraction is less and elongation is lower by up to 20%.

Barnes and Morris²⁰ compared the rates of setting achieved by simultaneous draw-texturising with that of texturising fully drawn 170-dtex/30-fil polyester fiber yarn under similar machinery conditions and found that the value of the exponential constant (setting constant) was doubled.

One of the objectionable features of false-twist textured woven fabrics is their glitter in bright light due to the greater cross-sectional distortion during drawing and twisting ^{4, 19}.

Soft, voluminous and cheaper false-twist textured yarns are still considered as the most preferable for weft knitting to produce desired bulk and handle¹⁸. But thermo mechanical mode of the process also restricts it to thermoplastic yarns only adversely affects versatility of the process^{2,4}.

2.2.3. Production of Combined or Plied Yarns.

For many end uses the denier available from a single- yarn is not sufficient for the fabric construction. In these cases it would be usual to combine or ply two or more ends together on the texturing machine (Intermingling) or by ply twisting on T.F.O. (Two For One twister). Fiberguide, Heberlein, Temco, Slack, Parr etc. are manufacturers offer a broad spectrum of intermingled jets to impart the desired yarn characteristics. Intermingling (or interlacing or entangling) jets may be located before or after second heater in case of false twist texturing¹⁹. Whereas two-for-one twister is used after texturing for combining textured yarns together³. Such yarns find use in automotive, woven apparel, narrow fabric, upholstery and industrial fabrics.

Commercial textured yarns are intermingled or ply twisted for four main reasons:

1. Yarn bundle can be hold together in the case of two-three-, or four-ply yarns. This enables them to be processed at higher efficiencies in weaving or knitting as well as on sewing machine, when used as sewing-threads (air jet textured yarn).
2. Single-ply yarn is intermingled, particularly in warp yarns for weaving, in order to hold the individual filaments together as

a tight, cohesive bundle. This helps to prevent yarn damage as the yarn passes through the reeds in the loom. Previously these yarns would have been twisted, sized or both before warping.

3. Yarns can be lightly intermingled or twisted purely to help the yarn unwind from the package (Velcro effect).
4. Special type of jet can be used to produce a detorque yarns, i.e. a single –ply with no residual torque for false-twist textured yarn.

Brief reviews of the commercial systems pursue the apparent aims of future technological development. Where more stress is imposed on increased production rates, linking of processes, to reduce production delay, obviation of cost adding factors from the process and definitely impart versatility in terms of raw material and end users.

2.3 Mechanical Texturising: A Novel Concept

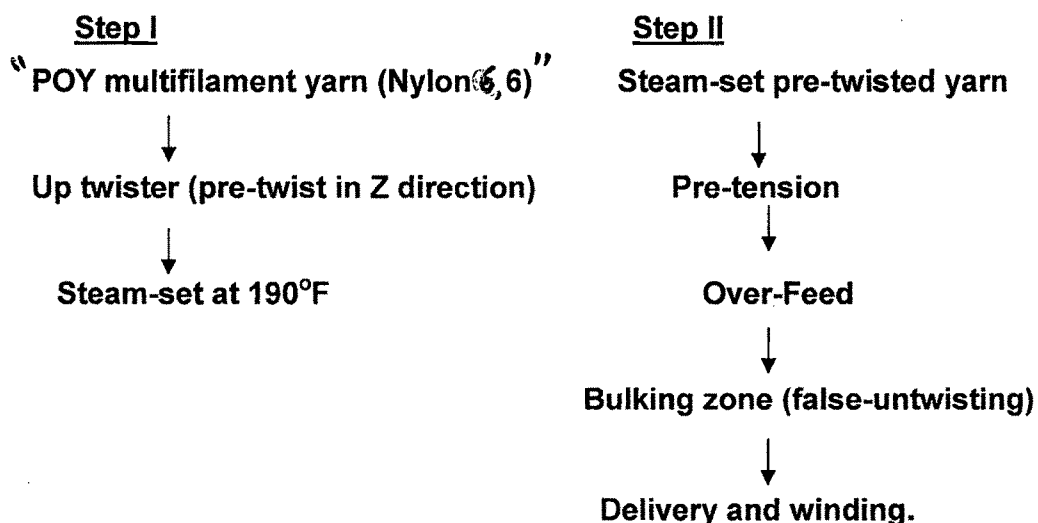
Need of thermoplastic feeder yarn hinders the versatility of cheaper false-twist texturising. So obviation of heat from the texturising process is required if it has been made versatile for thermoplastic as well as non-thermoplastic continuous filament yarns. Advent of air jet texturising is the outcome of these efforts. Production of air jet textured yarn from polypropylene; nylon, glass, polyester, rayon, acetate and Kevlar have been reported^{21, 22}. Air jet textured yarns are routinely produced from a yarn of 40 to 10,000 denier. Yarns are textured having filaments finer than one dpf (denier per filament) to filaments coarser than one dpf (denier per filament)²¹. Processing of

18,000 dtex glass yarns has been reported²³. All filament yarns or mixture of filament and spun yarns of different fibers and deniers can be textured.

2.3.1 Wray's Mechanical-Bulking Process

Sen and Wray²⁴ had put step towards the development of the new method of mechanical texturing called the mechanical –bulking. A mechanical simulation of the false twisting action of the air-jet had been used for the production of the bulked yarn, by eliminating costlier compressed air from the process. A schematic diagram of the process is shown in figure 2.2. They had also assessed a successful simulation of this novel yarn to that of air jet textured yarn²⁵.

Figure 2.2: Schematic diagram of Wray's Mechanical-Bulking Process



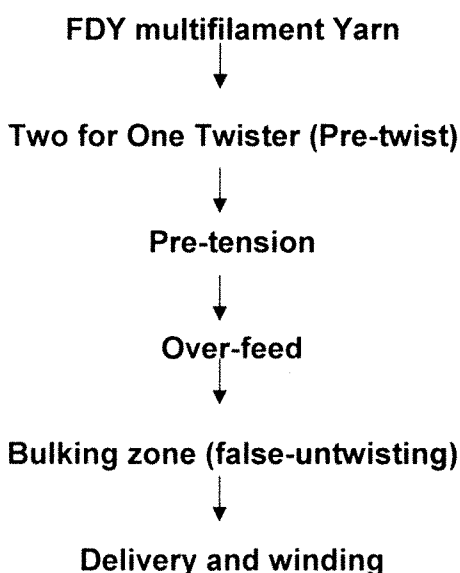


2.3.2 Single-step Mechanical-Bulking Process

Fascinated with the new concept of mechanical bulking, in 1997 one scaled-up model machine had been designed, fabricated and installed under AICTE R. & D. project, to produce mechanical bulk yarn in single step from fully drawn multifilament yarn without undergoing even preliminary heat setting²⁶.

Schematic diagram of process is shown in figure 2.3. The quality potential of the new product, so obtained was also verified successfully with the quality performance of the commercially successful air jet textured yarn ²⁷. Obviation of costlier compressed air, steaming and short process sequence had allowed in enhancing the product economy. But constrain for the use of expensive finer feeder yarn still stand off.

Figure 2.3: Schematic diagram of Single-step Mechanical-Bulking Process:



2.3.3 Mechanical Crimp Textured Yarn:

On the basis of the postulated bulking mechanism, a mechanical crimp texturing apparatus was designed to eliminate the use of finer feeder yarn. This process is aimed to produce crimped yarns with a wide range of properties at an economical rate.

The design concept used is, "Pre-twisted fully drawn yarn (FDY) flat multifilament yarn has been subjected to the higher false twisting (depending on yarn fineness) action under the condition of underfeed. The torque caused due to high level of false twisting, forces the filaments to follow helical path at a certain angle (depends on magnitude of twist and dpf) to the filament yarn longitudinal axis. Internal stresses arising in single filaments tend to bent the filament and take the shape of spatial helical spring. After the yarn has passed through the false twisting unit, the initial twist would reassert itself and lock the already formed crimp convolutions in position".

Theme of under feed is used in this system instead of overfeed as in the case of air jet texturing and mechanical bulking. This enable system to come out of major drawback of earlier mentioned mechanical texturing systems, viz; use of expensive finer feeder yarns helps in reducing product cost. Apart from that being purely a mechanical process and obviation of costlier compressed air from the process, makes it versatile for raw material and also economical.

2.4 Parameters Influencing Textured Yarn Quality

Textured yarn characteristics, such as texture, softness, cover, mechanical properties and stretch etc. could depend on a number of

materials and processing variables irrespective of heat set or mechanical way of texturising. They can be grouped into following three categories: 1) Raw material parameters like: type of the yarn, filament denier and number, total (yarn) denier, cross sectional shape of filament, spin finish and lusture. 2) Machine parameters like: type of pre-twist technique, type of false twist technique, feed systems and winding or take up mechanism and 3) Processing Parameters like: amount and direction of pre twist, amount and direction of false twist and percentage underfeed^{2,4,6}.

2.4.1 Material Variables

The physical as well as chemical constitution (polymer type) of the filament or yarn affects the factors like tension, twist and temperature that must be employed during texturising⁴. In case of false twist texturising adequate temperature to make the yarn plastic and sufficient tangential stress (longitudinal tension plus torsion caused by twisting) must be employed to permanently deform the filaments to their twisted position before cooling purely depends on polymer type^{2, 19}. Material with higher elongation at break like nylon-6 execute durable torque-crimp memory; although the greater the elongation before processing the finer will be the denier after processing, as it is necessary to strain the yarn sufficiently during torque-crimping to preclude substantially any ductility in the finished torque-crimp yarn. As after crimping if the yarn is ductile, the crimp could not be permanent².

Bending rigidity and torsional rigidity of filament or yarn are playing decisive role in acquiring new configuration on texturising. Hearle et

al³. have defined torsional rigidity (R) and bending stiffness (B) as follows:

$$\text{Torsional Rigidity } R(mNm) = \epsilon n T^2 / \rho \dots\dots\dots(\text{equ.2.1})$$

Where, ϵ =Shape factor (=1 for circular c.s. filament and higher for multilob fibers),

n =shear modulus (= 0.29-0.42 N/tex for Nylon and =0.62 N/tex for polyester),

T =Linear Density in tex,

ρ =Density; 1.14 g/cm³ for Nylon and 1.39 g/cm³ for polyester.

$$\text{Bending stiffness } B(mNm) = (1/4 \pi) (\eta E T^2 / \rho) \dots(\text{equ.2.2})$$

η =shape factor (=1 for circular cross-section and higher for multilob fibers).

E=Tensile modulus in N/tex (Nylon=1.7-3.3N/tex & Polyester=4.5N/tex).

T =Linear Density in Tex,

ρ =Density; 1.14 g/cm³ for Nylon and 1.39 g/cm³ for polyester.

It is clear from both the relationships that for rest of the material parameters constant, type of material decide texturising properties. Yarn with higher tensile/ shear modulus undergoes less deformation due to higher bending stiffness as well as torsional rigidity. Thus the low tensile modulus of nylon allows it to undergo more deformation as well as good recovery from the large deformation as compared to

the higher modulus polyester yarn. This makes nylon more suitable for high stretch yarns whereas polyester for non-stretch products^{3, 4}.

As the linear density of any material increases in general, the material loses its flexibility. Same way as the denier of the filaments increases they become more rigid and naturally the tendency of changing configuration also reduces²⁸. Thus yarn with less dpf (denier per filament) has higher stretch potential and resistance to extension as well as faster recovery. On the other hand, larger diameter filaments, become more rigid towards the change in basic configuration, produce textured yarns with crisper or harsh hand^{4, 28}.

The finding and conclusions of Acar et al²⁹ have shown that for an equal total yarn linear density, yarns consisting of finer filaments require smaller fluid forces to displace and entangle them than those consisting of coarser filaments. This is due to the reduced bending and twisting rigidities and increased surface and projected areas of finer filaments. Thereby finer filaments would be textured better.

Istvan Kerenyi³⁰ also found that yarn with finer filaments can be textured better and for that reason tenacity of air jet textured yarn is reduced more. In case of coarser filaments the strength loss is thereby less.

It can be seen from equation 2.1 that torque increases directly with the diameter of the individual filaments. Coarser the filament, higher the torsional energy required to distort (or twist) it and greater the retained energy after twisting and setting. As, the torsional stress in a filament is proportional to the square of denier.

Demier et al³¹ have shown that as the filament density increases the instability percentage (Acar's method) of the air jet textured yarn increases first and then decreases; the percent increase in linear

density of the yarn decreases; and the percent loss in yarn tenacity also reduces.

Acar et al²⁹ have also found the low instability at the fine filament end of the range may be because of the enhanced texturising effect, which may give rise to the interfilament friction that holds the entangled filaments and loops together under the applied loads. As the filaments get coarser, the entanglement and loop formation deteriorate, producing yarns with fewer loops and poorly entangled cores and resulting in a reduction in yarn instability.

The number of constituent filaments in a yarn influences the “hand”, feel and draping quality of the fabric. A yarn with more number of filaments will be more pliable and soft to feel when compared with same denier yarn but with less number of filaments³².

Yarns are generally twisted with a constant twist factor during false twisting. It follows that the finer denier yarn will be twisted to a higher twist angle and consequently will have a greater stretch potential^{2, 4}.

Bock et al³³ have concluded that at the same linear density and cross section of the filaments, a greater number of filaments, i.e. an increase in yarn denier, increase the tenacity and breaking elongation, whereas the coefficient of variation of tenacity and mass irregularity decreases. However, a significant decrease in stability when number of filaments is less than forty.

Acar et al²⁹ have concluded that with the increase in the number of filaments (total yarn linear density), an enhancement in yarn quality due to increased potential for filament entanglement. However it also been influenced by type of nozzle.

Bose and Govindraju³⁴ in agreement to Bock and Acar have also shown that as the number of filaments increases in the feeder yarn,

the tenacity and frequency of loops increases in case of air jet textured yarn.

Berkeley² has mentioned that the effect of denier, filament count and filament diameter on the properties of torque crimped yarns are interrelated. Shrinking power, or creping power, or latent torque-crimp energy varies with denier. Retained energy or latent torque power increases directly with the diameter of individual filaments. The coarser the filament the greater the energy required to distort, and the greater the retained energy after distortion and setting. While with the increase in filament diameter harshness get increases.

Synthetic filaments come in various cross sectional shapes, such as circular, trilobal, triangular and dog-bone. The torsional rigidity R of a filament varies directly with the shape factor ϵ , (equ.2.1). ϵ has a value unity for the circular cross section and decreases as the polygonal shape approaches a pentolobal. Textured yarns made from multilobal cross sectional shapes tends to have a silk like hand and appearance and also exhibits greater covering power as compared to the circular filament yarns with similar denier and number of filaments^{3,4,28}. However there is no remarkable change in the stability³³.

Thermoplastic yarns are generally given a spin finish after spinning to make them amenable to further processing. Spin finish, generally created by a lubricating additive, affects the deformability of filaments. An absence of spin finish would cause high frictional resistance between filaments and thus would prevent them from being twisted as desired and would results in very high thread line tension. This could then results in filaments with kinks and snarls, which are undesirable for a smooth appearance. On the other hand,

spin finish can affect the free movement of the yarn around the pin and can hamper the performance of twist trapper ⁴.

The fiber lusture is dependent on the amount of TiO_2 added to the polymer melt. According to Scheier and Lyons ³⁵ variations in TiO_2 content also affects the geometry of the fiber structure, namely, bright polyester fibers have a smooth surface, whereas dull fibers have a rough surface. Various levels of fiber surface roughness with respect to the TiO_2 content influence the frictional behavior of fibers. Schick ³⁶ has shown that friction in the hydrodynamic region is higher for smooth fibers (bright finished) followed by semi-dull and then dull fibers, whereas in the boundary region a reverse order has been observed.

Grindstaff ³⁷ and Wenzel ³⁸ have shown that rough polyester fibers wet better than the smooth one

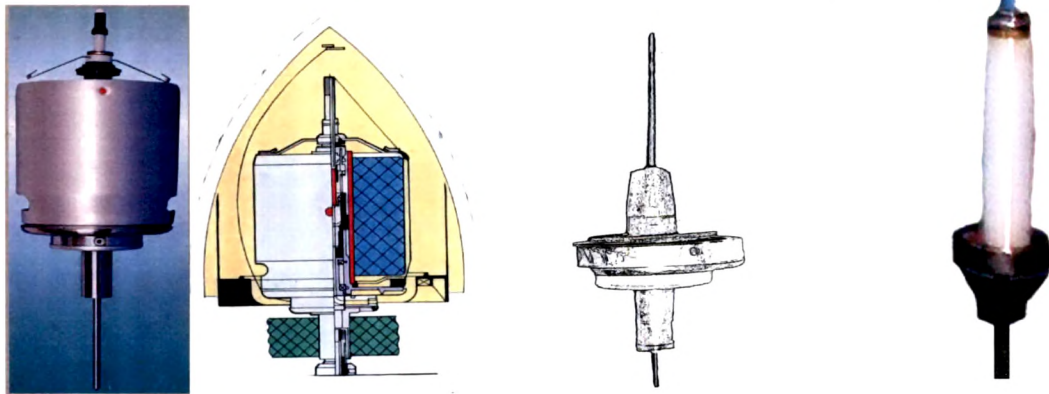
2.4.2 Machine Variables

Each texturising machine has its unique design feature, which includes yarn feed system; twisting system, false twisting system, and yarn take up mechanism. All these factors taken singly or collectively create a complex situation in the production of textured yarn. Nevertheless, it is deemed appropriate to explain briefly their importance in terms of reliability, reproducibility, ease of control, flexibility and economy of operation so as to control or maintain the consistency of the quality of texturising.

2.4.2.1 Type of Pre-twist Technique

Role of the pre-twister is to impart pre defined basic twist to the parent yarn as per the demand of end user. This can be achieved by various twisting medias like ring twister, up twister, two for one twister (T.F.O.), Tritec (three for one twister). Different types of two for one twister (T.F.O.) in use are shown in figure 2.4 (a-c) ³⁹.

Figure 2.4 Different types of Two for One twister (T.F.O.)



a) Aluminum Pot type T.F.O. b) Spindle type T.F.O. c) Cup type T.F.O.

2.4.2.2 Type of False-twist Technique

The heart of the mechanical crimp texturing process is the false-twist insertion device. False-twisting action gives the crimp character and bulk to the yarn. Over the years there have been many methods employed to give crimp and texture to the yarn. Brief review of two basic types of false-twisters, viz; A) Rotor type and B) Friction type is given.

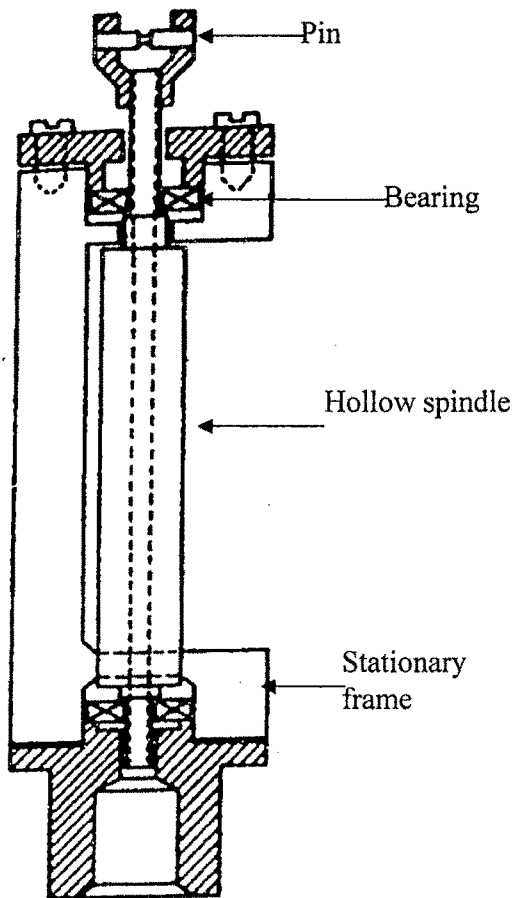
A) Rotor type False-twisting Mechanisms

The common feature of all rotor type mechanisms for false-twisting is the use of hollow spindle in the shape of a tube or rod of small diameter, which is called the false-twist spindle or revolving tube. Yarn passes along spindle axis and around the pin and inserting one turn of twist for each revolution of the spindle⁴⁰. Figure 2.5 (a-d) represents various types of false-twister spindle introduced in the market. The first false-twist rotor mechanism (figure 2.5 (a)) consists of hollow spindle of 8-12 mm, mounted on ball bearing was driven by belts. At the beginning the speed was 20,000rpm, but with the time, it was raised up to 70,000 rpm by reducing spindle diameter. SKF firm (FAG), had used improved ball bearing design to stretch this limit up to 1,20,000 rpm even at the increased cost of spindle figure 2.5 (b). The Lessona firm (USA) has proposed the use of tungsten-carbide bearing, capable of operating at a speed of 350-500 thousand rpm. However, the cost of such bearings turned out to be very high. The machine CS-6 of Scragg is equipped with twisting heads on air cushion, working with speeds of 1, 50,000 to 2, 00,000 rpm. The air cushion permits higher spindle speeds but with added cost of powerful compressor unit and the maintenance of complicated structure of spindle. The spindle speed was increased up to 2, 50,000 rpm by driving it with three discs, instead of belt figure 2.5 (c). This mechanism has not found success due to its complexity and big size requirement. Magnetic pin twister (figure 2.5 (d)) , where hollow spindle of 2-2.5mm diameter, is pressed by means of magnets to two discs, one is a driving disc, fixed on shaft which has bottom end mounted on bearing and provided with pulley, driven

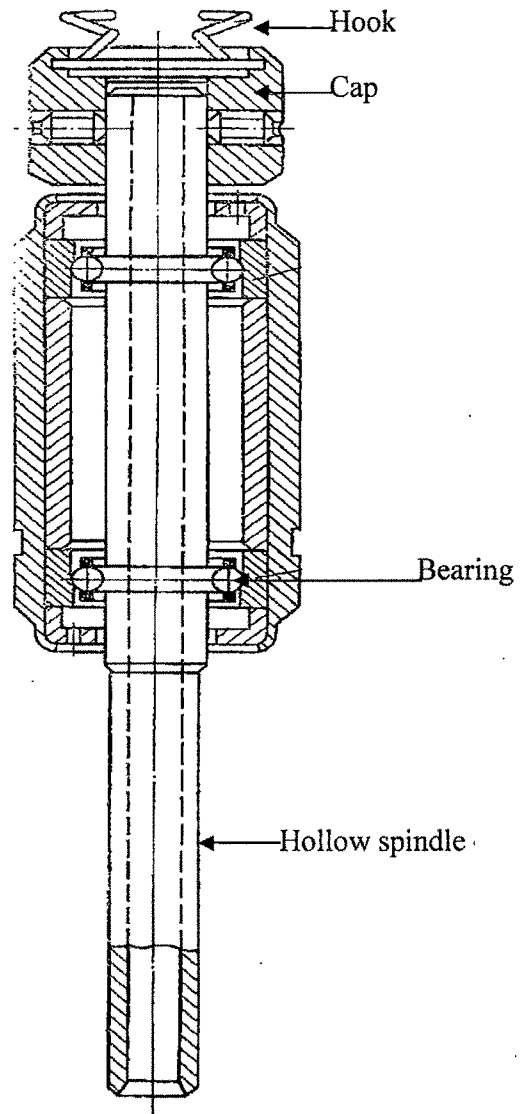
by flat endless belt. While second disc is rotated by friction created by attraction of spindle to magnet. The driving discs and blade are dynamically balanced to ensure smooth running. But still speeds beyond 10, 00,000 rpm are impossible due to severe mechanical limitations. At present single disc magnetic pin twister, introduced by FAG; Heberlein (Switzerland) in market in 1971 is used due to almost half the power consumption to that discussed earlier. Simple threading system, without the use of thread guide hooks makes it more reliable. Further need of increased speed had geared up the search for alternative to rotor spindle, resulted in the development of friction principle ^{3, 40}.

Figure 2.5 Rotor type Mechanisms

(a) Hollow spindle false twister



(b) False twist spindle made by SKF



(c) Three disks driven false twist s

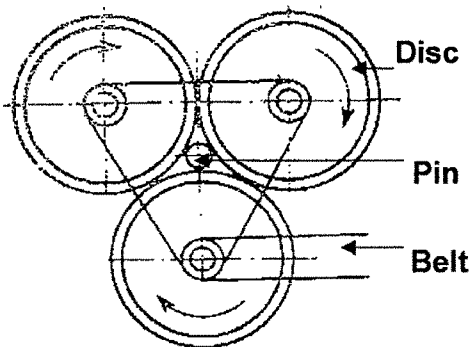
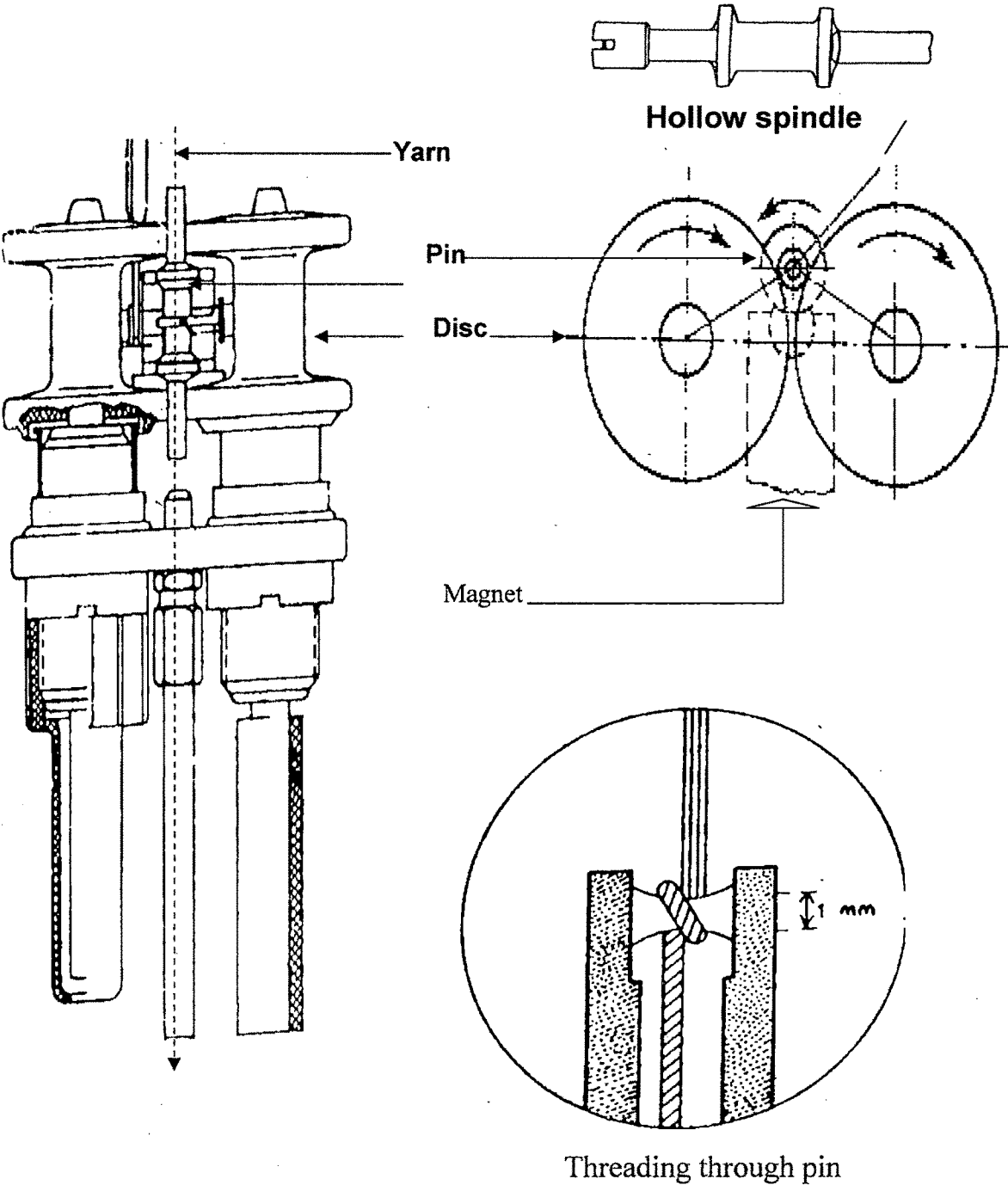


Figure 2.5 (d) Magnetic pin-twister

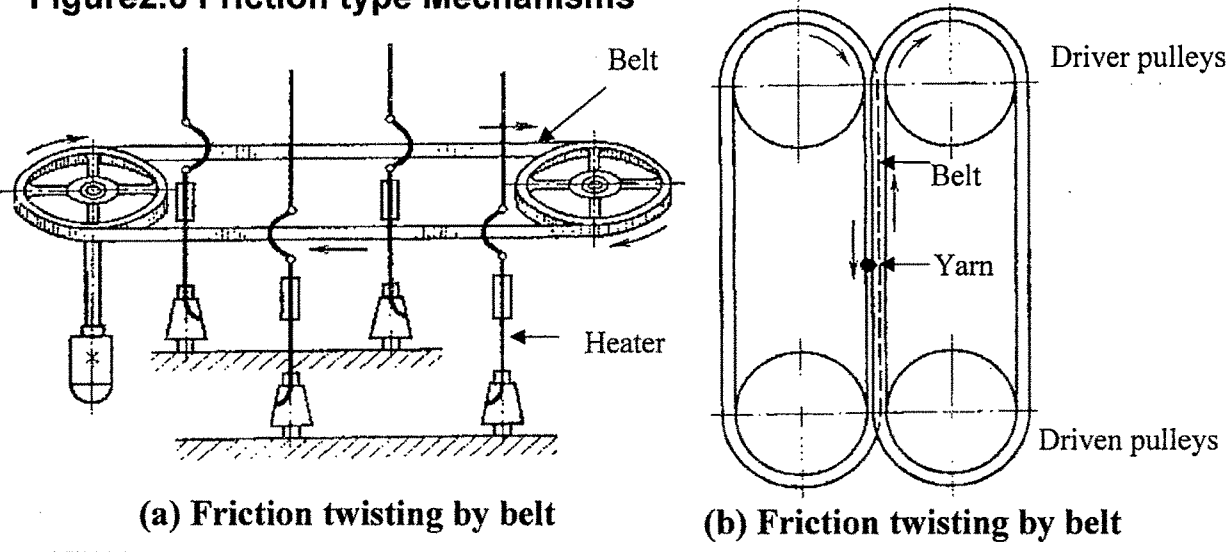


B) Friction type False-twisting Mechanism

Those commonly used friction type of false-twisting are: bush crimping; spindle or pin-crimping; ring-crimping; crossed-belt crimp; stacked discs^{2, 3}.

The surfaces of all elements coming in contact with the yarn must possess a high frictional factor. They are made of different materials and most frequently of polyurethane⁴⁰. An endless belt system has been illustrated diagrammatically in figure 2.6 (a). With low speed of belt, high twist of the order of 8, 00,000 rpm can be imparted. Simple and convenient method but small angle of belt contact and presence of guiding eyelets, not allow yarn-shifting belt at its motion. This drawback was overcome by the couple of endless belts running in the opposite direction figure 2.6 (b). Yarn passes perpendicular to belt direction. The ascending side of belt for driving pulley is more strongly tensioned than descending one, hence affects the yarn twisting adversely.

Figure2.6 Friction type Mechanisms

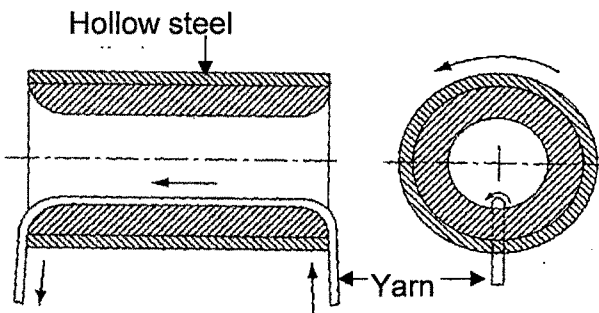


Twisting the yarn by rotating it with transversely moving surface such as rubber bush (figure 2.6 (c)) is the next system developed. Rubber ring is fixed inside the hollow steel bushing, which rotates for inserting twist to the yarn. Amount of twist K depends on relationship between ring hole diameter “ D ”, the yarn diameter “ d ” and the rotational speed of the ring, “ n ”.

$$K = (D \times n)/d \hspace{1cm} \text{.....equ.2.3}$$

Higher twist can be imparted with low speed of the bush and even costly bearings are eliminated, facilitates texturising of even high elastic yarns at high speeds. But gradual wear is the major drawback of the system⁴⁰.

Figure 2.6 (c) Bush type friction-twister



Two rotating bushings with rings of special rubber or polyurethane as shown in figure 2.6 (d) is the next system developed and used most widely.

The design of the mechanism ensures a large angle of contact between the rings and yarn and there by ensures twist flow without slippage. Since yarn comes in contact with interior surface,

threading becomes difficult. A false-twisting device, which provides a more rigid contact between yarn and the surface of friction element, along with ease of threading has been thought off. Few out of many designs of such friction type false-twister developed⁴¹ are shown in figure 2.6 (e).

Figure 2.6 (d) Two Rotating Bush type Friction-twister.

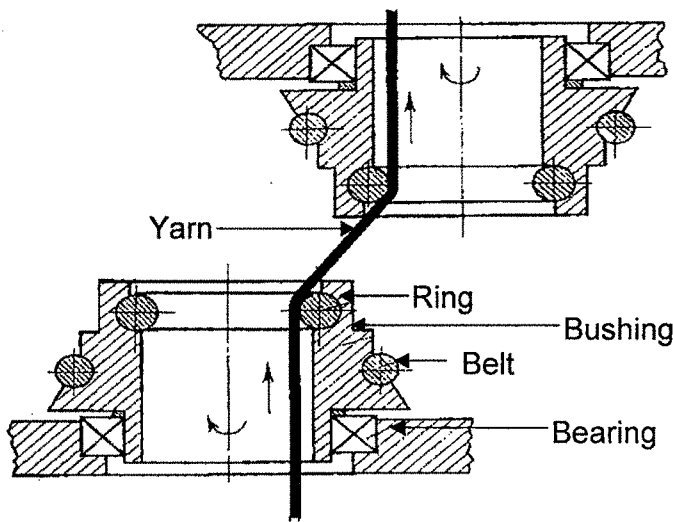
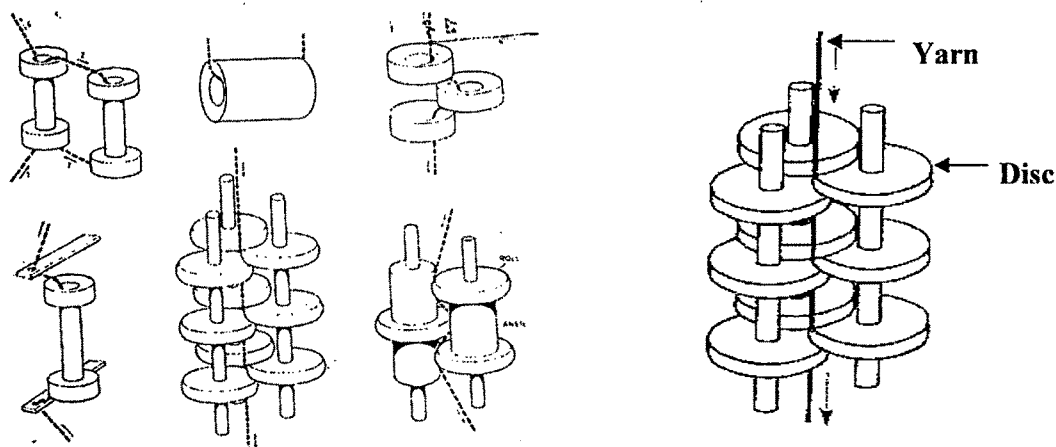


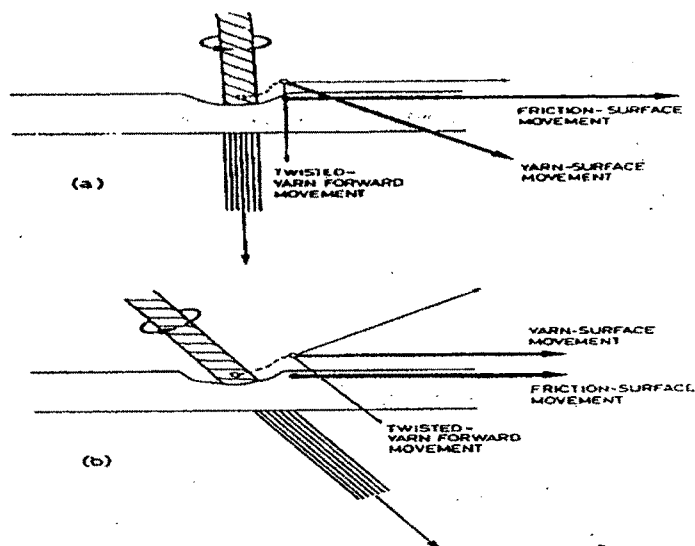
Figure 2.6 (e) Friction- twisters

Fig.2.6 (f) Stacked disc type



Stacked disc friction unit developed by Barmag and FAG is the most popular friction –twisting system. Yarn is twisted by frictional contact with outer surface of the disc stacks located on three shafts^{40, 41} (figure 2.6 (f)). The axis of the shafts is located on the aped points of equilateral triangles. The diameters and the inter-meshing of the stacked discs are such that they impart to the yarn, desired angle of contact (90° - 120°) with the rotating disc-surface, for the most efficient twist insertion. This system has generally, seven, nine or twelve discs, made up of high friction materials like polyurethane, ceramics etc. This relative sliding motion of the yarn along the frictional surface, slippage is inherent at the points of contact between the frictional surface and the yarn surface. Posi-torque friction disc system (figure 2.6 (g)) has been developed to overcome this drawback⁴¹. In this system the geometry of disc position and disc profile cause the yarn to contact the friction surface at a controlled angle, thereby avoids slippage even at higher speeds⁴¹.

Figure 2.6 (g) Posi-torque friction disc system



Limited versatility of the stacked-disc type of friction twisters led to the introduction of nip-controlled vector types, which are offered today in the form of both crossed belts and overlapping rings on a commercial basis¹⁹.

Fischer⁴² showed that, in a quasi-positive system of pin twister, there was a clear relationship with the yarn twist. The positive twisting action with simple control is, of course the main reason why pin twisters are in some specific areas still preferred to friction twisters, which offer much improved economics⁴³.

Hearle⁴⁴ and Greenwood⁴⁵ have concluded that the pin twister twists the yarn by applying a normal force to the yarn surface, with friction playing only an auxiliary part, and identifies friction between the yarn and pin and yarn-flattening at the yarn/pin interface as two possible main factors that ensure the positive twisting action of the pin twister. Since friction alone cannot account for the absence of the untwisting action, there would be less damage to the fiber surface than with friction twisters. This also get support from the industrial experience.

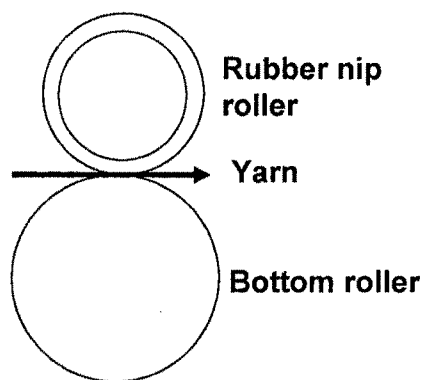
2.4.2.3 Feed Systems

The input and output rollers control the yarn tension during processing and are also meant for reducing chances of slippage in the twisting zone. By adjusting the speeds of these rollers overfeeding or underfeeding of the yarn is possible. Nip roller feeding, apron type feeding and idler roller type feeding are generally used feeding systems on texturising machines.

A) Nip Roller Feeding

In this system yarn is pulled through two rollers one of which is positively driven by gears, the diameter and rotational speed of the driving roller determines the linear speed of the yarn (figure 2.7 (a)). The chances of yarn abrasion and weakening of yarn is the major drawback of the system, becomes more critical for fine denier yarns. Even this system cannot eliminate the possibility of yarn slippage ¹⁵.

Figure 2.7 (a) Nip roller Feeding System.



B) Apron Feeding System:

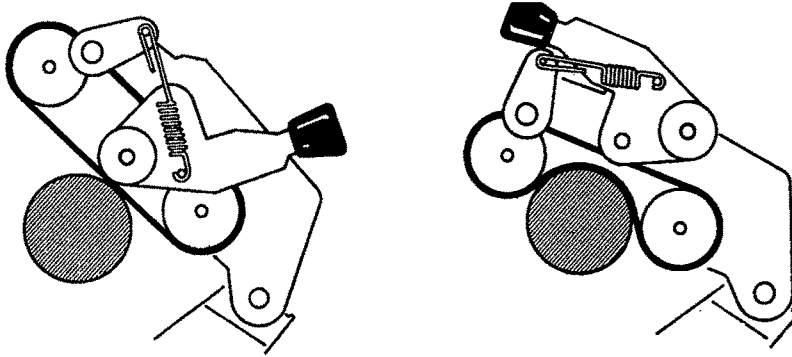
It consists of a synthetic rubber belt and roller assembly that is driven by contact against a chromed yarn feed shaft (figure 2.7 (b)). The assembly is spring-loaded and can be manually disengaged from contact with the feed roller. This system gives better control without affecting the quality of yarn adversely ¹⁵.

C) Idler Type of Feed System:

It consists of a set of rollers, a driving roll, a driven roll and an idler roll. The yarn is several times wound over the driven roller and idler

roll with the help of grooves provided in them. This reduces chances of slippage during yarn processing¹⁵.

Figure 2.7 (b) Apron Feeding System.



2.4.2.4 Winding or Take up Mechanisms

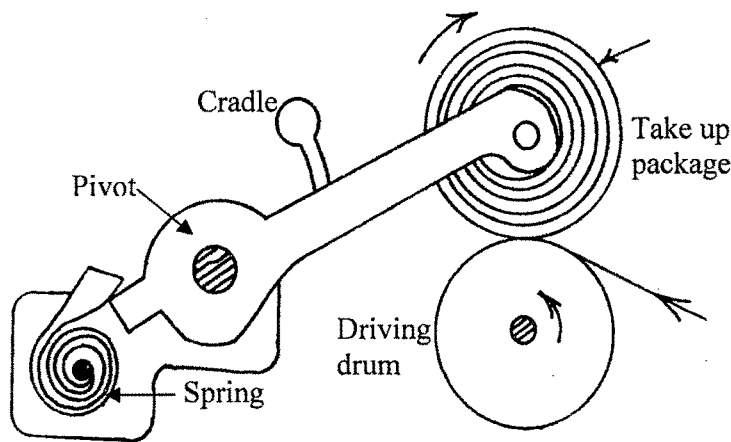
Over the years, increasing texturising speeds as well as increasing speed in knitting and weaving have imposed stringent requirements on the design of wind-up units on texturising machines¹⁹. Ease of unwinding of yarn from the package without slough off and, no excessive tension on the yarn during wind up are two important requirements of a winding system. Two types of winding systems are normally employed on texturising machines, viz; i) Conventional Spring loaded winding system and ii) Advance Package Support (A.P.S.) winding system¹⁵.

i) Conventional Spring Loaded Winding System

This system uses springs to control the interface force between the building package and the driving roller; these require over-centre

mechanism with resultant variation in the interfacial force and tendency to stick- slip mechanism¹⁵ [figure 2.8 (a)].

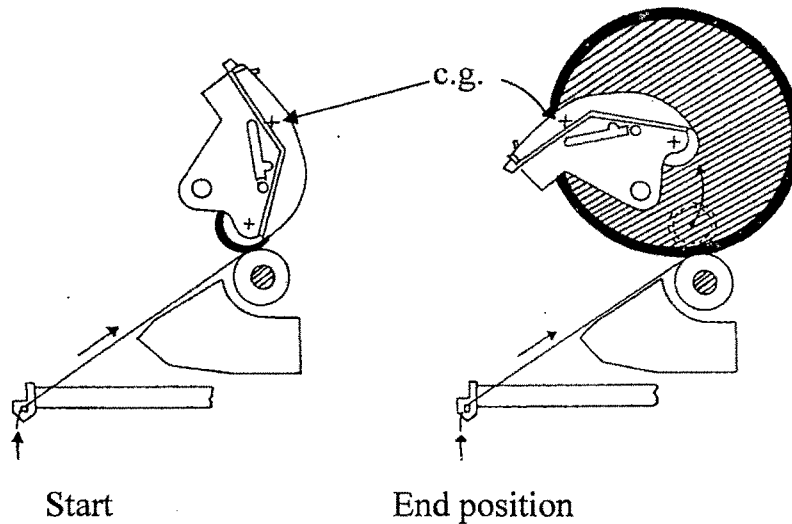
Figure 2.8 (a) Conventional Spring loaded



ii) Advance Package Support (A.P.S.) Winding System

Advance package support is used in this system, where with the build up in the package weight, the package support is redistributed about the pivot of the package support (figure 2.8 (b)). This helps in maintaining the uniform interfacial force between the package and the driving drum. Dampers are provided to avoid stick –slip in the mechanism. Automatic opening is provided for doffing of the package¹⁵.

Figure 2.8 (b) Advance Package Support (A.P.S.) winding system



2.4.3 Processing Variables:

Twisting (real-twist /False-twist) of the yarn is the most critical operation encountered during texturing process. Twist affects the yarn structure and is manifested in the deformation of individual filaments because of the helical path they follow and the radial disposition in the yarn cross-section. So amount and direction of pre-twist (real-twist) as well as false-twist employed during mechanical texturing process become important process parameters. Even ductility of the multifilament yarn plays a decisive role for the durability of the crimpy structure. Thereby percentage underfeed (draw ratio) is also an equally important texturing process variable.

2.4.3.1 Pre-twist

The majority of the texturising methods except air jet texturising use mechanical distortion during heat treatment of the thermoplastic filaments giving them a common characteristic of high extensibility under quite a low loads. The bulkiness of such yarns decrease with degree of tension imposed on them⁴. While in case of mechanical texturising the newly attained configuration of the textured yarn has been locked by real twist, known as pre-twist. Thus structure of mechanical textured yarn adequately simulates spun yarn character. Yarn surface is covered with curls or crimps locked in position by pre-twist. Thus bulk and stability of this new structure is greatly influenced by amount of pre-twist (real twist). Similar to flat twisted yarn at higher twist mechanical textured yarn expectedly execute crepe like compact, low bulk but more stable structure. Whereas textured yarn with low pre-twist likely to show soft, limpy and less stable structure but with high bulk^{3,4}.

2.4.3.2 False- twist

Yarn characteristics like the bulk, crimp, strength, elongation at break, and the retractive power of the end product are influenced by the amount of twist inserted during texturising^{2,4,40}.

Excessively high twist has a tendency to cause the yarn to have characteristics similar to crepe-spun yarn and also extremely twist lively. On the other hand low levels of twist cause the yarn to have a stringy appearance, probably because of the inability of the insufficiently distorted filaments to coil up in loops^{2,4}.

Burnip et al ⁴⁶ during their study on false-twist texturising have agreed to this phenomenon and also mentioned that after certain limits high twist levels destroy the bulked appearance.

Hearle et al³ have concluded inserting more twist to the yarn can increase the bulk. Thus to achieve softness and extra-fine pebble appearance in fabrics, higher twists are employed, whereas low twist levels would produce course and relatively harsh crepe-like handle.

The crimp rigidity increases sharply with increasing twist but at very high levels it tends to either level off or show a downward trend. At excessively high twists, the yarn tends to have tight spots that are detrimental to its bulking and dyeing behavior ⁴.

Twist also has a profound influence on the tensile properties of textured yarns. The breaking strength and elongation both show a decreasing trend. The basis for the selection of the processing twist is dependent on the consideration that the tenacity of the textured yarn does not fall below a certain desirable level ^{2,4}.

Krause ⁴⁷ has pointed out that high processing twist levels cause the yarn to develop high torque, which is enough for it to overcome the frictional resistance on the guide pins of the false-twist spindles, thus enabling the yarn to roll over the pin, causing slippage and resulting in a reduced amount of absolute twist in the yarn. This type of behavior can also cause reduction in yarn tension.

Burnip et.al ⁴⁶ have reported that the residual shrinkage of false-twist textured yarn is low when produced at higher false-twist level. As at high twist levels, the take up speed is less, and therefore the yarn is in the heater for a long period of time and is more likely to

shrink during that process. Consequently, it exhibits reduction in residual shrinkage.

2.4.3.3 Percent Underfeed:

Tension in the texturising zone gets increased with draw ratio along with the increase in processing speed. Low thread line tension conditions during processing results in loss of twist, formation of tight spots and poor crimp rigidity. Whereas high thread line tension conditions during texturising results in reduced bulk and elongation¹⁹. Instability can be reduced or completely eliminated by increasing underfeed. But this has disadvantages: crimp contraction is less, elongation is lower by up to 20 percent and it may also cause excessive yarn breakage, thus adversely affects the production efficiency^{4, 18, 19}. Maximum tension compatible with good product mechanical quality should be used to ensure the most stable processing^{4, 19}. Thus value of underfeed has been mainly influenced by the ductility and mechanical properties of the parent yarn, normally set to give 22-28 percent yarn extensions³.

The linear speed of the yarn through the feeding device being less than the linear speed of the yarn taken up by the winding mechanism by the amount of underfeed desirable in case of constant extension system⁴. So with the increase in amount of underfeed, take up speed also get increased, results in increased production rate¹⁹.

Degree of molecular orientation in the filament is determined by drawing caused due to underfeed. Higher draw ratio increases molecular orientation results in reduced dye uptake³.

Tenacity is a relative value, calculated from the breaking load and the measured denier, increasing the draw-ratio reduces the denier and increases the degree of molecular orientation, thereby developing strength in the yarn until the point is reached where it becomes over-extended^{2, 3, 4}.

With the increase in molecular orientation, the capability of the polymer chains to buckle and deform under the influence of heat is reduced, thereby restricting the degree of shrinkage that can be developed i.e. reduces the residual shrinkage³.

2.4.3.4 Bulking Zone Length

This term refers the distance between the exit point of twist trapper (twist stop) and the entry point to rotating false-twister. McIntosh¹⁸ has found that reducing the texturising zone length would allow a much wider choice of tensions. However bulk achieved is lower.

While dealing with apparatus for manufacturing mechanical bulked yarn without the use of air, Sen et al²⁴ have found that periodic bulk variations are less with a larger bulking length. This is mainly attributed to higher filaments freedom gives consistency of loop formation.

Sen et al²⁴ have also defined the mathematical relationship for the evaluation of optimum bulking zone length for any given set of processing conditions.

Investigation reports of Sen et al²⁵ on newly developed “mechanical-bulking method” have confirmed that there is a minor effect of bulking-zone length on the resultant bulked yarn characteristics.

2.4.3.5 Delivery Speed

Delivery speed has a direct impact on production rate as well as filament/s speed during texturing. With the increase in delivery speed, of course production rate of any texturing machine get increased. Positive shift of increased production must be looked along with the effect on texturing quality due to simultaneous rise in filament speed.

The biggest obstacle in increasing delivery speed for torque-crimp textured yarn is heating and cooling of a thermoplastic yarn. As molecules do not change their structure instantaneously, results in deterioration of texturing quality for the given set-up. Certainly the results will vary from fiber to fiber³.

In comparison with conventional heating and cooling, use of certain fluids results in a much more rapid transfer of heat⁴⁸. However, any fluid that comes into direct contact with a yarn is going to wash off some of the applied lubricant together with monomer and other impurities. This adversely affects the quality of the product yarn³.

Demier et al³¹ have found that in case of air jet texturing as delivery speed gets increased, filament speed is also increased and the resultant forces therefore decrease. Consequently the

texturising becomes less effective, as resulting in the formation of large and unstable loops.

2.5 Structural Mechanics of Twisted Yarns

Filament migration at the twisted stage of the texturising process is important in determining the geometry and structure of the final product yarn⁴⁹. Magnitude of the twist employed and its direction during false-twisting action are the detrimental factors for product yarn bulk and appearance. So it is appropriate to introduce briefly effect of false-twist level on textured yarns characteristics.

2.5.1 Twist Imparted to the Yarn by False-Twist Mechanism.

Twisting mechanisms of two main types, i.e. rotor and friction-mechanisms may affect false-twisting in single-process stretch yarn machines⁴⁰. For rotor type twisting mechanisms the twist is determined by the simple formula (equation 2.3), given below.

$$K = n/v..... \text{ equ.2.3.}$$

Where K =Twist per meter,

n= rotational speed of the twisting mechanism, rpm,

v = linear speed of yarn feed, m/min.

In this case the yarn section rotates with the same angular speed as the contact surface. Therefore, the number of turns imparted to the yarn section does not depend on the thickness of the

processed yarn or its type. Whereas amount of twist imparted to the yarn is greatly influenced by the ratio of friction surface diameter and yarn diameter in case of friction texturising. Twist angle β , twist factor α and amount of twist K may be used as measures of twist intensity.

For manufacturing high-stretch yarns, high-twist is used resulting in considerable yarn take up during twisting; the higher the initial twist, the greater is the yarn take up. In yarn twisting, if the cross section cannot approach each other, the filament yarns will undergo relative elongation ϵ_x , depending on their distance from the yarn axis R_x and the amount of twist K . The relative elongation is determined by the equation 2.4.

$$\epsilon_x = 2[\pi R_x K]^2 \dots\dots\dots \text{equ.2.4}$$

The angle of filament inclination β_x also depends on their distance to the yarn axis R_x and the amount of twist K and is determined by the following formula [equation 2.5].

$$\beta_x = 2\pi R_x K \dots\dots\dots \text{equ.2.5}$$

hence

$$\epsilon_x = \beta_x^2 / 2 \dots\dots\dots \text{equ.2.6}$$

With maximum twist [twist where the coils have the greatest angle of inclination], when the angle of inclination of external filament yarns $\beta = 45^\circ$ (0.785 radian), the relative elongation of these yarns will be; $\epsilon = \beta^2 / 2 = (0.785)^2 / 2 = 0.32$. When forces to retain the cross sections from approaching are not applied to the yarn, it

shortens under the action of arising stresses by the amount of relative elongation ⁴⁰.

2.5.2 Optimum Twist of Textured Yarn.

To determine the optimum twist “K” in false-twist texturising yarns of different linear density, many theoretical and empirical formulae have been advanced. Usenko⁴⁰ and Berkele² have given details in their publications. Some of them are given below.

The optimum twist of textured yarn may be determined by the formula used for determining the twist of the yarns of different linear density.

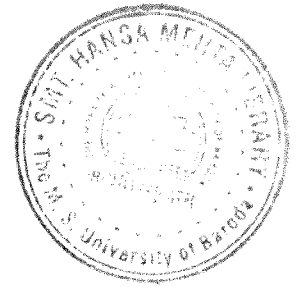
$$K = \frac{31.62 \alpha}{\sqrt{T}} \dots\dots \text{equ.2.7}$$

Where T =linear density of processed yarn in tex,
 α = twist factor depending on the angle of peripheral filament inclination β and the volume mass of yarn δ .

$$\alpha = 282 \tan \beta \sqrt{\delta} \dots\dots \text{equ.2.8.}$$

It has been found that for producing textured yarns of a linear density of 5-15.5tex, the tension should be within the range of 0.1-0.15N and twist factor α =250-275, at which the angle of peripheral filament inclination does not exceed 45°.

Sokolov² recommended use of the formula 2.9 for determining the twist factor of textured yarn.



$$\alpha = (115 + 16\sqrt{T})C \dots \text{equ.2.9.}$$

Where T=Yarn linear density in tex,

C = constant taking into account the properties of the twisted yarns

= 1, for polyamide and polyester yarns

= 0.75, for acetate

Mazov² proposes textured yarn manufacturing at a maximum twist K_{\max} , calculated by formula 2.10.

$$K_{\max} = 488 \tan \beta_{\max} \sqrt{[N(n|4n - 1)]} \dots \text{equ.2.10.}$$

Heberlain⁵¹ advances the formula 2.11

$$K = 800 + \frac{2,75,000}{D + 60} \dots \text{equ.2.11}$$

Fournet proposed the formula

$$K = \frac{28,630 \text{ to } 31,900}{\left[1 + \frac{15}{D}\right] \sqrt{D}} \dots \text{equ.2.12}$$

In the USA a simpler formula is used

$$K = 3840 - 12D \dots \text{equ.2.13}$$

Where, D is the yarn count in denier. All these formulae lead to close results, so that they may be used for approximate calculations^{2, 40}.

2.6 Methods of Analyzing Structure and Properties of Textured yarn

Methods adopted for the measure of the properties of textured yarn are purely dependent on its structure and means/ media used for achieving it. Three main features evaluate the properties of textured yarns apart from the normal physical properties, viz; Stability of crimp (/loops), bulkiness and degree of crimpiness. Stability of crimpiness characterizes the capacity of the textured yarns to maintain their parameters with time under the action of various factors (mechanical, thermal, chemical, etc.). Bulkiness refers the proportionate rise in the specific volume of the textured yarn to that of the supply yarn. While the degree of yarn crimpiness measures the amount of deformation (crimpiness) imparted to the feeder yarn at the bulking zone^{2, 3,40}.

A brief review of various methods adopted for the analysis of textured yarn structure and characteristics are mentioned in the foregoing sections.

2.6.1. Methods of Analyzing Textured Yarn Structure

Wray⁵² has suggested an optical test for the structural characterization of air jet textured yarns. Yarn specimens are sandwiched between two microscopic slides to flatten the projecting loops into a single plane and the number of loops are counted. Over all diameter (D) and core diameter (d) are measured to determine the loop size.

Bock⁵³ has described an optoelectronic instrument for assessing the yarn structure by projecting the shadow of the yarn on a line of 256 photodiodes.

Kollu⁵⁴ used a microdensitometer to determine the surface characteristics of air jet textured yarns. The negative photographic image of yarns are scanned at various distances from the core along the length of the yarn, each fiber end resulting in a peak owing to the difference between the image density and background density. This allows the measure of loop size and loop frequency of the textured yarn. Acar et al.⁵⁵ have further modified this instrument, so as to continuously analyze the structure of air jet textured yarn.

2.6.2 Methods of Measuring Instability of Textured Yarn:

There are two approaches to the measurement of stability of the crimp configuration of the textured yarn. They are: A) Measure of Percentage Crimp stability/Crimp Rigidity as in the case of false twist textured yarn, where deformations of the thermoplastic yarns have been heat-set.

B) Measure of Percentage Instability as in case of mechanical mode of texturing, viz; air jet texturing and mechanical bulking. In the present method any form of heat has not been used to impart morphological changes in the molecular structure to acquire new configuration and retain it. So, the first option becomes an irrelevant.

It becomes more realistic to go by methods true for mechanical texturing, viz; air jet texturing for instability measure.

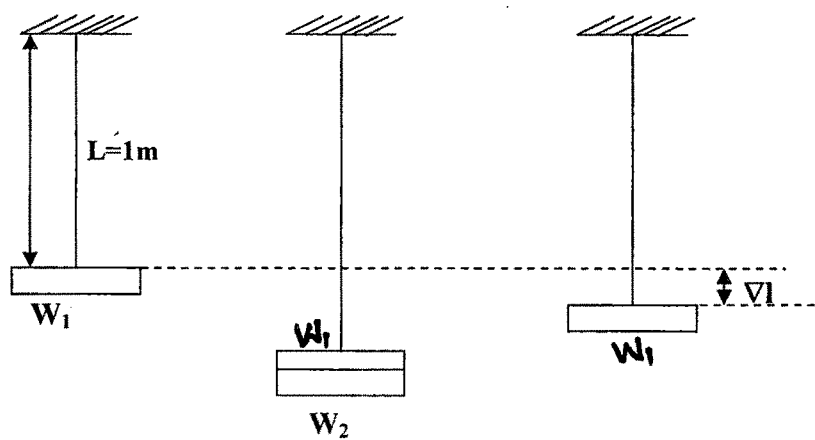
There are several approaches developed for the measurement of instability of air jet textured yarn. One is based on the permanent elongation of yarn after removing a specific load applied for a constant time while other is to measure the yarn extension due to the application of a load. Another approach is based on the principle of the repeated loading. There are no commonly agreed test procedures or standardization of testing parameters for the measure of instability. Brief description of various methods is given below.

2.6.2.1 Weight Hanging Methods

I) Du Pont's method:

This method is based on the principle of permanent extension. A basic load of 0.01gf/den (0.088cN/tex) is hung at the end of the yarn held at the top in a clamp and left on the specimen throughout the test. One-meter section on this tensioned specimen is marked. The specimen is then subjected to a load of 0.33gf/den (2.97cN/tex) for 30 seconds. The permanent elongation in the length of the specimen is measured 30 seconds after the higher load has been removed, by using 1-meter mark as reference. This percentage elongation is taken as the direct measure of the instability. DuPont⁵⁶ has suggested that for a satisfactory textured yarn the instability value should be less than 5%

Figure 2.9 Du Pont method



II) Heberlein method

The Heberlein Company of Switzerland uses a hank of textured yarn instead of a single yarn specimen⁵⁷ on a wrap reel of 1 meter circumference, the yarn is wrapped to form a hank of 2500 dtex.

Number of Wraps = 2500 /nd.equ.2.14

Where n is Number of legs (=2) and d is the dtex of the yarn under the test. The recommended basic load (W₁) and higher load (W₂) and time duration are 0.01cN/dtex, 0.5cN/dtex and 60 seconds respectively.

The instability I% is the extension percentage after 60 seconds at the load of 0.5cN/dtex;

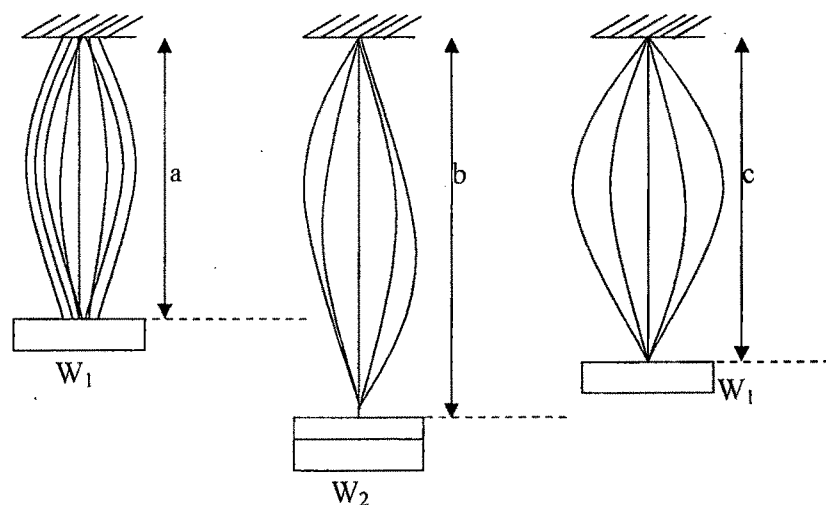
Whereas the instability II% is the permanent extension measured 60 seconds after the removal of the higher load.

Instability I (%) = [(b-a)/a] x100equ.2.15

$$\text{Instability II (\%)} = [(c-a)/a] \times 100 \dots\dots\dots \text{equ.2.16}$$

Instability-I measures the percentage elongation of the yarn under a specified load. Instability-II measures the permanent elongation of the yarn, similar to Du Pont method. However, it is not made clear why Heberlein suggests both the values of instability. One of the disadvantages of this method is that the instability values are influenced by the yarn-to-yarn friction which in turn is influenced by the surface geometry of the yarn.

Figure 2.10 Heberlein method



2.6.2.2 Extension Measurements under Static Conditions.

(i) Wray's Method:

Wray⁵² suggested a method for measuring the instability of air jet textured yarns made from twisted feeder yarns.

From the load-elongation curve of the constant rate of extension Instron tensile tester, he defined the percentage instability of the yarn as the difference between the extension percentage of the

textured and the corresponding feeder yarn at a constant load of 0.33gf/denier.

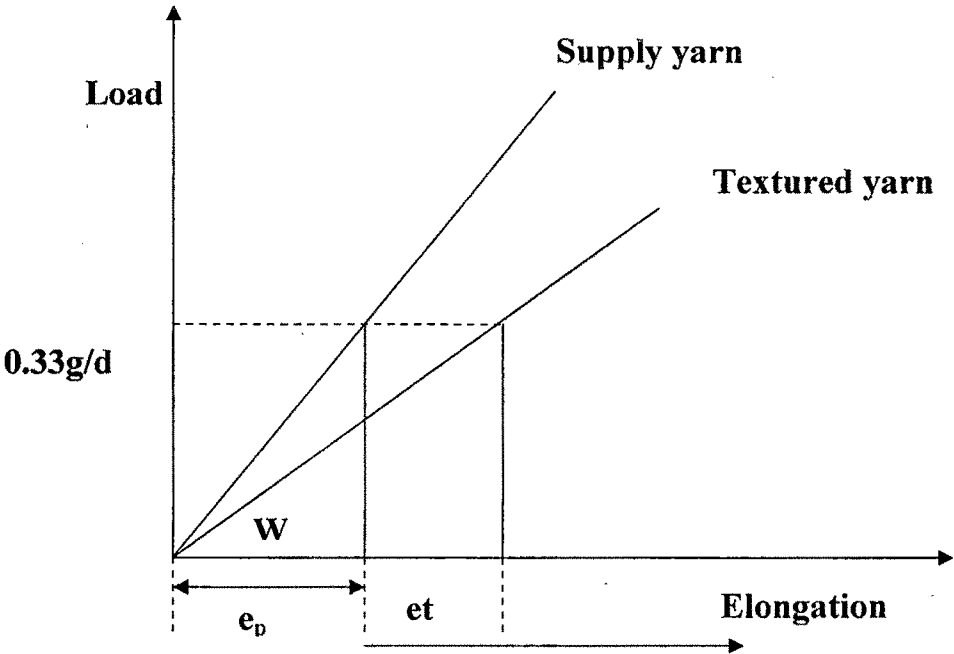


Figure 2.11 Wray's Method

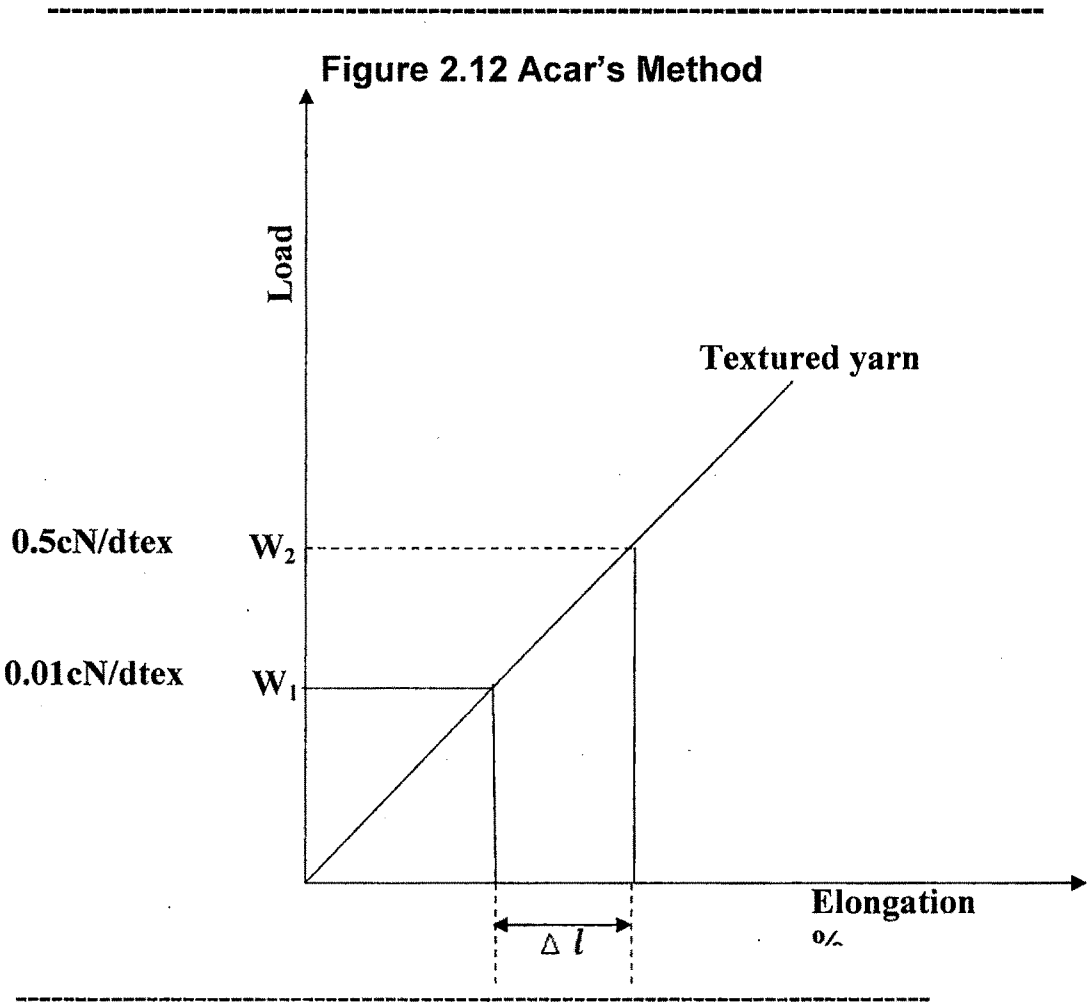
(ii)Acar's Method

Acar et al⁵⁷ suggested the use of load-elongation curves from a tensile testing machine of the Instron type for instability measurement of air jet textured yarns. They used a basic load (W_1) of 0.01cN/dtex and a higher load (W_2) of 0.5cN/dtex and measured the percentage instability as the percentage elongation between the higher and basic load. They suggested that the elongation of textured yarn under applied loads should be taken as a measure of instability rather than the difference of elongation of the textured and supply yarns, as suggested by Wray earlier,

because the extent of contribution of the extension of load bearing straight and parallel filaments of the textured yarn to the overall elongation is difficult to account for.

$$Instability\ (\%) = \frac{\Delta l}{l} \times 100 \quad \text{.....equ.2.17}$$

Where, Elongation between higher & basic 1oad is Δl and l is specimen length.



2.6.2.3 Methods Based on Thread Tensile Force during Stretching on a Running Yarn.

Wray⁵² also devised a quicker method using a Strainometer for the measurement of instability. In this method a 5 percent constant strain is imposed on the yarn as it passes continuously over two rollers, and a third roller between these two acts as a sensor to measure the tension in the yarns, which enables one to calculate the yarn instability.

Another way is to measure the thread tensile force in the stabilizing zone of the texturising machine on a running yarn⁵³. With constant draw ratio, the firmer the loops are tied into the yarn, the higher will be the resulting tensile force. In fact, Bock⁵³ has shown that as the thread tensile force decreases the instability of the yarn as shown by Du Pont's instability test increases. Acar et al²⁹ have also stated that the stabilizing tension is the measure of the stability of the textured yarn.

2.6.2.4 Permanent Extension as Instability in a Tensile Test.

Demier et al⁵⁸. exhaustively reported on the two methodologies used in the assessment of yarn instability as well as on the effects of specimen type and length, and simulation of weight hanging methods, using a tensile tester. They set the tensile testing machine in such a way so as to extend the yarn until it reaches the required load, the action being immediately reversed when the load is reached so that the conditions revert to zero loading. The permanent elongation of the textured yarn can be measured from

this method. The authors claim that the method is faster, accurate and relatively easier to perform than the weight hanging methods. They have also reported that the test duration and the specimen length have an insignificant effect on instability values.

2.6.2.5 Method Based on Repeated Loading (% Decay Method)

Sengupta et al⁵⁹. have suggested a method which is based on repeated loading principle. Since the yarns and the fabrics made from them undergo repeated loading during processing and while in use, this method is expected to give a realistic picture about the structural instability of air jet textured yarns. This method consists of subjecting the air jet textured yarns to cyclic loading between 0.01 to 0.33gf/den, till the area under the curve becomes more or less constant. The % decay can be calculated as follows.

$$\% \text{ Decay} = \frac{\text{Work done in first cycle} - \text{Work done in the last cycle}}{\text{work done in the first cycle}} \times 100$$

.....equ.2.18

The work done in the first cycle consists of the work needed to pull out the unstable loops and to extend the yarn elastically, whereas the work done in the last cycle is a result of the elastic deformation of the yarn.

2.6.3 Bulkiness of Textured Yarns

Bulkiness in a conventional sense is the volume in a given mass. Like instability, the bulkiness or bulk of textured yarns is also a key property. As different end products like industrial, apparel and technical fabrics demand different levels of yarn bulking; the proper assessment of bulk has assumed greater significance. Many techniques have been reported regarding the measurement of bulk of textured yarns; however there is no standard technique for the measurement of bulk of yarns so far.

Du Pont⁵⁶ has suggested a method for measuring bulk, which compares the package densities before and after texturing. A length of yarn weighing 85 gm is wound onto a package and a volumetrically similar package of textured yarn is then wound at the same tension. The ratio of the net weight of parent yarn to net weight of textured yarn expressed in percentage gives the physical bulk.

$$\text{Physical bulk (\%)} = \frac{\text{Net weight of parent yarn package}}{\text{Net weight of textured yarn package}} \times 100$$

.....equ.2.19

Another variation of this method is to calculate the ratio of the package density of the parent yarn to the package density of textured yarn which multiplied by 100, gives physical bulk.

$$\begin{aligned} \text{Physical bulk (\%)} \\ = \frac{\text{Package density of parent yarn \{g\|cc\}}}{\text{Package density of textured yarn (g\|cc)}} \times 100 \end{aligned}$$

:.....equ.2.20

Where,

$$\text{Package density \{g/cc\}} = \frac{M_{(b+y)} - M_b}{L(R_{(b+y)}^2 - R_b^2)} \dots\dots\dots \text{equ.2.21}$$

$M_{(b+y)}$ = total weight of bobbin and yarn,

M_b = weight of bobbin alone

L =length of yarn package

R_{b+y} = the radius of bobbin with yarn

R_b = the radius of bobbin alone

One of the main disadvantages associated with these types of measurement of bulk is controlling the winding tension. The resilience or compressibility of curls/loops and amount of air entrapped (bulk level) are quite dependent on the winding tension levels, the variation of which depends on the package type, winding speed and surface structure of textured yarns.

Wray⁵² suggested a measure of physical bulk of textured yarns as the ratio of the density of parent yarn fabric to the density of textured yarn fabric (both fabrics woven of similar constructions with parent and textured yarns as weft) multiplied by 100. The density of the fabric is given by the ratio of weight per unit area (W) to the thickness (T) of the fabric.

$$\text{Physical bulk (\%)} = \frac{W_p \times T_t \times 100}{T_p \times W_t} \dots\dots\dots \text{equ.2.22}$$

Where “p” refers parent yarn fabric and “t” refers textured yarn fabric.

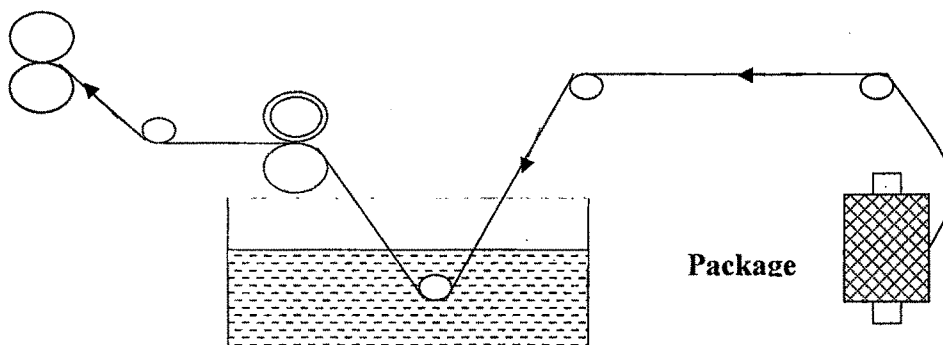
Wray and Sen⁶⁰ have suggested a water absorption test for the measurement of physical bulk of textured yarns. A constant length (400 yards) of yarn is allowed to pass through a water bath at constant speed (40 yards/min) and tension (0.1gf/denier). The amount of water absorbed by the yarn is ascertained. The same method is used for both the parent and textured yarns. The percentage increase in water absorption is given by;

$$\text{Increase in water absorption (\%)} = \frac{(W_b - W_p)}{W_p} \times 100$$

.....equ.2.23

Where, W_p =wt. of water absorbed by the bulked yarn (g) and
 W_b = wt. of water absorbed by the parent yarn (g)

Figure 2.13 Apparatus for Measure of Percentage increase in physical bulk of textured yarn by water uptake method



Burnip et al⁴⁶.have defined a bulking factor in relation to the specific volume of the yarn. This, in turn depends on diameter (d) and length (l) of sample.

$$\text{Specific volume } V = \pi d^2 l / 4 \dots \text{equ.2.25}$$

And

$$\text{Bulk - factor}(\theta) = V_t / V_y \dots \text{equ.2.26}$$

Where, V_t is the specific volume of the textured yarn and V_y is the specific volume of parent yarn. As applied tension affects the diameter considerably standard loading of 0.00536g/den is used. However Telesz⁴⁶ has commented about this method of measurement that bulk is the latent property of the yarn, whose full significance become apparent only at the wet treatment stage. The bulk and handle characteristics of the fabric would be greatly influenced by the severity of the wet treatment.

2.6.4 Degree of Crimpiness of Textured Yarns

Degree of crimpiness (E_c) is the ratio of the lengths difference of the straighten and crimped yarns to the length of yarns after crimp release, expressed as percentage. Crimp is released on the application of the load equal to the mass of 1000m of yarn on 100mm initial length.

$$E_c = \frac{(l_2 - l_1) \times 100}{l_2} \dots \text{equ.2.26}$$

Where l_2 is the average length after crimp release in millimeter and l_1 is yarn length before crimp release equal to 100 mm. Textured yarns and particularly crimped yarns have a very great

specific volume due to the crimpiness of the filaments and to the notable increase of air gaps between them. Textured yarns differ from common ones by great cross sections at a low linear density. The linear density of filament yarns is an indirect measure of their thickness regardless to air gaps. The linear density (tex) of textured yarn T_t is determined by the formula

$$T_t = \frac{T_s(E_c + 100)}{100} \dots\dots\text{equ.2.27}$$

Where, T_s is the linear density of the feeder yarn in tex⁴⁰.

2.7 Performance of Textured yarn during Fabric Formation

It becomes essential for the new product to ascertain whether the structural integrity of this yarn remains unimpaired during the fabric formation as well as after being subjected to finishing operations like washing, dyeing, and stentering etc. - a useful requirement for their acceptability in apparel end-uses. So the functional and comfort properties of both woven and knitted fabrics made from parent as well as textured yarn, by using same fabric construction variables need to be evaluated.

The range and variety of tests that have been devised for characterization of fabrics is now considerable. These tests are done to establish the suitability of newly engineered yarn to end-product process (weaving), at the defined quality level⁶¹.

Kothari et al⁶². has divided fabric properties into six groups, viz; i) Structural properties: Fabric sett, Warp and Weft linear densities,

Warp and Weft crimp (%), Weight per unit area, Fabric thickness etc. ii) Mechanical properties: Tensile strength, Tear strength, Abrasion resistance, Bursting strength etc. iii) Comfort related properties like Air permeability, electrical conductivity etc. iv) Aesthetics properties like drape, crease recovery etc. v) Low stress mechanical properties and vi) Other end use related properties. Structural properties define the constructional features of the fabrics while depending upon the type of end-use tests may be performed to assess suitability of the fabric quality.

Textured polyester filament yarns are popularly used as weft in the textile field due to their advantageous phenomenon. But due to their higher shrinkage, width-wise fabric shrinkage occurs leads to selvedge cut, stenter pin missing, short width or textured feel loss type damage²⁸.

Butterworth et al⁶³. have found that in case of false twist textured yarn the crimp geometry created by the false twisting process is converted into a latent status by a suitable heat treatment, developed back on wet treatment in fabric gives higher crimp contraction.

Chaudhari et al²⁸. have shown that fabric shrinkage in its broadest concept means "dimensional change" or decrease in the area of the fabric. Where, width shrinkage of the fabric is in direct proportion to crimp contraction. So, higher width shrinkage is likely for fabric woven with false-twist textured weft yarn having higher crimp contraction.

Saville⁶⁴ has explained that when yarns are woven into fabric they are subjected to considerable tensions, particularly in the warp direction. Subsequent finishing processes like stentering

increases tension and temporarily set in the fabric, which is dimensionally instable. While putting such fabric for hot-wet treatments like dyeing it tends to revert to its more stable dimension, which results in the contraction of the yarns. This effect is usually greater in the warp direction than in the weft direction.

Findings of Butterworth et al⁶³., Chaudhari et al²⁸., Saville⁶⁴ and Hearle⁶⁵ on contraction of stretch yarn fabric can be summarized. As per them fabric width shrinkage depends upon several factors like:

- a) Basic filament properties, such as polymer type, density, filament orientation, thermal history, and thermo-mechanical properties, torsional and flexural rigidity, shape factor and interfilament friction.
- b) Yarn construction that is the number and denier of component filaments. It has inverse relation with weft denier.
- c) The type of texturising process and the specific production settings employed.
- d) Tension during mechanical processes like pirn winding tension, shuttle tension etc.
- e) Fabric structure: as the cross over points in the fabric reduces, chances of yarn migration increases that ultimately increase the fabric shrinkage.
- f) The geometrical structure of the loom-state fabric and the response of this fabric structure to the stretch development process.
- g) The final finishing process.

Butterworth et al⁶³. have defined empirical weave multiplier to quantify the frictional and constructional restraints imposed upon the stretch filling yarns by a particular weave type. The weave multiplier W_M is defined as

$$W_M = [I_w/P_R] \times [I_F/E_R] \dots \dots \dots \text{equ.2.28}$$

Where,

I_w = the number of filling threads intersected by each warp yarn per weave repeat in the warp direction;

I_F = the number of warp threads intersected by each filling yarn per weave repeat in the filling direction;

P_R = the number of picks per weave repeat;

E_R = the number of ends per weave repeat.

Value of weave multiplier is 0.25, highest evaluated for plain weave. A low value of W_M is indicative of a loose, sleazy fabric while a high value indicates a tightly interlaced weave repeating on a small number of ends and picks.

Goswami et al⁴.have reported that in case of stretch yarns, the packing density of the filaments is very low and the filament segments between points of entanglement are very long. This combination results in tremendous mobility of the filament segments along the yarn axis and any direction away from the yarn axis. The tremendous mobility of the filaments means the stretch yarn structure is easily deformed and the yarn has poor dimensional stability.

Chaudhari et al²⁸. have shown that in case of textured yarn , mostly the residual shrinkage is of very low magnitude due to heat-setting.

Bose et al³⁴. have shown that fabric with air textured yarn as weft is exhibiting higher fabric assistance and crimp due to its more pliability and snagging in nature.

Kothari et al⁶⁶.have pointed out that air jet textured yarn with coils, loops and curls locked at random intervals along the length of the yarn, execute more stable structure when woven as weft in the fabric. Spun-like appearance and handle, high bulk and subdued lusture are some favourable features of fabric woven with mechanical textured yarn.

When the load is applied to the strip of fabric the crimp in the direction of loading is gradually reduced and the crimp in the transverse threads increases, a process known as "crimp interchange"⁶¹.

When a tensile force acts on the threads of one system, the threads of both systems undergo extension. Due to the crimp interchange, the maximum possible elongation of perpendicular threads depends on the fabric geometry⁶⁷.

Helena et al⁶⁷. have reported that there are many factors influence, directly or indirectly; the final values of the breaking force and elongation at break of a fabric in the warp and weft directions. It is the yarn used (warp and weft), i.e. its mechanical and physical properties (count, breaking force and breaking elongation, fineness, number of twists, raw material composition, after-treatments etc.), which has the most significant effect^{68,69,70,71}. Slightly lower is the effect of the constructional properties

of a fabric, such as the weave, warp and weft thread density. There are also other factors which have an indirect influence on final values, such as the conditions in which weaving takes place: temperature, humidity, yarn tension during the weaving process etc.

The breaking force and elongation at break of a fabric are in close relation to the tensile properties of the yarn used. However, the breaking force of such fabric is not equal to the sum of the breaking forces of the threads, because there are several other factors in a fabric, which should be taken into account⁶⁴.

Offermann Peter et al⁷². have investigated the influence of yarn friction on breaking strength of woven fabric. They concluded that the number of weave interlacing points in the fabric is not the sole factor of significance for fabric strength, but their distribution is also considerable importance. An increase in number of interlacing points in the thread system increases the load bearing capacity of fabric only to a limited extent although the static friction rises due to increase in arc of contact between the threads.

Tensile strength of component threads in the fabric is increased as it is assisted by fabric structure. This effect is known as fabric assistance^{34,61}. Vernekar et al⁷⁶. has defined Cloth Assistance Factor (CAF) by following relationship.

$$\text{Cloth Assistance Factor (CAF)} = \frac{\text{Fabric strength per thread}}{\text{Yarn strength in bobbin}}$$

...equ.2.29

Helena et al⁶⁷. have concluded that if the different wefts did not have any influence, the breaking force of the fabrics in the warp direction would be totally or almost equal.

Mukhopadhyay et al⁷³. have shown that irrespective of type of weft yarn the extension at peak load is higher in the case of single yarn fabric in the weft direction of loading as compared to ply yarn. However, the extension at peak load is higher for doubled weft yarn fabric in the warp and biased direction of loading.

Elsaid et al⁷⁴. have concluded that constituent yarns linear density get increased as a result of shrinkage that occurred during bulking process, similar to those under which the fabrics are dyed.

Grosberg⁷⁵ has summarized the warp and weft extension behaviour during tensile testing by pointing out that, by and large, the first part of the extension is due mainly to crimp redistribution while the latter part of the extension is due to fiber extension and, to a certain extent, to thread compression.

Mukhopadhyay et al⁷³. have reported that normally, the higher crimp in the constituent threads leads to higher fabric extension provided the structural jamming does not takes place.

Helena et al⁶⁷. have concluded that the breaking force and elongation in the warp direction were higher when doubled yarns were used as the wefts instead of single threads.

As per Harrison⁷⁷ the fabric characteristics allow, the threads to group closer together under the force of the tearing agency and so, instead of the successive breakage of individual threads, the action becomes more of strength on group of yarns. Type of weave and fabric shrinkage has a great influence on the grouping efficiency.

General conclusions drawn by various laboratories for resistance to tear can be summarized⁶¹ as follows:

- 1) Thread breaks singly or in very small groups during the tear, therefore the single –thread strength of the component yarns is of great importance.
- 2) Where the fabric characteristics allow, the threads group closer together under the force of tearing agency and so, instead of the successive breakage of individual threads, the action becomes more of a strength test on plied yarns.
- 3) Weave who can exhibit better resistance to tear have higher tear strength.
- 4) High-set fabrics preclude thread movement and the assistance by thread grouping therefore greatly reduced.
- 5) Some finishing treatments like drip-dry reduce tear strength.

Saville⁶⁴ has reported that the various factors that influence the abrasion resistance of the fabric include; fiber type, fiber properties, yarn twist and fabric structure. Abrasion resistance is also reported to increase with linear density at constant fabric mass per unit area.

Air-permeability is mainly attributed to the porosity of the fabric. Porosity of the fabric is dependent on the porosity of the constituent yarns and air gaps between the constituent yarns after interlacement⁷⁸.

Textured yarns due to crimping show greater amount of air trapped in the structure and also provide better cover of fabric when used as weft. As a result of this air resistance of such fabrics get increased, reduces air permeability^{34, 66}.

Clayton's work⁷⁹ also showed that the twist factor in the yarns has a great influence on air permeability. He found that for constant cover factor of warp and weft, only by changing twist factor of weft, air permeability increases linearly.

Thicker fabric with higher weight per unit area results in increased stiffness thereby executes higher bending length and as a result of this higher bending rigidity value. Stiffer the fabric more will be the drape^{61, 80}.

Cusick⁸¹ suggested that bending and shearing moduli were determinative factors of the drape coefficient, and deduced a regression equation using only bending length and shear angle as independent variables.

The type of woven structure and characteristics of constituents largely affect crease recovery⁶¹.

Relationship has been developed for the evaluation of knitted fabric bulk as follows⁸²:

$$\text{Fabric Bulk (B)} = \frac{\text{Fabric thickness (cm)}}{\text{Fabric area density (g/cm}^2\text{)}} \quad \text{.....equ.2.30.}$$