CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This section summarizes the relevant research in fasciated spinning technology in the veins of design and development of nozzle, process parameters, uniqueness of feed material requirements with high drafting system, structural and characteristics of these sector yarns and comparative performance with the other system. The trends and the related research done in carded compact spinning systems and general approaches used in the analysis of yarn structure in spun yarns are explained.

Ring spinning has undergone steady development and achieved significant superiority in the past 100 years. For the past 50 years, many attempts have been made to surpass limitations of ring spinning. These attempts to surpass limitations have led to the development of new and innovative principle methods such as adhesives, open end spinning and false twist spinning techniques. The adhesive method lost its place and open end methods like rotor spinning systems produce only coarser yarns. The friction spinning systems are fairly recognized in the technical yarn sector. False twist technique, also called fasciated spinning, is used widely. Air jet spinning has become established in synthetic double yarns, particularly in polyester staple fibres. Using both false twist and open end spinning technology, air vortex spinning system was initially introduced for cotton fibres and recently it is
used for viscose fibres due to reduction in good fibre loss. So, the limitations in fasciated spinning process were sustained.

2.2 HISTORY OF FALSE TWIST NOZZLE DEVELOPMENTS

2.2.1 DuPont Nozzles

The history of fasciated spinning false twist nozzle originates with the DUPONT in 1963. DUPONT initially started the false twist nozzle for the filaments. In 1971, using short staple fibres DuPont patented a combination of aspirating nozzle and twisting nozzle (E.I. Du Pont de Nemours & Co. Inc., US Patent. 3 079 746, 1963). The main object of two nozzles is that, as the fibres leave the final drafting rolls, they are picked up by an aspirating nozzle and forwarded to a twisting nozzle. The twisting nozzle applies a torque to the fibre bundle by means of a vortex. Because the bundle is ribbon-shaped as it leaves the front rolls, the twist applies non-uniformly across the bundle. The inner core of fibres starts to twist first. The twisting core bundle receives a lesser amount of twist and then catches up the outer fibres. The fibres are consolidated into a yarn having a highly twisted core and less twisted surface fibres. This development was patented as rotofil process.

2.2.2 Toray Nozzles

Toray nozzle system consists of front nip rollers of the drafting zone, a pair of top and bottom endless belts, a suction nozzle and a single jet nozzle. The fibres are transferred by using suction nozzle to the nip point between the two belts after they leave the front roller nip. False twisting nozzle imparts false twist in the fibres. Hence, the wrapped yarn is formed using the two belt principle of Toray nozzle (Toray Industries, Inc. Tokyo,
Japan U S Patent 4 003 194, 1977). It was claimed by the manufacturers that this nozzle can be used for 100% synthetic staple fibres.

2.2.3 Toyota Nozzles

In the beginning of 1980’s, several machinery manufacturers came out with their single air-jet spinning nozzle system, but with lesser success (Basu 1999). Toyota Automatic Loom works Ltd., Japan, exhibited its air-jet system, TYS, at ITMA, 1983.

The Toyota Nozzle system comprises of a drafting device for forming a fleece, a deflection roller, and a pneumatic twisting nozzle. The twisting nozzle injects air into a twisting tube to form a swirling air stream so that the fleece twists into yarn. The deflection roller is placed adjacent to the front roller, for varying the direction of fleece. It supplies the fleece along an outer peripheral wall of the front roller. It separates ends of peripheral fibres from the fleece as free fibres. These fibres will be twisted by the pneumatic twisting nozzle to be wound around central main fibres, thereby forming a bundled yarn (Kabushiki Kaisha Toyota Chuo Kenkyusho, Aichi, Japan U S Patent 4 434 611, 1984).

2.2.4 Murata Air Jet Twin Nozzles

Since the introduction of DuPont to single jet spinning nozzle, there was not much significant achievement. In the year 1982, Murata Machinery exhibited the two nozzle principle. This Murata Jet Spinning (MJS) nozzle created a revolution in the fasciated yarn world. A lot of research has been done in this MJS nozzle.
Zeng et al (2005) critically analysed MJS nozzles for design factors. He concluded that the force of the vortex can be adjusted using the number of jet orifices, the orifice angle, the inner diameter of the jet orifice and the velocity at exit of the jet orifice (i.e. corresponding to nozzle pressure). Studies by Huifen GUO et al (2007) on MJS nozzle focused on dimensions and construction using numerical studies as shown in Figure 2.1(A) for the first nozzle and 2.1(B) for the second nozzle.

![Figure 2.1 Murata Air Jet Twin Nozzles by Huifen GUO et al (2007)](image)

**Figure 2.1 Murata Air Jet Twin Nozzles by Huifen GUO et al (2007)**

It reveals that the first nozzle vortex zone is created by the 3 jet orifices of diameter 0.45mm at 45° drilling angle at 11mm from the fibre inlet as shown in Figure 2.1(A). Below this vortex zone, there will be four rectangular grooves, designed in between the 3 slots. The groove’s length l, depth h and width w are 8 mm, 0.8 mm and 0.3 mm, respectively.
As shown in Figure 2.1(B), the second nozzle the vortex is formed into the twisting chamber through the air orifices of diameter 0.26 mm, 6 numbers of slots at drilling angle of 86° at high air pressure level and opposite direction to that in the first nozzle.

2.2.5 Murata Air Vortex Single Jet Nozzles

In the Murata Vortex Spinning (MVS), the nozzle plays an important role to achieve wrapper fibres in a single vortex zone as shown in Figure 2.2. In MVS, the high-speed whirled airflow twists the open-end trailing fibres that converge at the inlet of the hollow spindle into a yarn (Murata Japan U S Patent 5 528 895, 1996), William Gray (1999), William Oxenham (2001), Stuart Gordon (2001) and Guldemet Basal (2003).

![Murata vortex air vortex nozzle](image)

Figure 2.2 Murata vortex air vortex nozzle

The strength of the vortex zone and strength acting on the vortex spun yarn by the whirled airflow was investigated with an analytical model based on simulating the flow field inside the nozzle block by Zhuanyong Zou et al (2008).
Limitation of MVS nozzle was critically analyzed by Cotton Incorporated USA (2000) and Stuart Gordon (2001) for the good fibre losses of 8-12% during the processing of cotton fibres. Different nozzle geometry and pressures can be used to reduce these figures although alteration of such spinning parameters may cause significant changes in yarn properties (Stuart Gordon 2001).

A few other companies, such as Schlafhorst AG&CO (DE) and Machinenfabrik Rieter AG, Winterthur (CH) patented their air-vortex spinning nozzles but commercially they were not so successful.

### 2.2.6 Other Nozzles

Howa of Japan introduced ‘Fs-Fasciated Spinning’ nozzle. This nozzle consists a combing roller, as in rotor spinning for drafting the fibres. Yarn is spun using a single jet. This imparts only a very low degree of twist to the yarn.

A few other companies, such as Schubert and Salzer Maschinenfabrik AG, Germany (1985), NPK Tekstitno Mashinostroene, Bulgaria (1986), and Maschinenfabrik Rieter AG, Germany (1994) patented their air-jet spinning nozzles but, commercially they were not successful.

### 2.3 NOZZLE AND PROCESSES PARAMETERS

The false twist nozzle is the heart of the fasciated spinning processes. It decides the yarn characteristics and the performance. Any design of nozzle has its own variable to suit its application. The effect of nozzle variable must be related to yarn properties. Research was undertaken in MJS
and MVS nozzles. In all two nozzles, there are some variables with similarity and their yarn quality characteristic also varies.

2.3.1 MJS Nozzles

In the MJS Nozzle the list of process parameters considered by various research workers are First nozzle pressure, Second nozzle pressure, Delivery speed Draft, Air feed angle on both nozzles, Feed ratio, Twisting Chamber diameter, Effect of surface friction of twisting chamber, First nozzle to front roller distance and Distance between first nozzles to second nozzle.

2.3.1.1 Air pressure in the first and second nozzle

With this MJS, an increase in the first nozzle pressure improves the yarn tenacity for polyester (Miao 1986) and also polyester-cotton blended (Puttachiyong 1994) yarns. This increment is accompanied by the increment in the number of wrappers per unit length (Wang and Jordan 1984).

The increase in yarn strength can be at the compensation of evenness (Artzt and Conzelmann 1989). It was reported that at lower first jet pressure, more even yarn is produced. When the first nozzle pressure increased, the number of thin places and thick places remain practically constant at higher pressure even as the nep count increases in parallel with yarn strength and elongation. Lawrence and Baqui (1991), while using long staple fibres in their experiments, observed that, at the lowest first nozzle pressure (within their experimental range), the strongest yarn was produced. The tensile properties deteriorated with increase in first and second nozzle pressure. Increase in first nozzle pressure increased the irregularity and imperfections whereas the second nozzle pressure had no significant influence on the irregularity and imperfections of the MJS yarns.
In contrast, it was observed by Punj et al (1997) that the tenacity and breaking extension of air-jet spun yarn (polyester-viscose blend) increased with first nozzle pressure up to a certain limit. Further increase in first nozzle pressure decreased the yarn tenacity.

Increase in percentage of wrapper fibres by increasing the first nozzle pressure caused by increase in traverse forces. Further increase in first nozzle pressure increased wrapper fibres but wrapper extent decreased due to increase in random wrapping. Unwrapped portions in yarn increased, thus showing lower tensile strength. An increase in second nozzle pressure increased the yarn tenacity and breaking extension (Punj et al 1997) and resulted in an increase in the percentage of tight wrappers and wrapper extent. The increase in percentage of long wrappers along with a decrease in percentage of short wrappers caused the increase in tenacity.

2.3.1.2 Delivery speed

At a high surface speed of the front roller, the air flow caused by the drafting rollers plays an important role (Stalder 1988). The tenacity of the yarn improves with increased delivery speed but the thick places and nep
comes higher (Lawrence and Baqui 1991). Studies carried out on commercial machines show that the yarn strength increases in delivery speed up to a certain limit, after which it deteriorates (Venkatapathy and Nishimura 1992 and Wang 1987). The hairiness increases rapidly with increase in delivery speed, whereas unevenness is not significantly affected. (Kaushik et al 1992) reported that U% increases as the production speed is increased. In the case of acrylic—cotton air-jet spun yarn, the abrasion resistance increases with increase in production speed (Sengupta et al 1992). It was reported (Artzt and Conzelmann 1989) that the yarn twist increases with increase in yarn delivery speed.
2.3.1.3  Air feed angle on nozzles, surface friction

The effect on the yarn properties due to different design parameters of the second nozzle, such as axial orifice angle, twisting chamber diameter, and the surface friction of twisting chambers, were investigated by Oxenham and Basu (1993) and Chen (1988). These parameters have significant influence on yarn properties (Oxenham and Basu 1993). For cotton or polyester-cotton yarn, the yarn quality improves with the increase of axial orifice angle up to 50°, and then it starts deteriorating. For polyester fibre, the optimum yarn properties are achieved at a jet orifice angle of 45°. Twisting chamber diameters of 1.6 mm give the maximum yarn strength of 100% cotton. Three twisting chamber surface material such as brass 0.13, PTFE 0.07, ceramic 0.272 have been taken for studies by Basu 1993. A lower friction coefficient of the PTFE (Polytetrafluoroethylene)-made twisting chamber improves the strength of 100% cotton yarn. Even if brass has lower strength than that of PTFE, brass could be an optimum choice for performance factors, life span of nozzle and the dimension stability under high volume air handling properties.

2.3.1.4  Draft, feed ratio, first nozzle to front roller distance

The main draft has a significant influence on the breaking load, elongation-at-break, and the hairiness of air-jet spun yarns. All these parameters increased with increase in main draft. The effect of a specific first nozzle pressure on the yarn evenness is different at different drafts. This implies that the number of wrapper fibres is affected as draft changes and hence a simple change of draft can affect yarn structure also (Chasmawala et al 1990). Drafts of up to 170 can be used to produce yarn with very good regularity (Altzt et al 1985).The optimum main draft is 35 and the maximum break draft can be up to 5. With the increase in main draft, the relaxation shrinkage of yarn reduces significantly (Barella et al 1993).
The tenacity of air-jet yarn increases marginally with feed ratio then passes through a maximum value. The elongation-at-break follows a similar trend (Lawrence and Baqui 1991, Puttachiyong 1986). The yarn uniformity is improved with increased feed ratio. An optimum value was found to be 0.98 (ratio of surface speed of delivery roller and surface speed of front roller).

The increment of feed ratio progressively increases the yarn stiffness and measured twist (Wang and Jordan 1984). The strength curve goes through a maximum at a nominal feed ratio of 0.98. Yarn hairiness also tends to increase up to a small extent. There is no significant effect on yarn evenness and imperfections. The distance between the two nozzles is also important, though this parameter cannot be changed on commercial machines. Studies on an experimental unit show that, as the inter nozzle distance increases, the yarn tenacity and breaking elongation improve along with a deterioration in evenness and imperfections of the yarn (Lawrence and Baqui 1991).

Increase in the gap between the first nozzle and the nip of the front roller from 8mm to 14mm in increments of 1mm, have a small favourable effect on yarn properties (Wang and Jordan 1984). Decreases in the gap reduce yarn bending stiffness. However, this provides for only marginal improvement because the reduction in stiffness is accompanied by a small reduction in yarn strength and a small increase in hairiness

2.3.2 MVS Nozzles

Guldomet Basal and William Oxenham (2006) critically analyzed the MVS 851 model machine nozzle variables and their effect on yarn structure and characteristics. Comparison of front roller to the spindle
distance 19.6 and 20.5 mm, nozzle pressure 4.5 and 5 kg/cm$^2$, nozzle angle 65 and 70, and spindle diameter of 1.2 and 1.3mm was done.

The short distance between the front roller and the spindle produces more even yarns with less imperfection and less hairiness. The nozzle angle had a significant effect on evenness and hairiness values. A high nozzle angle caused more even and less hairy yarns. The interaction of a high nozzle angle and short front roller to spindle distance led to better irregularity.

Nozzle pressure and spindle diameter only affected hairiness. The hairiness was low at the high nozzle pressure and the small spindle diameter. The yarn speed had a significant effect on the number of thick places and hairiness. A low yarn delivery speed caused a smaller number of thick places and low hairiness. The interaction of the yarn speed and nozzle angle had a significant effect on hairiness as well.

Huseyin Gazi Ortlek and Sukriye Ulku (2005) also made detailed studies on MVS nozzles, in order to determine the role of nozzle pressure, delivery speed, and yarn count in obtaining optimum yarn characteristics. Three levels of nozzle pressure, 4, 5, 6 kgf/cm$^2$, three levels of delivery speed, 300, 350, 400 m/min and also three different yarn counts, Ne 20, Ne30, and Ne 40 were selected. All the samples of yarn were produced with the following spinning conditions: 70° nozzle discharge angle, 2P130d L7-9, 3 type needle holder, 1.2 mm spindle inner diameter, 36-36-49 mm top roller gauges, and 36-36-44.5 bottom roller gauges, on the MVS-851 vortex spinner. This study demonstrates that various properties of vortex yarns are significantly affected by delivery speed, nozzle pressure and yarn count. The number of neps decreased with increased delivery speed.
The results also showed that, as the delivery speed increases, the tensile properties of the yarn decreases, and Yarn hairiness increases. Nozzle pressure is a highly significant factor for the vortex yarn properties. Decrease in the nozzle pressure resulted in improved evenness and imperfection values except for the number of thin places.

Nozzle pressure was found to be an insignificant factor for the number of thin places. From the results it was concluded that increase in the nozzle pressure resulted in significantly improved hairiness and tensile properties of MVS yarns due to the better wrapping. Yarn count was also highly correlated with the vortex yarn properties. Generally coarser yarns yielded better yarn properties in terms of yarn evenness, imperfection values, hairiness and tensile properties. As a result, it can be concluded that, the choice of delivery speed, nozzle pressure and yarn count significantly affects the resulting properties of vortex yarns.

2.4 INFLUENCE OF FIBRE PROPERTIES ON MJS AND MVS YARN CHARACTERISTICS

**Fibre length** is very important for fasciated yarns, more than twisted yarns (Santjer 1991 and Kato 1986). In polyester/cotton blended yarns, there is a need for long staple cotton fibres as well as a high concentration of polyester to maximise the yarn strength (Looney 1984).

The strength of the yarn core results largely from the frictional effect and from fibre migration. As a result, yarn strength would be strongly dependent on fibre length (Looney 1984, Lord 1987, Puttachiyong 1986, Punj, Moitra, and Behera 1998). The effect of fibre length on evenness of air jet spun yarn is far higher than for ring spun yarns (Sreenivasamurthy et al 1993).
Looney (1984) observed that the use of 50% fibres shorter than 38 mm (polyester) increased yarn uniformity by 10% and the total imperfections by almost 100%, relative to the use of totally 38mm fibre. Yarn non uniformity (CV %) increased by 30% when combed cotton was replaced by carded cotton. Similarly Uster imperfections were four times greater and yarn strength tended to be lower.

Krause and Soliman (1989) showed by their theoretical analysis, by wrapping twist in single jet false twist spinning, that this spinning technique requires relatively long fibres of an even length distribution. Greater fibre length and minimal short fibre content contribute to improved quality in 100 percent cotton air-jet spun yarns (Kametches 1991). Increase in 2.5% span length and 50% span length by 3 mm results in an increase in tenacity of 1 cN/tex (Artzt and Dalirnan 1989). Short fibre content has the most significant effect on yarn quality (Kametches 1991, Aachen 1989, Gilbert 1985). Le Blanc 1989 observed that, for polyester yarns, the fibre length does not influence the Uster CV% of the yarns. In a core-sheath yarn, fibre length in the core is most important (Santjer 1991).

Fibre Fineness and the tenacity of the yarn are expected to increase as the number of fibres per cross-section increases. Such a trend was observed by Lord (1987) and Kaushik et al (1993). Long coarse fibres tend to create more imperfections and machine-stops than finer fibres (Lord 1987). Air-jet spun yarn produced from fine fibres has considerably lower flexural rigidity and higher elastic recovery (Kaushik et al 1993). In contrast, it has been commented by Miao (1986), Puttachiyong (1986), Basu and Oxenham (1992) that the ratio of wrapper to core fibre decreases when fine fibres are used, resulting in decreased yarn strength.
Gilbert (1985) reported that the yarn strength peaked at medium level micronaire for both 100% cotton and polyester-cotton blended yarns and came down again with higher micronaire of cotton. The breaking load of a fibre increases with increased fibre denier (Rajamanickam et al 1997). The results of simulation showed (Grosberg et al 1987), that the effect of the decreased number of fibres in the cross-section predominates in fine yarn counts and this causes yarn strength to level off when coarse fibres are used for fine count yarns. Coarser polyester fibres and combed cotton in a polyester-cotton blend, lead to a higher number of hairs (Bhortakke, Nishimura et al 1997).

Fine polyester fibre in the mixing can increase the production of the machine without significant loss in yarn strength and unevenness, but with a considerable deterioration in the yarn imperfection level and hairiness due to the predominant effect of higher delivery speed. Artzt and Steinbach (Artzt and Steinbach 1993), opine that fibre fineness has virtually no effect on yarn strength as long as a sufficient number of fibres are present in the cross-section. In another publication they report that for processing 100% polyester through air-jet spinning, 1.3 dtex is the optimum fineness for good spinning stability (105).

**Fibre strength and elongation** have maximum influence on the tensile properties of air-jet spun yarn (Basu and Oxenham 1992), (Artzt and Steinbach 1993). The correlation coefficient of elongation-at-break with yarn tenacity is found to be 0.98-0.99, and with fibre tenacity is 0.85-0.86. The wrappers formed by higher extensible fibres can hold the core fibres with a tight grip for a longer period when the yarn goes through stress. A study by (Sengupta et al 1981) on the characteristics of rotor spun yarns showed that the wrappers under strained condition extend and thereby reinforce the yarn matrix to restrict fibre slippage. As yarn strength is significantly influenced by
fibre strength, in general, stronger fibres should be preferred for producing air-jet spun yarn (Salhotra 1992).

However, this aspect should always be considered along with fibre elongation. In the case of polyester, it has been observed that fibre tenacity beyond 7.0 g/d offers no additional advantage in yarn strength due to reduced fibre elongation in such super-high tenacity fibres. Those fibres have high orientation and brittleness and are therefore easily damaged during mechanical operations at the fibre producers’ end, and in opening and carding at the mills. The strength loss incurred in this operation can be as high as 15% (Santjer 1991).

**Frictional Characteristics and Other Properties** Air-jet spun yarn structure depends very much on fibre to fibre friction for good yarn strength. High-static fibre-to-fibre friction is helpful (Santjer 1991). The interactions of fibre friction and fibre tenacity towards yarn tenacity have been analysed by Rajamanickam et al (1997). Three level of fibre friction (0.05, 0.10 and 0.15) and three levels of fibre tenacity (2, 4 and 6 g/d) were considered. It was observed that the yarn tenacity increases slightly with increase in fibre-to-fibre friction, and that it depends more on fibre tenacity than on fibre friction.

The total frictional force acting on a fibre depends on frictional force per unit length and fibre length. For a given value of fibre friction coefficient, the total frictional force acting on a fibre will increase with increase in fibre length (Punj et al 1996). An increase in the total frictional force will generally increase the number of breaking fibres. An analysis of the interaction between fibre friction (Coefficient of friction = 0.05, 0.10 and 0.15) and fibre length (30, 45 and 65 mm) shows that there is a significant interaction between the two, towards yarn strength. The effect of increased
fibre friction is more pronounced at lower fibre length. The cleanliness of cotton fibre is very important for air-jet spinning. Any trash particle or fibrous aggregates such as nepes hinder the rotation of the yarn in the narrow air path of the air-jets (Santjer 1991). This leads to a short-term interruption of twist insertion, creating weak places and end breaks. The machine life is also adversely affected by such abrasive trash particles.

Chellamani et al (1995) reported that it is possible to produce jute-polyester blended yarn by air-jet spinning, despite the brittle nature of jute fibres. The maximum permissible limit for the jute proportion appears to be 20%. Higher proportions of jute lead to significant deterioration in the all major yarn properties.

**Sliver fed and roving fed:** Three passages of drawing are preferred for air-jet spinning. The study quoted (Puttachiyong 1986), revealed that the third passage of drawing sliver reduced spinning stops by 50% when compared with second passage of drawn sliver. Both the total number of imperfections (thin and thick places, and nepes) and yarn unevenness decreased as the number of draw passages were increased from 2 to 3. There was no significant effect on yarn strength.

The direction of presentation of sliver plays an important role in determining the properties of yarn (Behera and Hazra 1997). According to Nakahara (Nakahara 1988), three passages of drawing produces stronger yarn when compared with two passages, due to more parallel alignment of fibres.

The condenser width coming out from the drafting zone is the ultimate to produce more wrappers. For increased width, more fibres go out of control of the false twist and they form more wrappers (Basu 1991). The optimum setting was observed to be between 10-12mm for cotton yarn. At a
condenser width of 10 mm, the strongest polyester yarn could be produced with maximum number of wrappers (Miao 1986). Tyagi and Dhamija (1998) and Shah (1995), observed that wider condensers increase the tenacity of yarn, along with some increase of unevenness and abrasion resistance. So, there are many advantages for yarn quality characteristics while feeding three passage draw frame sliver as feed material even though the total draft is 150-250. During research work Grosberg et al (1987) have taken roving as a feed material for analysis of three different systems such as single jet system, two jet similar rotation system and reversible rotation of nozzles systems. He concluded that reversible rotation of nozzle system found to have better yarn strength as compared to other two systems. In single jet system is found to have lower number of wrapper fibres than other two systems and it is laid in same direction as that of core fibre arrangement resulting in lower yarn strength.

2.5 MJS YARN PROPERTIES IN COMPARISON WITH OTHER YARNS

2.5.1 Tensile Properties

Air-jet spun yarn is weaker than ring spun yarn. The tenacity value of cotton air-jet spun yarn is 55-60% of that of similar ring spun yarn. This value is 80-85% for polyester or polyester-cotton blended yarns (Stalder 1990). Similar observations are reported by Kato (1986), Nierhaus (1984) and Lunenschloss Brockmanns and Phoa (1986). It is observed by Sreenivasamurthy et al (1993), that single-yarn tenacity is lower for air-jet spun yarns in comparison with ring yarns. The difference between the two types of yarns is lower (30-59%) for polyester-cotton blended yarns than for all-cotton yarns (about 55%).
Elongation-at-break for air-jet spun cotton yarns is more or less similar to that of respective ring yarns; however, it is 15% lower in finer yarns.

For polyester-cotton blended yarns, it is about 7-19% lower and the difference widens with decrease in yarn fineness. The work-of-rupture for air-jet spun yarns is lower by 55-64% compared to ring spun yarns of cotton, and by 34-60% for polyester blended material. Polyester-viscose blended air-jet spun yarn is 14-18% weaker than the corresponding ring spun yarn (Kaushik et al 1992). After doubling, the increase in tenacity of air-jet yarn is greater (14 - 46%) than that of ring spun yarn (around 12%) (Punj et al 1997).

2.5.2 Evenness and Imperfections

Air-jet spun yarn is more even than equivalent ring spun yarn (Nierhaus (1984), Lunenschloss et al (1986), Kaushik et al (1992), Punj et al (1997) and Deussen (1989)). Unevenness of air-jet spun yarns is lower by 25% and 20% respectively for cotton and polyester-cotton blended materials when compared with similar ring spun yarn (Sreenivasamurthy et al 1993). Where the effective fibre length is mainly influenced by the cut length of the polyester fibre, actual unevenness follows the trend of theoretical irregularity. U% decreases with increasing number of fibres in the cross-section.

Yarn imperfections, in terms of thin places, thick places and neps are lower for air-jet yarn when compared with ring yarn. Total imperfections are lower by about 70%. If ring spun irregularity is taken as 100%, air-jet yarn irregularity lies between 65-95 % (Deussen 1989). Rotor spun yarns, which are usually considered more even than ring spun yarns also, cannot achieve the results obtained by air-jet spun yarns (Artzt and Conzelmann 1989). The lower CV% of yarn may be due to the feeding of very uniform sliver with a low CV% (Wang and Jordan 1984).
2.5.3 Yarn Hairiness and Frictional Properties

Air-jet spun yarns are less hairy when compared with ring spun yarns (Stalder 1988, Wang and Jordan 1984, Lord 1987). In general, the range in values of hairiness is lower for rotor spun yarns compared to ring spun yarn. Air-jet spun yarns are similar to ring spun yarns for 1-2 mm intervals, but they fall to the level of rotor spun yarn for 3-4 and 4-6 mm intervals and finally they drop below other yarns.

In a blend of cotton and acrylic, the cotton-rich yarns are relatively more hairy than yarns which are having higher acrylic content (Tyagi and Dhamija 1998), although the latter are more bulky. After studying the static and dynamic frictional behaviour of cotton and acrylic air-jet spun yarns, Kalyanaraman (1988), concluded that air-jet cotton yarn has a higher coefficient of friction than that of similar ring spun yarn. Acrylic yarns show higher coefficients and more abrasion on machine parts in processing. For polyester-cotton blended yarn, the friction factor of air-jet spun yarn is higher than that of ring spun yarn (Murata 1982).

2.5.4 Stiffness and Abrasion Resistance

Air-jet spun yarns have higher bending stiffness when compared with ring spun yarns (Kaushik et al 1992, Vohs et al 1985, Punj et al 1996, Cheng et al 1994) and they are less compressible than ring spun yarns (Vohs, Barker and Mohamed 1985). The flexural rigidity of air-jet spun acrylic-cotton blended yarn is 15-20% higher than that of rotor spun yarn (Sengupta et al 1992). In the air-jet spun yarns, the clustering effect of core fibres due to their parallel arrangement and winding by tight wrapper fibres allows little freedom of movement of fibres during bending, causing higher flexural rigidity.
The bending stiffness can be reduced by changing various process parameters but this is achieved with a significant loss in yarn strength and increase in yarn hairiness (Wang and Jordan 1984). After doubling, the increase in flexural rigidity of air-jet spun yarn is lower when compared with that of ring spun yarn, narrowing the difference (Jidoshokki 1983).

The abrasion resistance of air-jet spun yarn is higher than that of ring spun yarn (Nikolic et al 1993). Acrylic-cotton air-jet spun yarn shows 30-40% lower resistance to abrasion than similar rotor yarn. The tight wrappers make the air-jet yarn sheath immobile, unlike the rotor-spun yarn sheath which is mobile and thus enhances the abrasion resistance (Sengupta et al 1992). Toughness index, which is an indicator of the ability of a textile substrate to absorb work, also significantly affects the abrasion resistance. The lower toughness index of acrylic-cotton air-jet yarns compared with that of similar OE rotor yarns thus signifies lower abrasion resistance. After doubling of air-jet spun yarn, the improvement in abrasion resistance is greater than that of ring spun yarn (Punj et al 1997).

2.5.5 Yarn Structure

The structure has been studied by different researchers. Lawrence and Baqui (Lawrence and Baqui 1991) reported that air-jet spun yarn consisted of an untwisted core of fibres and surface layers of fibres wrapped around the greater part of the core. According to them, the yarn can be classified into three types of structure. Class I structure consists of a twist-less core, which at time is crimped but is wrapped uniformly by a thin fibre ribbon with a uniform helix angle and direction. Class II structure consists of a twist-less core randomly wrapped by fibres in a singular state and in groups, showing 'Z' and 'S' direction of wrap with differing helix angles. Class III structure contains unwrapped sections of yarn cores at times having left over
twist. The relative frequency of different classes and their mean lengths can be varied by varying the process parameters.

Cheng et al (1991) also observed that the yarn produced by air-jet spinning is different from that produced by other spinning methods. The yarns are formed by two parts; bundle fibres and outside wrapping fibres. In the bundle fibres, a majority of the fibres are inclined at an angle of 5-10° in an 'S' and 'Z' direction (Miao 1986 and Basu). Hearle et al (1965) have used the following classifications of the yarn structures in their studies:

- The part of the yarn that has regular helical wrappings and the yarn core crimpness. This core strand appears to be a spatial curve similar to a helix. The yarn crimpness is due to the buckling force generated by wrapping fibre torque and tension.
- This structure has no wrapping fibres on the surface and has geometry similar to a ring spun yarn, but with a low twist level.
- This structure consists of a straight yarn core wrapped by regularly twisted wrapping fibres. Generally these wrapping fibres are less tight.
- This structure has a straight yarn core with wrappers of irregular twist.

The effect of spinning parameters on the structure and properties of air-jet spun yarns has been investigated. First, the ratio of the two nozzle pressures was varied; keeping the second nozzle pressure constant, then the ratio of the front zone draft to the back zone draft of the roller drafting system was varied, keeping the total draft constant. Yarn properties such as breaking load, breaking elongation, evenness, and hairiness were evaluated. A new
scheme of fiber classification that accounts for and characterizes the special shapes and configurations of fibers in air-jet spun yarns is proposed. Under this scheme, fibers are grouped into five different categories: core, wrapper, wild, core-wild, and wrapper-wild. Data on fiber configurations shows an increase in the number of wrapper fibers and a reduction in the number of core fibers with increasing pressure in the first nozzle and also with increasing main draft. The yarn breaking load, breaking elongation, hairiness, and irregularity show an increase with increasing first nozzle pressure and main zone draft. An attempt is made to relate yarn properties to the changes in yarn structure caused by changes in spinning conditions.

The unique structures associated with these yarns are a possible reason for the difference in yarn quality parameters. The higher tenacity values of vortex yarns can be attributed to the higher number of wrapper fibres in these yarns. The number of wrapper fibres is critical to yarn strength since they hold the internal parallel fibre bundle tightly together, and this effect is more critical for cotton fibres. In air jet spinning, edge fibres ultimately produce wrapper fibres, and the number of edge fibres depends on the fibres at the outside.

2.5.6 Migration and Fibre Extent

Ishtiaque and Khare (1993) reported a study of internal structures of ring, rotor and air-jet spun blended yarns. Punj et al (1997) observed that the extent of short wrappers, long wrappers and migrated core fibres is more for viscose fibre when compared with polyester fibre. Viscose core fibres show less fibre extent than polyester fibres due to more hooks in the case of the former. The average fibre extent of viscose fibre is more in polyester/viscose blended yarns, despite viscose having more hooking tendency. The fibre extent varies with changing process parameters such as second nozzle pressure, spinning speed, etc.
2.6 MVS YARN PROPERTIES IN COMPARISON WITH OTHER YARNS

Aung Kyaw Soe (2004), Huseyin Gazi Ortlek (2005) studied the Structure and Properties of MVS Yarns in Comparison with Ring Yarns and Open-End Rotor Spun Yarns. He compared these in a schematic diagram of the yarn structure as shown in Figure 2.3. No significant evenness differences exist in the three kinds of yarns, except for a higher frequency of thick places and neps in the MVS yarn. The hairiness length (1mm) for the MVS yarn was similar to the rotor yarn and lower than the RS yarn. For the hairiness length (3 mm), MVS yarn hairiness is much lower than the other two kinds of yarns. The reason for this low hairiness of MVS yarn is the thin layer of wrapper fibres, which prevents the main yarn body from forming wild fibre loops along with yarn axis.

Figure 2.3 Schematic diagrams of the yarn structures
The yarn tenacity value of ring yarn is higher than that of rotor yarns and MVS yarns due to the lack of fibre parallelization, which causes a non-uniform load distribution. With regard to MVS yarns, the twisted fibre core of ring yarn as opposed to the non-twisted core of the MVS yarn creates a stronger bond between the fibres. These fundamental structural effects cause the higher tenacity value of ring yarn compared with MVS yarn. MVS yarn is the bulkiest of the three kinds of yarns by the existence of loose wrapper fibres. They are formed by swirling air around the spindle under no tension and also by the creation of loops of wild fibres.

Migration in MVS was dealt with by Tyagi (2004) and Guldemet Basal (2006). The images captured during the analysis of yarn structure suggest that the fibre migration in vortex yarns differs from that in both air-jet and ring yarns. In vortex spinning, fibres emerging from the front rollers are sucked into the spiral orifice at the inlet of the air jet nozzle and move towards the tip of the needle protruding from the orifice. In the meantime, these fibres are subjected to a whirling air flow and receive twist. In air jet spinning, only the edge fibres become wrapper fibres.

Most of tracer fibres first showed core fibre characteristics, lying parallel to the yarn axis and then wrapper fibre characteristics, being helically wound onto the core. Guldemet Basal (2003) compared the properties of MJS and MVS yarn properties. MVS yarns found better tensile and elongation properties compared with the MJS yarns. The main difference between the air jet and vortex yarn is the number of wrapper fibres which is much higher in vortex yarns. Fibre processing laboratory, Cotton Incorporated USA 2000 critically analysed the comparison of performance of short fibre content on ring and MVS systems in cotton yarns. Stuart Gordon (2001) dealt with the effect of short fibre and nep levels on MVS efficiency and product quality on different ginning conditions of cotton yarns.
2.7 COMPACT SPINNING SYSTEMS

Compact spinning is a modification in regular ring spinning process which has special advantages, and can be used for short, medium and long-staple fibre spinning. Many research works have been carried out in this area. The Compact yarn has better fibre arrangements in the yarn structure with minimum peripheral fibres and with a better twist distribution (Kampen 2000, Meyer 2000, Stalder 1995, Guldemet Basal and William Oxenham 2006, Ganesan and Ramakrishna 2006, Morton 1956). In an interesting finding from another article, the author has critically analyzed the yarn similarities, structural differences and mechanical properties of regular ring yarn and compact yarn produced using medium staple fibres. Compact spinning technique has been used for the long fibres also. A work done by Pinar Celik et al (2004) on 100% wool, 45/55 wool/polyester, 50/50 wool/acrylic and 100% acrylic yarns shows in detail the properties and their applications. Many attempts have been done in short, medium and long fibres. 100% cotton short staple fibres are used in combed compact spinning system, whereas little R&D work has been carried out on carded compacting yarn.

Normally combed roving is used in regular compacting technique. Compacting of carded roving has more short fibres when compared to combed roving without spinning triangle, which is one of the interesting phenomena. In carded compact yarn formation, fibres are uniformly oriented and also compacted into the yarn axis at the delivery point of the drafting system. Thereby, the carded compact yarn can ensure better tenacity, elongation, and hairiness properties than regular ring carded yarns, which are the essential characteristics for the better working performance in the subsequent process.
In compact spinning system, the improved fibre integration, lower end breakage and reduced fluff are the some of the factors to produce high quality yarn in respect of hairiness, evenness and tensile properties. In Suessen compacting system, the compact is achieved by fibre transport through the perforated lattice and air drawn through inclined slots of the suction tube. Recently Suessen introduced a novel concept of D-slot (as shown in Figure 2.4) which is specially designed for the carded compact yarn.

![Figure 2.4 Suessen D-Slot compact systems](image)

2.8 YARN STRUCTURAL ANALYSIS

Yarn structure plays a key role in determining the yarn physical properties and the performance characteristics of yarns and fabrics. The best way to study the internal structure of the yarn is to examine the arrangement of single fibres in the yarn body and analyze their migration in crosswise and lengthwise fashions. This requires visual observation of the path of a single
fibre in the yarn. Since a fibre is relatively a small element, some specific techniques have to be utilized for its observation. In order to perform this task, previous researchers developed two different techniques.

a. **Tracer fibre technique:** This technique involves immersing a yarn which contains a very small percentage of dyed fibres, in a liquid whose refractive index is the same as that of the original undyed fibres. This causes the undyed fibres to disappear from view and enables the observation of the path of a black dyed tracer fibre under a microscope. Dyed fibres added to the raw stock before spinning act as tracers. Morton and Yen introduced this technique (Morton and Yen 1952).

b. **Cross sectional method:** In this method, embedding medium locks the fibres in their original position, then the yarn is cut into thin sections and these sections are studied under microscope. As in the tracer fibre technique, the yarn consists of mostly undyed fibres and a small proportion of dyed fibres such that there is no more than one dyed fibre in any yarn cross-section.

Regular compact spinning was recognized as a revolution of ring spinning in recent years. This technology is claimed for the superior quality and better raw material utilization (Kampen 2000, Meyer 2000 and Stalder 1995). The regular compact spinning system produces a different yarn structure when compared to regular ring yarn structure. Even though many research works have been done on the properties and appearance of compact yarn, only a few research works have been done to study the inner structure of the compact yarn (Guldemet Basal et al 2006, Ganesan and Ramakrishna 2006). The effect of twist on fibre migration for ring and rotor yarns has been

Fibre migration of ring and mechanical compact spun combed cotton yarns has been studied by Ganesan and Ramakrishna (2006). It is observed that the migration parameters for compact yarn made from mechanical compacting system – positive nip are 10-15% lower than that of the ring yarn and similar to that of pneumatic compact yarn of the same count. However, only a marginal reduction (2-6%) is observed in migration parameter for compact yarn made from mechanical compacting system – semi-positive nip as compared to ring yarn and it is not significant. Significantly lower degree of migration is observed in mechanical compact yarn spun from mechanical compacting system – positive nip than in ring yarn due to the significant reduction in size of the spinning triangle in the system and its consequence in the tension gradient. In the case of mechanical compacting system – semi-positive nip, the base of the spinning triangle remaining the same, its altitude increase causes slight reduction in tension gradient, resulting in marginal change in migration parameters.

Yarn diameter of mechanical compact yarn from mechanical compacting system –positive nip system is found to be significantly lower than that of ring yarn and similar to pneumatic compact yarn, which contributes to increase in strength by 10-15%. The yarn from mechanical compacting system –semi-positive nip system has shown a marginal reduction in yarn diameter and hence the increase in strength is marginal (3-5%).

The effect of twist on fibre migration for regular compact spun yarns has been studied and it is found that the rate of fibre migration is higher when compared to regular ring yarn (Guldemet Basal and William Oxenham 2006). In ring spinning, the main source of the fibre migration is due to the
tension differences between fibres during the yarn formation. When a thin ribbon-like fibre bundle is transformed into a roughly circular shape by twist insertion, fibres at the edges of bundle are faced with tension whereas fibres in the middle are subjected to compression. To release the stress, fibres which are subjected to tension will try to shorten their path during the yarn formation, whereas fibres which are under compression will try to lengthen their path. As a result of this, fibres leave their perfect helical path and migrate between layers of the yarn (Lord 1971).

In regular compact spinning, tension differences between fibres during the twist insertion is smaller than those in ring spinning due to the elimination of the spinning triangle. Therefore fibre migration in compact yarns could be lesser than that in conventional ring spun yarns. If any modification or changes are done in compacting zone, there will be possibilities of change in the migration of fibres and it will change properties of the yarn.