

**THE EVALUATION OF MIXED YARN FABRICS OF  
*GONOMETA POSTICA* SILK, ACRYLIC AND  
WOOL.**

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# Chapter 1: General Introduction

## 1.1 Introduction:

Silk is a natural protein fibre (Kadolph & Langford, 2002), that is produced by the silkworm to make its cocoon. Most commercially cultivated silks are the product of *Bombyx mori* (Wingate & Mohler, 1984), a genus developed specifically by the Chinese over many centuries for its silk generating properties. The so called “wild” silks originate from a number of silk moth types, of which *Gonometa postica* is a local South African example. The *Gonometa postica* caterpillars feed on the leaves of the camelthorn tree, *Acacia erioloba* (Paterson, 2002:67).

Silk occupies a very special position as a textile fibre, possessing an extraordinary combination of beauty and strength. However, the labour intensive nature and, hence, high cost of its initial production and subsequent processing make it unaffordable to the average consumer (Miller, 1992:36). Efforts are therefore being made to determine whether silk can be incorporated into mixed yarn fabrics that can be produced at reasonable cost, while maximizing the benefit of its unique properties.

The physical structure and rich texture of hand spun and hand woven wild silk suggest the construction of a mixed yarn fabric, by mixing with a fibre that will complement the properties of silk, therefore wool and acrylic were selected.

Wool was chosen because it is also a natural protein fibre (Kadolph, 2002). It's a form of hair, which is naturally curly and readily available (Collier, 1974). The protein fibres contain many of the same characteristics, as those of silk, thus making a good candidate for use in mixed yarn fabrics, which is why a cellulose fibre e.g. cotton was not chosen.

Acrylic fibre was chosen because it is a synthetic fibre, which imitates the properties of wool and could therefore also be used in a mixed yarn fabric with the *Gonometa postica* silk. Acrylic is also readily available and has two important characteristics; its adaptability for common usage and low price (Moncrieff, 1970).

In October 2007 the price of 100g of commercially available wool yarn was set at R40.00, while the price of 100g of Courtelle yarn was R15.00. In contrast, *Gonometa postica* silk yarn was trading at R130.00 per 100g (Olivier, 2007; [www.capewools.co.za](http://www.capewools.co.za); Singer). This indicates that the price of the mixed yarn silk fabric should be considerably less than the price of a 100% *Gonometa postica* silk fabric.

## **1.2 Research problem:**

*Gonometa postica* silk is a very unique fibre with outstanding properties, which already make it expensive, but silk must go through many labour intensive processes before it can be used as yarn in a textile material, which makes it even more expensive and less available to the consumer.

The researcher proposes to construct mixed yarn fabrics consisting of *Gonometa postica* silk weft and wool warp, as well as *Gonometa postica* silk weft and acrylic warp, in order to make this fabric more affordable without changing the unique properties of the silk.

### **Sub problems:**

1. To evaluate and compare the properties of the *Gonometa postica* silk fabric with the mixed yarn fabrics containing wool and acrylic fibres.
2. To determine whether wool or acrylic fibre creates a more suitable mixed yarn fabric with the *Gonometa postica* silk.

### **1.3 Hypotheses:**

In order to compare pure *Gonometa postica* silk fabric with mixed yarn fabrics having either a *Gonometa postica* silk weft and a wool warp, or a *Gonometa postica* silk weft and acrylic warp, certain properties need to be evaluated.

The following hypotheses are proposed:

1. There will be a significant difference between the number of rubs needed to break two yarns of the *Gonometa postica* silk fabric and the number required by *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics, when abraded with the Martindale wear and abrasion tester.

2. There will be a significant difference in weight loss of the *Gonometa postica* silk fabric, as opposed to that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics, when abraded with the Martindale wear and abrasion tester.
3. There will be a significant difference between the maximum load required to break the *Gonometa postica* silk fabric in the weft direction and that required to break the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the same direction, when measured with the Instron tensile tester.
4. There will be a significant difference in the maximum load required to break the *Gonometa postica* silk fabric in the warp direction and that required to break the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the same direction, when measured with the Instron tensile tester.
5. There will be a significant difference between the displacement of the *Gonometa postica* silk fabric in the weft direction, at maximum load, and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the same direction, when measured with the Instron tensile tester.

6. There will be a significant difference between the displacement at maximum load of the *Gonometa postica* silk fabric in the warp direction, at maximum load, and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the same direction, when measured with the Instron tensile tester.
7. There will be a significant difference between the stiffness of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the weft direction, when measured with the Shirley stiffness tester.
8. There will be a significant difference between the stiffness of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the warp direction, when measured with the Shirley stiffness tester.
9. There will be a significant difference between the crease recovery of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the weft direction, when measured with the Shirley crease recovery tester.

10. There will be a significant difference between the crease recovery of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the warp direction, when measured with the Shirley crease recovery tester.
11. There will be a significant difference between the thickness of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics, when measured with the Essdiel thickness gauge.
12. There will be a significant difference between the moisture regain of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics, determined by weight loss after drying in a drying oven.
13. There will be a significant difference between the shrinkage of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the weft direction, when exposed to water.
14. There will be a significant difference between the shrinkage of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the warp direction, when exposed to water.

15. There will be a significant difference between the dimensional stability of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the weft direction, when exposed to steam.

16. There will be a significant difference between the dimensional stability of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the warp direction, when exposed to steam.

## **1.4 Definition of terms:**

### 1.4.1 Abrasion resistance:

The ability of a fibre to withstand the wear and rubbing of everyday use (Hollen and Saddler, 1973:9)

### 1.4.2 Absorbency:

The ability of a fibre to take up moisture (Hollen and Saddler, 1973:9)

### 1.4.3 Elasticity:

The ability of a fibre to immediately return to its original size after being stretched (Hollen and Saddler, 1973:10).

### 1.4.4 Filling or weft:

This refers to the yarns perpendicular to the selvage, which interlace with the warp yarns in a woven fabric (Kadolph and Langford, 2002:400).

#### 1.4.5 Lustre:

The light reflected from a surface. It is subdued and the light rays striking the surface are broken up (Hollen and Saddler, 1973:11).

#### 1.4.6 Moisture regain:

According to Hollen and Saddler (1973:9), it is “the percentage of moisture that a bone-dry fibre will absorb from the air under standard conditions of temperature and moisture”.

#### 1.4.7 Resilience:

The ability of a fibre to return to its original shape after folding, creasing or deformation (Tortora, 1978:15).

#### 1.4.8 Relaxation shrinkage:

Fibres become elongated during weaving and finishing and will relax to their natural size after being exposed to moisture (Tortora, 1978:17).

#### 1.4.9 Progressive shrinkage:

This occurs when the fibres continue to shrink each time they are exposed to moisture (Tortora, 1978:17).

#### 1.4.10 Tenacity:

This describes the strength of a fibre and the force at which the fibre ruptures or breaks (Kadolph and Langford, 2002:412).

#### 1.4.11 Textile fibre:

A fibre is “any substance, natural or manufactured, with a high length-to-width ratio and with suitable characteristics for being processed into a fabric” (Kadolph and Langford, 2002:400).

#### 1.4.12 Textile:

Textile is a term used to refer to fibres, yarns, or fabrics, or anything made from fibres, yarns and fabrics (Kadolph and Langford, 2002:412).

#### 1.4.13 Van der Waals’ forces:

These are weak attractive forces between adjacent molecules that increase in strength as the molecules move closer together (Kadolph and Langford: 413).

#### 1.4.14 Weaving:

Weaving is a process that is used to produce a fabric by interlacing two or more yarns at right angles (Kadolph and Langford, 2002:414).

#### 1.4.15 Warp:

The warp yarns are the yarns that are threaded through the loom in a woven fabric, parallel to the selvage (Kadolph and Langford, 2002:414).

## Chapter 2: Literature review

### 2.1 Silk

#### 2.1.1 The production of silk:

The silk protein polymers that are produced by silkworms are classified into two general groups. These are respectively; the “domestic” or cultivated varieties, e.g. *Bombyx mori*, and the so-called “wild” varieties, e.g. *Gonometa postica* (Kweon and Park, 2001). Cultivated silk is produced by a carefully controlled process in which the silkworm lives an artificial and protected life for the single purpose of producing fibres. On the other hand, wild silk production is not controlled. Instead, these silkworms feed on leaves and spin cocoons in the wild under natural conditions (Hollen and Saddler, 1973:28). There are 400-500 species of silk-producing moths in the world, but only 9 species are commercially cultivated. The domesticated mulberry silk moth, *Bombyx mori* produces 99% of the world’s silk (Dingle *et al.*, 2005: VI).

According to Dingle *et al.* (2005: VI) silkworms are classified into different categories according to the number of generations they produce per year. Univoltines produce only one generation per year, while bivoltines produce two generations and multivoltines more than two generations in a year. Multivoltine silkworms have a short larval period and the females lay non-dispausing eggs that can tolerate higher temperature and humidity.

However, their cocoon size is smaller which results in a shorter bave length than those of the univoltine/bivoltine cocoons.

The commercial value of univoltine or bivoltine cocoons is therefore higher than that of multivoltine cocoons. According to Franck (2001: 21) bivoltine strains produce a larger quantity of thread per cocoon with up to 1600 metres or more. The quality of the thread is very good as it is lustrous, even and strong. Unfortunately, these strains are more vulnerable to disease and require very hygienic and controlled conditions for rearing. The multivoltine strains are resistant to disease and will accept imperfect rearing conditions, but they produce low quantities of about 400 – 800 metres per cocoon. Their thread is of poor quality in terms of physical characteristics.

The Tussah silkworm is larger than *Bombyx Mori* and is both monovoltine and bivoltine. With monovoltines, the cocoons are only harvested once per year. With bivoltine *Tussah* in North China, the spring harvest is used for grainage purposes, while the autumn crop cocoons provides for reeling into raw silk.

The cocoons are reeled fresh because the moths only emerge in the following March. This is fortunate because these cocoons are very hard and the filaments are coarse (Textile Institute, 1991: 5).

According to Tortora (1978:88) silkworms go through four basic stages of development:

1. Laying of eggs by silk moth.
2. Hatching of eggs into caterpillars.
3. Spinning of a cocoon by the adult caterpillar.
4. Emerging of silk moth from cocoon.

During the caterpillar stage, the worm wraps itself in a protein liquid secreted from the two large glands in its head (Lee, 1999:1). Silk proteins are produced in the glands after biosynthesis in epithelial cells, followed by secretion into the lumen of these glands where the proteins are stored prior to spinning into fibres (Altman *et al*, 2003: 401). The ducts that leads from these glands merge into a single duct at the spinneret, which leads to the production of a double thread fibre described as a “bave” (Perez-Rigueiro *et al*, 2000). This protein liquid hardens when exposed to air. These filaments are bonded by a second secretion, sericin, which forms a solid cocoon (Lee, 1999:1). The silk cocoon can withstand prolonged exposure to weather, which shows that sericin is very weather resistant (Gohl and Vilenski, 1983:84). Under natural conditions, a moth eventually breaks through the cocoon, but in sericulture, the larvae are killed in the cocoon by steam or hot air before metamorphosis (Lee, 1999:1).

To obtain filament silk, the cocoons are sorted for fibre size, fibre quality and defects (Kadolph and Langford, 2002:62). The size of the cocoon differs according to silkworm variety, rearing season and harvesting conditions (Lee, 1999:1).

After the cocoons have been sorted, they undergo immersions in hot and cold water to soften the sericin and permit the unwinding of the filament as a continuous thread. About 1% of the sericin is removed at this stage, because the silk gum is needed for protection during the further handling of the delicate filament (Corbman, 1983:294).

Each cocoon is then brushed to help find the external ends of the filaments, several of which are gathered together and wound onto a reel in a process referred to as “reeling”. Twist can be added at the same time to hold the filaments together and this is referred to as “throwing”.

Staple silk is produced from cocoons in which the filament broke, or where the moth was allowed to escape (Kadolph and Langford, 2002:62). The filament length determines the workload, production rate and evenness of thread. The length of the cocoon filament corresponds to the variety of silkworm (Lee, 1999:3).

Thrown silk yarns still contain some sericin that must be removed to reveal the natural lustre and soft feel of the silk. During the degumming process there can be a weight loss of up to 25% (Corbman, 1983:299). Degumming is the removal of the sericin by dissolving it in boiling water or other solvents (Mamedov *et al*, 2002: 3407). Only a low percentage (about 11%) of sericin is removed in the degumming process of wild silk (Corbman, 1983:301). Degumming weakens the non-covalent interaction of core fibroin, such as hydrogen bonds and Van der Waal’s bonds.

The decrease in average failure strength after degumming suggests that this treatment has an effect on the intrinsic molecular order of the silk (Jiang *et al*, 2006:920).

After degumming there is a decrease in fibre thickness, weight, bending length, flexural rigidity, tenacity and crease recovery (Sharma *et al*, 1999:293).

The percentage of sericin removed and correct execution of the degumming process will also affect the lustre, smoothness and good dyeing potential of the yarn (Reddy and Krisnan, 2003:26).

The tussah silkworm differs considerably in appearance and habits from the *Bombyx mori*. It is usually larger and greener in colour, covered with tufts of gingerish hair (Cook, 1984:151). The coarser food that the wild silkworm eats leads to an irregular and coarse filament. The tannin in the leaves gives the wild silk a tan colour. In addition, the *Tussah* silkworm leaves one end of its cocoon open, sealing the hole with a layer of sericin gum before settling down to its metamorphosis. When the moth wishes to emerge from the cocoon, it breaks through the sericin wall (Cook, 1984:152). In doing so, the cocoons are always pierced and the fibres are shorter than reeled silk (Corbman, 1983:299). These short lengths of filaments are combed and spun to form silk thread. These threads are less lustrous, strong and elastic than reeled silk and will become fuzzy with wear (Lee, 1999:3).

## 2.1.2 The chemical composition of silk:

Silk is a natural protein consisting of two separate proteins: fibroin, a fibrous protein, and a nonfibrous material called sericin (Freddi *et al*, 2003: 102; Jiang *et al*, 2006). Fibroin is a crystalline protein, while sericin is an amorphous protein (Reddy and Krisnan, 2003:26; Jiang *et al*, 2006).

The silkworm has one spinneret on each side of the head that produces two filaments of fibroin, which are cemented together and to the cocoon by the sericin. Fibroin accounts for about 75% and sericin for about 25% of the fibre's weight (Freddi *et al*, 2003: 102; Jiang *et al*, 2006).

According to Kadolph and Langford (2002:63) fibroin is comprised of 15 amino acids that form a polypeptide chain, but according to Freddi *et al*. (1994:776) the fibroin of the Muga silk comprise of 18 amino acids, while Yanagi *et al*. (2000:873) listed 16 amino acids. Most authors agree that the simple amino acids such as glycine, alanine and serine comprise the largest portion of the fibre (Yanagi, 2000:874; Lotz and Cesari, 1979:207) which forms antiparallel  $\beta$ -sheets in the spun fibres (Kim *et al*, 2004:787). Therefore the fibroin polymer consists mostly of the repeated polypeptide sequence Gly-Ala-Gly-Ala-Ser (Li *et al*, 2001:2185). Peters (1963:304) states that there are small differences in the amino acid content, which arises from the different locations where the silk was produced.

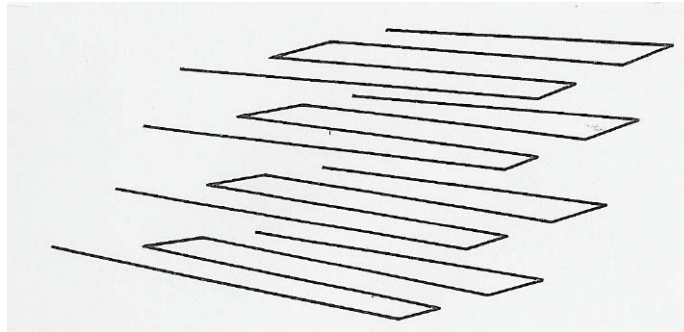
Yanagi *et al.* (2000:873) states that silk fibroin consists of the following 16 amino acids:

Table 1: Constitution of silk fibroin.

Name	mg	Wt %
Aspartic acid	0.044	2.90%
Threonine	0.019	0.91%
Serine	0.233	11.01%
Glutamic acid	0.040	1.87%
Proline	0.011	0.54%
Glycine	0.733	34.58%
Alanine	0.604	28.51%
Valine	0.047	2.21%
Methionine	0.031	1.46%
Isoleucine	0.025	1.17%
Leucine	0.021	1.00%
Tyrosine	0.211	9.97%
Phenyl alanine	0.043	2.03%
Lysine	0.006	0.29%
Histidine	0.014	0.66%
Arginine	0.036	1.71%
Total	2.119	100.00%

Fibroin chains are aligned along the fibre axis and are held together by a network of hydrogen bonds (Freddi *et al.*, 2003:102). The molecular chains in the polymer system are not coiled, but are layers of folded linear polymers. This explains why silk is estimated to be about 65-70 % crystalline and 30-35 % amorphous. The fibroin polymers must be closely packed together (Gohl and Vilenski, 1983:86).

This high orientation contributes to its strength. Its elasticity is due to some amorphous areas between the crystalline areas (Kadolph & Langford, 2002:63).



The arrangement of folded linear polymers that provides the very crystalline polymer system of silk (Gohl and Vilenski, 1983:86).

Silk sericin is a natural macromolecular protein. It consists of 18 amino acids. Most of these amino acids have strong polar side groups such as hydroxyl, carboxyl and amino groups. Sericin has many useful properties. It resists oxidation, is antibacterial and UV resistant and will absorb and release moisture easily (Zhang, 2002:91).

According to Ito *et al* (1995:757) silk sericin consists of 17 amino acids as shown in the following table.

Table 2: The amino acid composition of sericin.

Amino Acid	Mol %
Gly	14.2
Ala	5.0
Val	2.6
Leu	0.7

Ile	0.4
Pro	0.4
Phe	0.4
Ser	34.3
Thr	7.0
Tyr	2.7
Asp	17.5
Glu	6.8
Arg	2.4
His	0.9
Lys	3.8
Met	0.1
Cys	0.5

Fibroin and sericin differ considerably in their chemical composition and accessibility. Fibroin consists roughly of 76% of amino acids with non-polar side chains and only about 21% polar groups. In sericin, however, the ratio is about 25% non-polar groups and about 75% polar side chains. This difference in composition makes sericin more water soluble than fibroin (Chopra and Gulrajani, 1994:76).

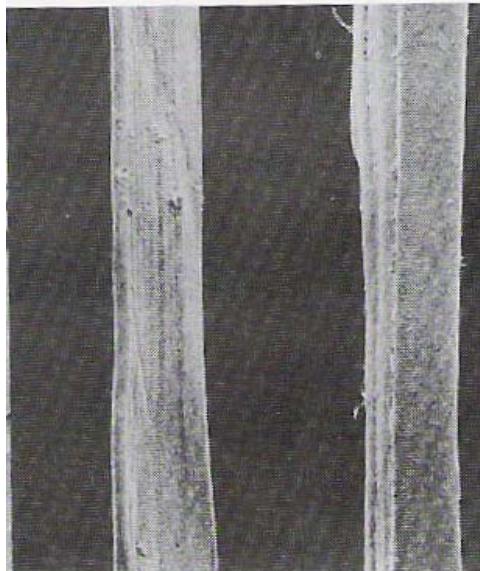
According to Gohl and Vilenski (1983:85) the silk polymer differs from the wool polymers as follows:

1. Silk consists of less amino acids than the keratin polymer of wool.
2. Silk polymers do not consist of any amino acids that contain sulphur; therefore silk's polymer system doesn't contain any disulphide bonds.
3. The chemical groupings of the silk polymer are the peptide groups which lead to hydrogen bonds and the carboxyl and amine groups which lead to salt linkages.

### 2.1.3 Physical structure of silk:

Naturally there is a difference between the physical structures of wild silk and cultivated silk. Cultivated silks usually have a colour range between white and yellow, whereas the wild silks can be grey or brown. Wild silk can also be distinguished by its irregular width (Cook, 1984:158).

The longitudinal view of wild silk reveals a rough, cracked surface containing many striations. The Tussah has a flat appearance with marked striations running diagonally. There are also diagonal markings on the fibre that have the appearance of shadows (Cowan and Jungerman, 1973:36). These cross-markings are caused by the overlapping of one fibre on the other before the substance of the fibre has completely hardened, in consequence of which such areas are flattened out (Brick, 1975:785).



The longitudinal view of silk (Kadolph, 2001).

When degummed the cross-section of the fibres appear triangular with rounded corners and the fibres usually lie with two flat sides facing each other.

The diameter differs and the filaments become thinner towards the inside of the cocoon (Cook, 1984:159). The roughness is in the sericin layer. Tussah silk is darker in colour, less regular in cross-section, and not as smooth as cultivated silks, thereby making it more difficult to handle in the manufacturing and finishing processes.



The cross-sectional view of silk (Kadolph, 2001).

The gum is removed with difficulty (Hess, 1958:236). The removal of the sericin brings out the soft and glossy properties of the silk and is usually carried out by means of a process referred to as degumming (Peters, 1963:304).

It is washed in hot water and soap, or synthetic detergent, for two to four hours and rinsed for one to three hours in clean hot water. The fibres of the wild silkworm are yellowish brown instead of yellow-grey (Wingate & Mohler, 1984:277). Natural Kalahari Tussah has a rich tawny colour.

Treatment of wild silk with chromic acid will cause the wild silk to disintegrate into a bunch of finer filaments, fibrils or micelles about 1.0 $\mu$ m in diameter.

The cross-section of the filament is dotted with markings, which correspond to the striations running lengthwise through the filament. These mark the boundaries between the fibrils, which are less closely held together than in cultivated silk (Cook, 1984:158).

Raw silk needs to be soaked and oiled before throwing and weaving or knitting. The manufacturer can choose precisely when to boil off sericin and what the quantity should be, but usually about 25% is removed to still leave a trace of sericin. Note, however, that while the sericin helps the yarn to resist abrasion (Textile Institute, 1991:12), its glue-like proteins are a major cause of adverse problems with biocompatibility and hypersensitivity to silk (Altman, 2003:404).

#### **2.1.4 Physical properties of silk:**

Silk is soft, supple, strong, and lighter in weight than any other natural fibre. It is also prized for combining lightness with warmth, sheerness with strength and delicacy with resiliency (Potter and Corbman, 1967:272).

The macro structural characteristics such as denier, filament length and cross-section are different between wild and cultivated silk (Kushal and Murugesh, 2004:1102). Cultivated silk fabrics also show lower values of stiffness, compression resilience, bending rigidity and tensile resilience (Sharma *et al*, 2000:57).

#### **2.1.4.1 Lustre:**

Fibres appear lustrous when there are specular reflections from the outer surface. Hence, those with smooth longitudinal surfaces or circular cross-sections appear more lustrous than fibres with irregular cross-sections such as triangles (Wynne, 1997:13). Tortora (1978:11) agrees that fibres with triangular cross-sections such as silk have a lower covering power and reduced lustre. Fibres with smooth longitudinal surfaces appear more lustrous (Wynne, 1997:13). The triangular cross-section of silk contributes to a soft lustre, but the silk filament is usually slightly twisted around itself and the angle of light reflection changes constantly. This leads to a broken intensity of reflected light that result in a soft subdued lustre (Gohl and Vilenski, 1983:85; Cai and Qui, 2003:42).

Wild silks have a duller lustre because of their coarser size and irregular surface (Kadolph and Langford, 2002:63). Only 11% of the sericin is removed during the degumming process of wild silk, which also leads it to be less lustrous (Lee, 1999:5).

#### **2.1.4.2 Strength:**

Strength relates to the load-bearing property and change in dimensions under tension (Wynne, 1997:16). Silk is the strongest natural textile fibre as a result of its molecular arrangement, which is highly oriented (Stout, 1970:129). Wet strength is about 80 to 85% of dry strength (Joseph, 1986:60). A continuous length of individual filaments provides a factor of strength, which is higher than that possible with short staple fibres (Potter and Corbman, 1967:272).

The tenacity values increase along the filament length within a cocoon from the outer to the inner layers. This is true for all the silk varieties (Kushal and Muruges, 2004:1103).

The inherent strength of silk along with its lightness and fineness makes it desirable for sheer, yet durable fabrics. But the strength of silk fabric is affected by its construction as well as its finish, e.g. spun silk yarn is weaker than thrown silk (Potter and Corbman, 1967:272). In addition, the harsher methods of sericin removal can cause fibre degradation and a resultant loss of strength (Freddi *et al*, 2003:103).

Abrasion first modifies the fabric surface and then affects the internal structure of the fabric by damaging it (Alpay *et al*, 2005:607). Pilling occurs on the surface of fabrics and can be defined as “the entangling of fibres during washing, testing or wear to form balls or pills that stand on the surface of a fabric” (Göktepe, 2002:625). It is due to the curling of loosened fibre ends, which with wear and abrasion, form pills on the fabric surface (Dennison & Leach, 1952:489). Fabric type also affects the formation of pills. Fabrics with a loose structure pill more because it allows easier migration (Göktepe, 2002:625). According to Conti and Tassinari (1974:119) and Cooke (1984:206) pilling consists of three different stages; 1) fibres are surfaced as a result of mechanical action; 2) surfaced fibres entangle into the configuration of a pill; 3) the pill is worn, or pulled away from the fabric.

For a fibre end to pull out of the yarn construction it must overcome inter-fibre frictional forces and must also bend to work its way under and over cross-yarns of the fabric. Fibres which resist this bending (stiff fibres) have increased frictional restraining forces. When the restraining force exceeds fibre breaking strength, the fibre will rather break than pull out. Wool has low tenacity and therefore breaks instead of pulling out (Gintis and Mead, 1959:580).

The configuration of the fabric influences the accessibility of the individual yarns to the abrading force and influences the breakage in the fabric (Alpay *et al*, 2005:607). The most important factors that influence the abrasion of a woven fabric are fibre content, fibre tenacity, fabric count, yarn size, fabric thickness and float length (Kalaoglu *et al*, 2003:980). Some chemical finishes on a fabric can change the frictional properties of the surface and influence abrasion resistance. In addition to these properties, moisture and direction of abrasive force can also influence the abrasion of a woven fabric. Fabric rubbing, scraping and friction produce abrasion during wear (Alpay *et al*, 2005:607).

The smoothness of the silk filament yarns reduces the problem of wear from abrasion (Potter and Corbman, 1967:272).

#### **2.1.4.3 Elasticity:**

When a tensile force has been applied to a structure, there is a change in the dimension. Conversely, when the load is removed, forces from inside the fibre attempt to pull it back to its original shape (Wynne, 1997:19).

Silk is an elastic fibre, but its elasticity varies, as may be expected of a natural fibre. Gradually it returns to its original size and loses little of its elasticity (Potter and Corbman, 1967:272). The core filaments of silk are composed of highly organized  $\beta$ -sheet crystalline regions and semi-crystalline regions that are responsible for its elasticity (Altman, 2003:413). However, the non-mulberry silks contain more amino acid residues with bulky side groups. These enable molecular chains in non-crystalline regions of the fibre structure to slip easily when stretched and show higher elongation at break (Kushal and Muruges, 2004:1105).

At 2% elongation the fibre has a 92% elastic recovery (Joseph, 1986:60), and a breaking elongation of 20%. It is not as elastic as wool because it has no cross-linkages to retract the molecular chain.

Silk contains the elements carbon, hydrogen, oxygen and nitrogen, which are joined together in wavy molecular chains. These chains are single, and this structure gives silk an elasticity of 15-20% (Peters, 1963:304).

Elasticity of the fabric and the yarn is affected by the kind of yarn used (i.e. thrown or spun), the construction of the fabric and its finish (Potter and Corbman, 1967:272).

Silk is viscoelastic and hence, when subjected to a constant load, it will rapidly extend to a certain point and then continue to elongate very slowly for hours or days. Since the cross-sectional area of the fibre decreases as it stretches, the force per unit area eventually increases beyond its capacity and the fibre fails (Kaswell, 1999:39).

Viscoelasticity, also known as anelasticity, describes materials that exhibit both viscous and elastic characteristics when undergoing plastic deformation. According to Meyers and Chawla (1999:98), viscous materials resist shear flow and strain linearly with time when a stress is applied. Conversely, elastic materials strain instantaneously when stretched and just as quickly return to their original state once the stress is removed. Viscoelastic materials have elements of both these properties and exhibit time dependent strain.

#### **2.1.4.4 Resilience:**

Rees (1948:131) defines resilience as “the amount of energy returned by the material between the same limits of pressure”.

Beckwith and Barach (1947:306) state that resilience is “the ratio of work returned upon release of a compression load to the total work done in compressing”.

Silk fabrics can retain their shape and resist wrinkling rather well, especially those made from wild silk. Fabrics made from short-staple spun silk have less resilience (Potter and Corbman, 1967:272).

Silk is pliable and supple, which together with its elasticity and resilience, give it excellent drapability (Potter and Corbman, 1967:272). Drape describes the ability of a textile material to orient itself into folds in more than one plane under its own weight. This is a unique characteristic that offers a sense of fullness and graceful appearance (Hu and Chung, 1998: 913).

Unfortunately, silk has a very low wet resiliency (Cai and Qiu, 2003: 42). This is due to its lack of intermolecular chemical cross-linkages. When the fibres absorb water and swell, the salt linkages between polymers, which give the fibre high crease recovery when dry, are broken (Hu & Jin, 2002: 1009).

#### **2.1.4.5 Absorption and moisture regain:**

Regain refers to a dried sample and is the amount of moisture that the sample will absorb from the atmosphere. The regain of a textile material depends on the relative humidity of the air around it (Wynne, 1997:20).

The good absorptive property of silk contributes to its comfort in a warmer atmosphere. Silk has a moisture regain of 11% (Kadolph and Langford, 2002:64; Cowan and Jungerman, 1973:36). This property also contributes to silk's ability to be printed and dyed easily (Potter and Corbman, 1967:273). Unlike many other fibres, silk also absorbs dissolved substances (Lee, 1999:9) such as metal salts, which tend to damage it by weakening the fibre, or causing actual ruptures to occur when the fabric is not handled properly. Silk can absorb a great deal of moisture up to 30% and still feel quite dry (Cai and Qiu, 2003:42; Joseph, 1986:60).

#### **2.1.4.6 Dimensional stability:**

A fibre swells when it absorbs water and the swelling will show as an increase in diameter and sometimes even in length. Fibres which absorb little water tend to swell less than those that are very absorbent.

Such swelling of fibres is an important cause of fabric shrinkage (Wynne, 1997:21).

However, with filaments being so straight, smooth surfaced silk fabrics only shrink a little and are easily restored by ironing (Potter and Corbman, 1967:273). Furthermore, the molecular chains are not easily distorted, which is the reason why silk swells only a small amount when wet (Kadolph and Langford, 2002:64).

Silk exhibits the phenomenon of inverse stress relaxation. Inverse stress relaxation is a response of the fibre that reflects the textile material's behaviour during processing and use. It is particularly related to dimensional stability and resilience (Kushal and Muruges, 2004:1108).

#### **2.1.4.7 Handle:**

Natural silk is preferred over silk-like synthetics because of its superior "handle". This characteristic of silk describes its ultra-soft touch, high flexibility and volumetric feeling. Silk fabrics exhibit low stiffness and are deformable (Sharma *et al*, 2000:52).

### **2.1.5 Thermal properties of silk:**

Silk will ignite and burn when there is a source of flame. After removal from the source, it will sputter and extinguish itself. It leaves a crisp, brittle ash and gives an odour like that of burning hair or feathers. The burned portion is usually semicircular in form. When heated to about 135°C, silk will remain unaffected for a long period, but if the temperature is raised to 177°C, rapid degradation occurs (Joseph, 1986:60).

Silk is a protein fibre and therefore is not a conductor of heat. Because silk prevents body heat from radiating outward, it is desirable for winter apparel, including scarves. Thin silk fabrics are comfortably warm when used for lingerie, pyjamas, robes and linings. However, silk may also be used for summer fabrics, even though it is a non-conductor of heat, because being fine and strong it can be made into very fine yarns for weaving into very sheer fabrics. This permits the body heat and air to pass freely through the open construction of such cloth (Potter and Corbman, 1967:273).

## **2.1.6 Chemical properties of silk:**

### **2.1.6.1 Effect of alkalis:**

Silk is less damaged by alkalis than wool, and Tussah silk is particularly resistant (Cook, 1984:161). Alkaline solutions cause the silk filament to swell, because the alkali molecules cause partial separation of the silk polymers. The salt linkages, hydrogen bonds and van der Waals' forces that hold the polymer system of silk together, are all hydrolyzed by the alkali. Therefore dissolution of the silk filament occurs rapidly in an alkaline solution. Initially this means only a separation of the silk polymers from each other, but prolonged exposure results in peptide bond hydrolysis, which leads to polymer degradation and complete destruction of the silk polymer (Gohl and Vilensky, 1983:86; Lee, 1999:9). Concentrated solutions of caustic alkalis will destroy lustre and cause a loss of strength (Cook, 1984:161). Weak alkalis such as soap, borax and ammonia cause little or no damage to silk unless it remains in contact for a long time (Joseph, 1986:60).

### **2.1.6.2 Effect of acids:**

Silk is more readily degraded by acids than wool. This is because wool's polymer system contains disulphide bonds, while in silk there are no covalent cross-links between silk polymers. Thus, any acidic compound will cause breakdown of silk's polymer system. Usually this is noted as a distinct weakening of the textile material (Gohl and Vilenski, 1983:87).

Hydrochloric acid dissolves fibroin, especially when heated (Lee, 1999:10), while moderate concentrations of other mineral acids cause fibre contraction and shrinkage (Joseph, 1986:61).

Nitric acid attacks fibroin because of its oxidizing properties and at the same time, nitration of the benzene nuclei can occur (Peters, 1963: 311). A dilute solution of nitric acid produces a bright yellow colour on silk. Hot sulphuric acid causes sulphating of the tyrosine (Peters, 1963:311). If silk is treated with concentrated sulphuric acid for only a few minutes, then rinsed and neutralized, it shrinks and has less lustre but shows little loss in strength (Hess, 1959:241). Organic acids have little effect at room temperature, when diluted, but if concentrated, the fibroin may be dissolved (Peters, 1963: 311).

The molecular arrangement permits rapid absorption of acids, but tends to hold the acid molecules so they are difficult to remove.

Some authors hold that the scroop of silk, a rustling or crunching sound, is not a natural characteristic, but is actually obtained through exposure to organic acids (Joseph, 1986:61).

### **2.1.6.3 Effect of bleach:**

Silk is attacked by oxidizing agents at three possible points:

- 1) the side chains
- 2) the N-terminal residues, and
- 3) the peptide bonds (Lee, 1999:10).

Bleaches such as hydrogen peroxide are absorbed by silk and form complexes with amino acid groups and peptide bonds (Lee, 1999:10). Hypochlorite bleaches rapidly tenderize silk and should never be used (Cook, 1984: 161). A mild bleach of hydrogen peroxide or sodium perborate may be used with caution (Potter and Corbman, 1967:273).

### **2.1.6.4 Effect of sunlight:**

Silk has a low resistance to sunlight and weather mainly because of the lack of covalent cross-links in the polymer systems (Gohl and Vilenski, 1983:87). Sunlight tends to accelerate the decomposition of silk. It increases oxidation and results in degradation and destruction of the fibre. This in turn leads to loss of strength and colour (Lee, 1999:2). Raw silk is more resistant to light than degummed silk (Potter and Corbman, 1967:273)

### **2.1.6.5 Effect of perspiration:**

Human perspiration contains dissolved salts and, depending on individual body chemistry, can be acid or alkaline. The silk garment will absorb the body moisture as well as the dissolved salts.

Within the fibre, the salt attacks the fibroin and eventually will destroy both the polymer and the fibre. Human body oil is partially soluble in water and is absorbed along with perspiration. When the clothes dry, the oil remains in the fibre and, if the build-up is sufficient, it will cause a permanent stain.

Silk is best protected by the use of antiperspirants that do not contain high levels of metal salts (Smith and Block, 1982:101). Silk garments often break under the armpits, or across the shoulders, before the remainder of the garment becomes worn (Hess, 1958:242).

#### **2.1.6.6 Effect of water:**

Silk will not dissolve in water (Cook, 1984: 160). It decreases by about 20% in strength when wet, but regains the original strength upon drying. The fibre swells, but doesn't dissolve when steeped in warm water (Hess, 1958:241). Significant degradation can be caused by water or steam at 100°C (Peters, 1963:302).

#### **2.1.7 Biological properties:**

Silk resists attack by mildew, unless left for some time in a damp state, or under extreme conditions of tropical humidity. It is relatively resistant to bacteria and fungi, but it is destroyed by rot-producing bacteria. Silk has good resistance to the clothes moth, but carpet beetles will eat it (Joseph, 1986:61).

#### **2.1.8 Care:**

According to Joseph (1986:61) the preferred method of care for silk fabrics and products is dry cleaning, as the solvents do not damage silk. It is recommended for silk items because of dyes having poor colour fastness and dry cleaning doesn't damage fabric construction.

Wild silk fabrics should be ironed dry at moderate heat with a pressing cloth to prevent distortion of the silk filaments (Cook, 1984:163).

## **2.2 Wool**

### **2.2.1 The production of wool:**

The word wool is restricted to the description of the curly hairs that form the fleece produced by sheep (Rogers, 2006:931). The sheep's fleece is removed once a year by power-operated clippers. The soiled wool at the edges is removed before the fleeces are graded and baled. The price of raw wool is influenced by fineness and length. This is representative of the yarn into which it can be spun. The average fibre length will also determine the type of fabric for which it will be used (Collier, 1974:24).

Newly removed wool is known as raw wool and contains impurities such as sand, dirt, grease and dried sweat. Altogether, these can represent between 30 and 70% of the wool's weight (Kadolph, 2002:51). The wool is sorted by skilled workers who are experts in distinguishing quality by touch and sight. The grade is determined by type, length, fineness, elasticity and strength (Corbman, 1983:271).

Long wool fibres will be combed and made into worsteds, while short wools are described as carding, or clothing wools. When the quality has been determined, the wool is offered for sale as complete fleeces or as separate sections (Collier, 1974:24).

When the wool arrives at the mill it is dirty and contain many impurities that must be removed before processing. The raw wool is scoured with a warm alkaline solution containing warm water, soap and a mild solution of alkali, before being squeezed between rollers (Corbman, 1983:272). This procedure is repeated three to four times, after which the wool is rinsed in clean water and dried.

The quality and characteristics of the fibre and fabric depend on a number of factors, such as the kind of sheep, its physical condition, the part of the sheep from which the wool is taken, as well as the manufacturing and finishing processes (Corbman, 1983:273).

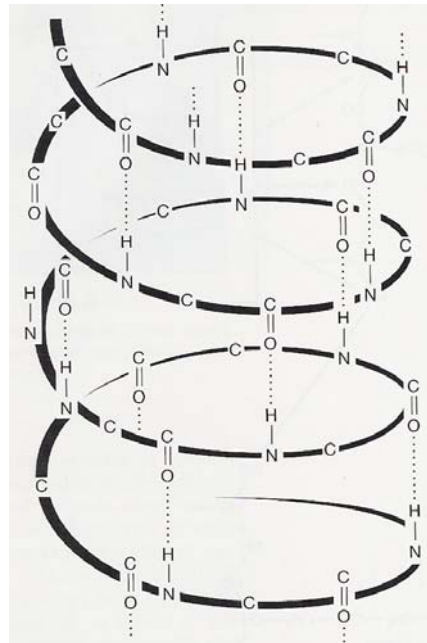
### **2.2.2 The chemical composition of wool:**

The protein of the wool fibre is keratin (Azoulay, 2006:26), which contains carbon, hydrogen, oxygen and nitrogen, but in addition wool also contains sulphur. These are combined as amino acids in long polypeptide chains (Kadolph, 2002:54). Wool contains 18 amino acids, of which 17 are present in measurable amounts (Joseph, 1986:48).

These are glycine, alanine, valine, leucine, isoleucine, phenylalanine, proline, serine, threonine, tyrosine, aspartic, glutamic, arginine, lysine, histidine, tryptophan, cystine and methionine (Stout, 1970:107). In addition to the long-chain polyamide structure, wool has cross-linkages called cystine or sulphur linkages, plus ion-to-ion bonds called salt bridges and hydrogen bonds (Tortora, 1978:74).

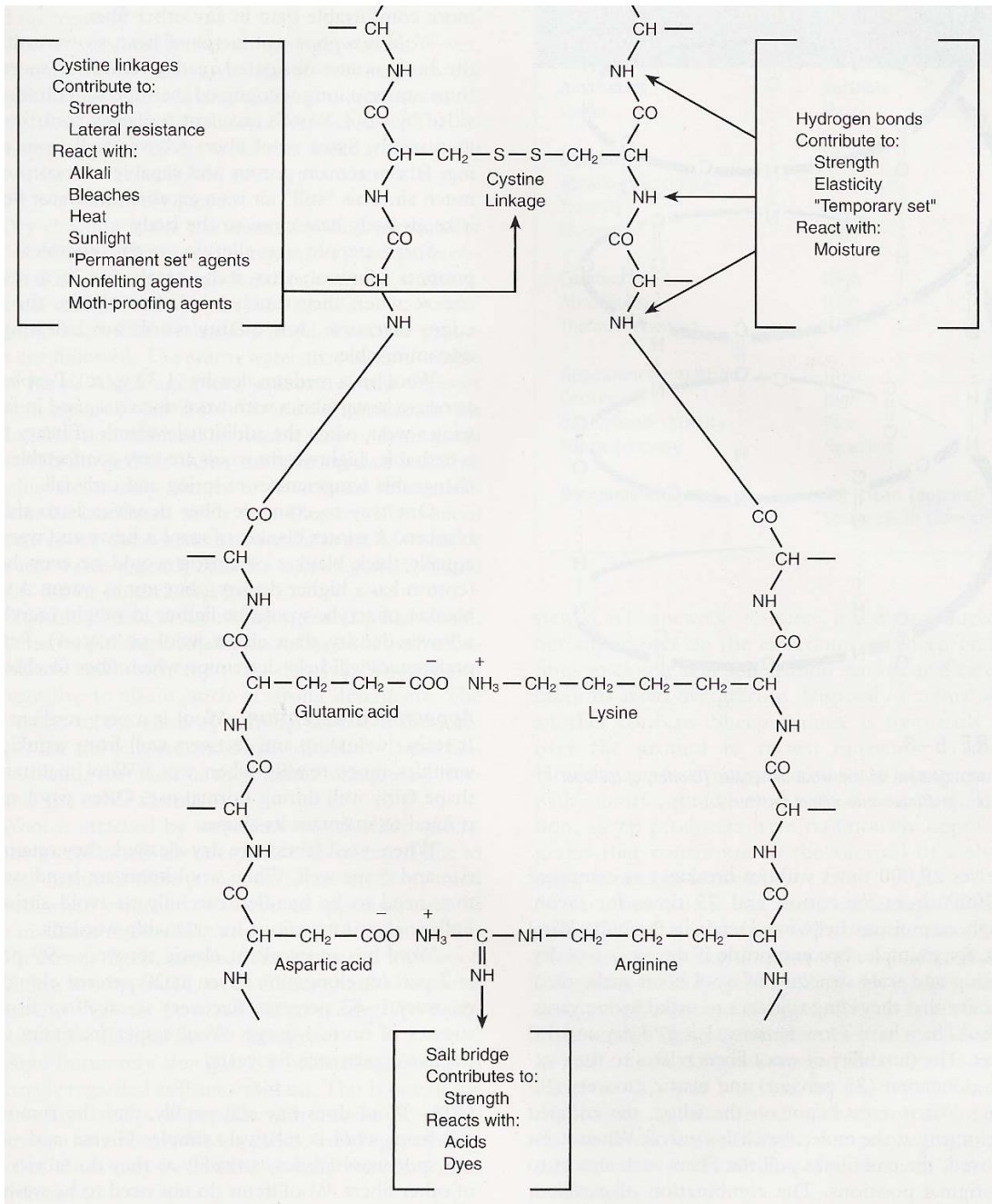
The cross-linkages in the chains permit the ends to move up and down, which provides the resiliency of the fibre (Labarthe, 1975:51). Keratin reacts with both acids and bases, which makes it an amphoteric substance (Hollen and Saddler, 1973:17).

When keratin is in a relaxed state it has a helical, or spiral structure called alpha-keratin (Gohl and Vilensky, 1983:75), which is responsible for wool's high elongation property (Kadolph, 2002:54). When the fibre is stretched it tends to unfold its polymers and this unfolded configuration is known as beta-keratin (Gohl and Vilensky, 1983:78).



Helical arrangement of the wool molecule (Wool Bureau, Inc. as cited in Kadolph, 2002:56).

The tenacity of wool is improved by the presence of the hydrogen bonding between the oxygen and hydrogen atoms of alternate spirals of the helix. This strengthens the structure and a greater force is required to stretch the molecules (Smith and Block, 1982:91).

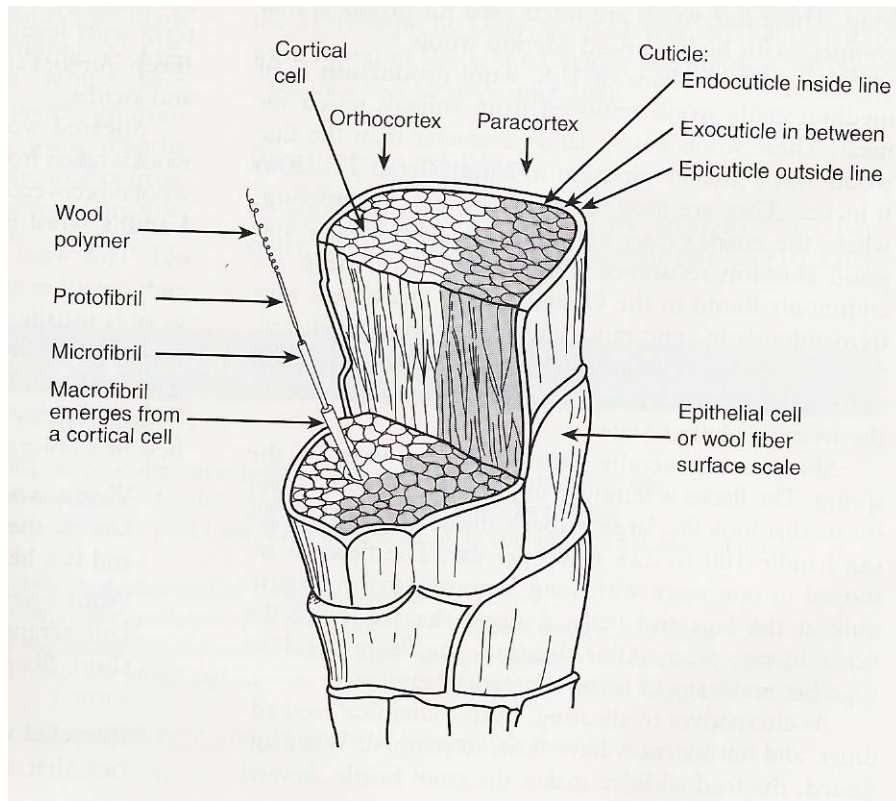


The structural formula of the wool molecule (Kadolph, 2002:55).

### **2.2.3 The physical structure of wool:**

The fibre consists of three layers – an outer layer of scales called the cuticle, a middle layer called the cortex and an inner core, called the medulla (Joseph, 1986:49).

The wool fibre is a cylinder, tapered from root to tip and covered with scales (Ito *et al*, 1994:440). The scales are irregular in shape and overlap each other towards to the tip of the fibre. These then have a directional effect that influences the frictional behaviour of wool because of its resistance to deteriorating influences (Joseph, 1986; Hall, 1969:15). These scales are responsible for wool textile's tendency to undergo felting and shrinking as a consequence of the difference of friction in the 'with-scale' and 'against scale' directions (Silva *et al*, 2006:634; Cortez *et al*, 2004:64). Each cuticle cell contains an inner region of low sulphur content, known as the endocuticle, plus a central sulphur rich band, known as the exocuticle. Around the scales is a shield, a membrane called the epicuticle (Maxwell and Hudson, 2005:127), which acts as a diffusive barrier and can also affect the surface properties of the fibre. The epicuticle is present as an envelope that bounds the entire inner surface of the cell (Swift and Smith, 2001:204). The sub-cuticle membrane is a thin layer between the cuticle and the cortex (Morton and Hearle, 1975:59).

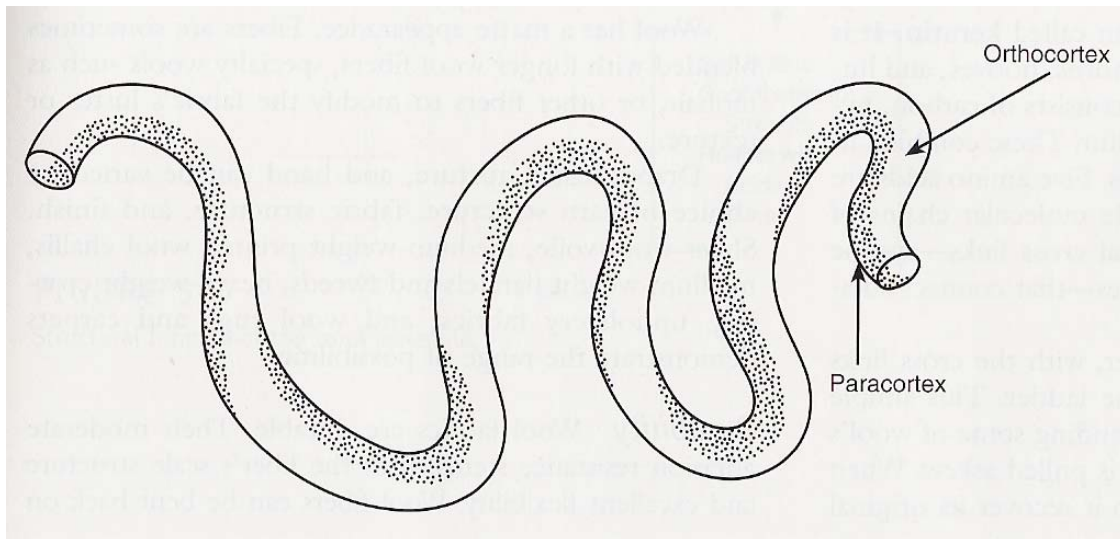


Physical structure of a wool fibre (Gohl and Vilensky, 1983:73).

The cortex is the bulk of the fibre and the hollow core at the centre is called the medulla. The cortex consists of millions of long and narrow cells, held together by a strong binding material. These cells consist of fibrils, which are constructed from small units and lie parallel to the long axis of the long narrow cells. The wool fibre gets its strength and elasticity from the arrangement of the material composing the cortex (Collier, 1974:25). The medulla resembles a honeycomb, i.e. contains empty space that increases the insulating power of the fibre (Hollen and Saddler, 1973:19).

Wool appears to be divided longitudinally into halves because of its bilateral structure, with one side called the paracortex and the other the orthocortex.

The chemical composition of the cells of the ortho- and paracortex is different, i.e. the paracortex contains more cystine groups that cross-link the chain molecules and is therefore more stable. It is this difference between the ortho- and paracortex that brings about the spiral form of the fibre and explains why the paracortex is always found on the inside of the curve as the fibre spirals around in its crimped form. In addition, these two parts react differently to changes in the environment, which leads to the spontaneous curling and twisting of wool (Gohl and Vilensky, 1983:74).



Three-dimensional crimp of the wool fibre (Gohl and Vilensky, 1983:75).

The fibres have a natural crimp, i.e. a built in waviness, which increases the elasticity and resiliency of the fibre. The spiral formed by the crimp is three-dimensional and does not only move above and below the central axis, but also to its left and right (Joseph, 1986:49).

The cross-section of the wool fibre is nearly circular and in some cases even oval in shape (Joseph, 1986:49). The longitudinal view shows both the scale structure, plus the striations on the epicuticle that can occur on the original undamaged fibres. These arise from an interaction in the follicle with the cuticle of the inner root sheath. When the fatty acids are stripped from the surface, the striations have been shown to reflect a corresponding irregularity of the epicuticle's surface (Swift and Smith, 2001:203).

Wool fibres vary in length between 2cm to 38cm, depending on various factors such as the breed of the sheep and the part of the animal from where it was removed (Joseph, 1986:50; Smith and Block, 1982:92). The diameters of the wool also vary. Fine fibres have a diameter of 15 to 17 $\mu\text{m}$ , medium fibres have a diameter 24 to 34 $\mu\text{m}$  and coarse wool has a diameter of about 40 $\mu\text{m}$  (Joseph, 1986:50). Hollen and Saddler (1973) differ in as much that they claim the diameter of a wool fibre varies from 15 to 50 $\mu\text{m}$ , with Merino lamb's wool averaging 15  $\mu\text{m}$  in diameter.

The colour of the natural wool depends on the breed of sheep, but most wool is an ivory colour, although it can also be grey, black, tan and brown (Joseph, 1986:50).

## **2.2.4 Physical properties of wool:**

### **2.2.4.1 Lustre:**

The lustre of a fibre depends on the amount and pattern of light reflected from the fibre (Hopkins, 1950:593).

The lustre of wool varies, but it is not generally considered to be a lustrous fibre. Nevertheless, lustre also depends on factors such as the specific breed of sheep, conditions of living and the part of the animal from which it was taken (Tortora, 1978:76). Fine and medium wools have more lustre than coarse fibres (Joseph, 1986:50) because lustre is due to the nature and transparency of the scale structure (Stout, 1970:113).

#### **2.2.4.2 Strength:**

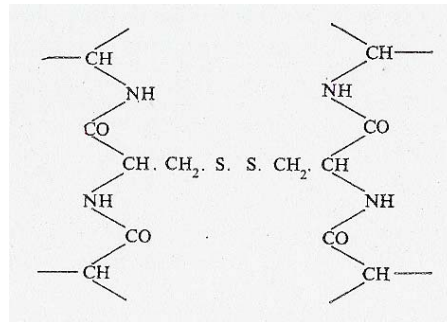
Wool is a weak natural textile fibre (Corbman, 1983:280). It has a large amorphous area containing bulky molecules that can't be packed close enough together to allow strong hydrogen bonding. Thus wool has many weak bonds and a few strong cystine linkages. Moisture weakens the hydrogen bonds, which makes the fibre even weaker when wet (Hollen and Saddler, 1973:20). When a garment is wet, the weight of the water puts strain on the weakened fibre and the shape can be distorted (Hollen and Saddler, 1973:21).

The strength of a fibre is dependent on the cross-sectional area of the fibre being tested. The smallest fibre diameter and the rate of change in diameter are important determinants of strength. There are a variety of environmental and physiological factors that influence the strength of wool fibres. The nutrient supply has a great influence as it provides amino acids, trace elements and vitamins. The fibre strength is also influenced by pregnancy and lactation through competition for essential nutrients (Reis, 1992:1337). During wear, however, resistance to abrasion is more important than tensile strength.

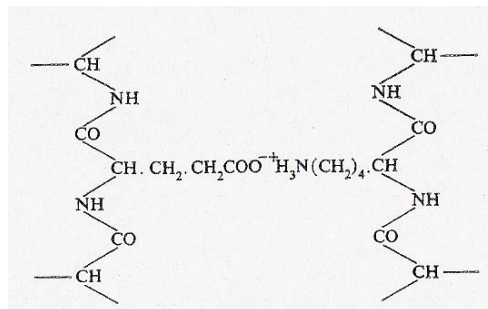
The scale structure of the wool fibre gives excellent abrasion resistance, which makes wool fabric very durable (Smith and Block, 1982:93).

### 2.2.4.3 Elasticity:

Wool fibres are very elastic and, when stretched, they quickly return to their original size (Smith and Block, 1982:92). This is due to the crimp, or waviness, of the fibre which enables it to be stretched out and then relaxed to the crimp form, like a spring (Collier, 1974:26). The molecules are in a folded state, but become straightened when stretched. The cross-linkages between the molecules, plus the disulphide and salt linkages tend to resist any permanent alteration in shape (Collier, 1974:27).



Disulphide linkage (Collier, 1974:27)



Salt linkage (Collier, 1974:27)

Wool fibres can be stretched from 25 to 30% of their original length before breaking, which also reduces the chances of tearing under tension (Corbman, 1983:280).

Wool's recovery is excellent and after a 2% extension the fibre has an immediate regain in length of 99% (Joseph, 1986:50). Elasticity is a valuable characteristic because it leads to the easy shedding of wrinkles. Wrinkles will easily hang out of wool garments, especially when hung in a damp atmosphere (Tortora, 1978:76).

#### **2.2.4.4 Resilience:**

The molecules in the wool fibre are arranged in long parallel chains, which are held together by cross-linkages. When the fibres are stretched or distorted, these cross-linkages will force the fibre back to shape (Cowan and Jungerman, 1969:9). This shows that the fibres will recover quickly from creasing (Thiry, 2005:19; Azoulay, 2006:26), but through the application of heat, moisture and pressure, pleats and creases can be put into the fabric. This is a result of the molecular adjustment and the formation of new cross-linkages in the polymer.

The resilience of the wool fibre also contributes to the fabrics' loft, which can either produce open porous fabrics with good covering power, or thick and warm fabrics that are also light in weight (Joseph, 1986:50).

Wool is classified as a resilient fibre. Therefore a bunch of irregular fibres should: a) offer moderate resistance to compression, and; b) spring back vigorously upon relaxation (Demiruren and Burns, 1955:666).

Wool and silk have the ability to resist the formation of wrinkles (Buck and McCord, 1949).

#### **2.2.4.5 Absorption and moisture regain:**

Water is usually shed by the wool fibres because of a combination of factors that include, for instance, the protection by the scales and the membrane, interfacial surface tension, uniform distribution of pores and low bulk density (Joseph, 1986:51).

However, once the moisture seeps between the scales, the high degree of capillarity within the fibre will cause ready absorption (Ito *et al.*, 1994:440). Wool can absorb 20% of its own weight in water without feeling wet (Corbman, 1983:282). According to Cowan and Jungerman (1969:9) wool is a hygroscopic fibre because it absorbs water vapour. Most of the moisture is absorbed into the spongy matrix, which then causes the rupture of hydrogen bonds and leads to the swelling of the fibre. The absorbent nature is due to the polarity of the peptide groups, salt linkages and amorphous polymer system (Cook and Fleischfresser, 1990:43). Wool dries very slowly (Corbman, 1983:282).

Hydrogen bonds are broken by moisture and heat, so the wool structure can be reshaped by mechanical action like that of an iron. While the heat dries the wool, new hydrogen bonds are formed in the structure as the water escapes in the form of steam. The new hydrogen bonds maintain the new shape while humidity is low. When the wool is dampened or in a high humidity atmosphere, the new bonds are broken and the structure returns to its original shape.

This is why garments shaped with ironing lose their creases and flatness, and show relaxation shrinkage on wetting (Hollen and Saddler, 1973: 21)

Wool produces heat as part of the absorption function (Azouly, 2005:25), which is known as heat of wetting. This is due to the energy generated by the collision of water molecules and the polar groups in the wool polymers. The polymer system will continue to give off heat until it becomes saturated. As wool begins to dry, the evaporation causes the heat to be absorbed by the fibre and a chill may be experienced (Joseph, 1986:51).

The behaviour of wool in relation to moisture can be summarized by saying that wool is water repellent, but with prolonged exposure to moisture the fibre does absorb large quantities of water. Since the moisture is held inside the fibre, the surface still feels dry (Tortora, 1978:77; Ethers, 1999). Wool is hydrophilic and contains various amounts of absorbed water depending on the conditions (Cook and Fleischfresser, 1990:43). The standard moisture regain of wool is set at 16 to 30% (Hollen and Saddler, 1973:22), but according to Lyle (1976:29) and Hunter (1978:46) it is only 15%. Cowan and Jungerman (1969:9) and Joseph (1986) report a regain of 13 to 16%.

#### **2.2.4.6 Dimensional stability:**

The structure of wool fibres contributes to its non stability (Joseph, 1986:51). All fabrics made of wool are subject to shrinkage (Corbman, 1983:282). Two kinds of shrinkage occur: felting shrinkage and relaxation shrinkage. Felting shrinkage occurs as a result of combined agitation, heat and moisture (Lenting *et al.*, 2006:711; Cortez *et al.*, 2004:64).

When wet, untreated wool fabric is agitated, the fibres will tend to move in a root ward direction and the root curls upon itself (Gohl and Vilensky, 1983:71). The scales interlock and hook together, causing the fibres to become entangled (Silva *et al.*, 2006:634).

When the felting is not properly controlled, the fabric will become stiff and thick, and it will shrink considerably (Joseph, 1986:52). Felting is enhanced by heat, which causes the fibre to become more elastic and thus more likely to move. This, in turn, will make it distort and entangle itself with other fibres. Heat also causes the fibre to swell, a condition that is enhanced by acid or alkaline conditions. Swelling leads to more inter-fibre contact and inter-fibre friction (Gohl and Vilensky, 1983:71).

Relaxation shrinkage occurs as a result of the elasticity of the fibre. Fibres are stretched and extended during the construction of fabrics, and when the fibre is exposed to moisture, the yarns return to their original length that causes the fabric to shrink (Joseph, 1986:52; Garcia *et al.*, 1994:466). This also includes exposure to steam, which causes shrinkage (Lyle, 1976:103).

The felting shrinkage of wool is progressive. Wool will continue to shrink if it is not washed in cold water with a neutral pH and minimum handling to minimize felting (Tortora, 1978:77).

#### **2.2.4.7 Warmth:**

The warmth of wool is due to its spongy structure and scales that incorporate many extremely small pockets of air (Miller, 1992:26).

Stationary air is a bad conductor of heat and therefore wool is a good heat insulator and feels warm (Corbman, 1983:281).

Wool absorbs atmospheric moisture and through the heat of absorption makes the wearer feel warmer (Cowan and Jungerman, 1969:9), and the fibre is protein and therefore doesn't transmit heat quickly (Miller, 1992:29).

### **2.2.5 Thermal properties of wool:**

Wool is not a very flammable fibre. Dry wool will burn slowly with a sputtering smoky flame, and will self-extinguish when removed from the source of flame (Smith and Block, 1982:94). Wool fibres scorch at 204°C and will eventually turn to char at 300°C. During combustion it will give off a smell similar to burning feathers. When removed from the flame each fibre will form a charred black knob (Cook, 1984:90).

### **2.2.6 Chemical properties of wool:**

#### **2.2.6.1 Effect of alkalis:**

Wool is easily attacked by alkalis. Weak alkalis like soap, sodium phosphate, ammonia, borax and sodium silicate will not damage wool if the temperatures are low (Labarthe, 1975:63). Alkaline solutions can open the disulphide cross-links of wool, while hot alkalis may even dissolve it (Chapman, 1974:56). Wool dissolves when boiled in a 5% solution of sodium hydroxide (Labarthe, 1975:63). Caustic soda will completely destroy wool. Wool turns yellow as it disintegrates, then it become slick and turn into a jelly-like mass, and goes into solution (Hollen and Saddler, 1973:22).

Weak solutions of sodium carbonate can damage wool when used hot, or for a long period (Hall, 1969:17).

Concentrated alkalis below 31°C gives wool increased lustre and strength, by fusing the scales together; it is called mercerized wool (Labarthe, 1975:63).

#### **2.2.6.2 Effect of acids:**

Wool is more resistant to acids. This is because they hydrolyse the peptide groups but leave the disulfide bonds intact, which cross-link the polymers. Although this weakens the polymer system, it doesn't dissolve the fibre (Gohl and Vilensky, 1984:81).

Wool is only damaged by hot sulphuric acid (Corbman, 1983:282) and nitric acid (Joseph, 1986). Acids are used to activate the salt linkages in the wool fibre, making it available to the dye (Hollen and Saddler, 1973:22). Concentrated mineral acids will destroy wool if the fabric is soaked in it for more than a few minutes. It will also destroy wool when it dries on the fabric (Labarthe, 1975:63).

#### **2.2.6.3 Effect of bleach:**

Bleaches that contain chlorine compounds will damage wool. Products with hypochlorite will cause wool to become yellow and dissolve it at room temperature. Various forms of chlorine are used to make 'unshrinkable wool', by destroying the scales. This wool is weaker, less elastic and has no felting properties (Labarthe, 1975:63).

Bleaches containing hydrogen peroxide, sodium perborate, sodium peroxide (Corbman, 1983:282) and potassium permanganate won't harm wool and are safe to use for stain removal (Wingate and Mohler, 1984:308).

#### **2.2.6.4 Effect of sunlight:**

Wool will weaken when exposed to sunlight for long periods (Schmidt and Wortmann, 1994). The ultraviolet rays will cause the disulfide bonds of cystine to break, which leads to photochemical oxidation. This will cause fibre degradation and eventual destruction (Joseph, 1986:53).

Wet fabrics exposed to ultraviolet light are more severely faded and weakened than dry fabrics (Labarthe, 1975:62).

#### **2.2.6.5 Effect of perspiration:**

As already stated, wool is easily deteriorated by alkalis and therefore perspiration which is alkaline will weaken wool as a result of hydrolysis of peptide bonds and amide side chains (Maclaren and Milligan, 1981:89). Perspiration in general will lead to discoloration (Corbman, 1983:283).

#### **2.2.6.6 Effect of water:**

Wool loses 10 to 25% of its strength when wet, although it is regained upon drying (Stout, 1970:113). Prolonged boiling will dissolve and decompose small amounts of the fibre. Boiling water will reduce lustre and promote felting (Labarthe, 1975:63). The heat makes the fibre more elastic and plastic which makes it easier to move and entangle itself with other fibres (Gohl and Vilenski, 1983:72).

## **2.2.7 Biological properties of wool:**

Wool is vulnerable to the larvae of moths and carpet beetles (Corbman, 1983:282), as they are attracted by the chemical structure of the cystine cross-linkages in wool (Tortora, 1978:78).

Raw wool may contain inactive spores, which becomes active when wet. Mildew will develop when wool is left in a damp condition for a long period (Labarthe, 1975:59).

## **2.2.8 Care:**

Dry cleaning is the recommended care method for wool items (Kadolph, 2002:56), because the solvents do not harm wool and create less wrinkling, fuzzing and shrinkage (Hollen and Saddler, 1973:22). Wool fabrics should not be tumble dried, because the tumbling of the damp fabrics may cause excessive felting shrinkage. The dryer will provide all of the conditions necessary for felting, namely heat, moisture and friction (Tortora, 1978:78).

Wool items should be dried flat to prevent strain on any part of the garment. Heat has a negative effect on wool fibres and therefore it is necessary to keep ironing temperatures low, and to use a press cloth (Tortora, 1978:78). Steaming will partially shrink and condition the fabric, so should be done with care (Wingate and Mohler, 1984:319).

## **2.3 Acrylic fibre**

### **2.3.1 The production of acrylic fibre:**

Acrylic fibre is “a manufactured fibre in which the fibre-forming substance is any long-chain synthetic polymer composed of at least 85% by weight of acrylonitrile units” (Ardrey *et al.*, 1979). Acrylic fibres can be produced by use of a dry- or wet-spinning process (Hall, 1969:67). In both methods the solvents range from highly polar organic compounds to concentrated aqueous inorganic salts.

The organic solvents include dimethylformamide, dimethylacetamide, dimethylsulfoxide, and succinonitrile and ethylene thiocyanate.

A comparison of the solvents indicates that dimethylformamide is the most efficient and produces a polymer solution with a stable viscosity. When the polymer is dissolved in a concentrated salt solution, it is spun into a more dilute solution of the same salt for coagulation (Carter, 1971:115).

The temperature is important during the wet-spinning process in determining the quality of the fibre. Low temperatures of 10°C and below are necessary for an optimum balance of fibre properties (Carter, 1971:115).

Courtelle fibres are produced by wet spinning (Hall, 1969:67). Preparation of spinning solution: The polymer is dissolved in a solvent. This polymer can be a homopolymer or a copolymer.

A homopolymer is a pure polymer produced from the polymerization of acrylonitrile, while a copolymer are produced from the polymerization of acrylonitrile together with up to 15% of one or more different modifiers. For the production of Courttelle, a copolymer is used and it contains mostly acrylonitrile (Phillips, 1987:127), together with vinyl acetate and methacrylate (Hall, 1969:67).

Dimethylformamide is generally used as the solvent with polymer concentration ranging from 15 to 40% or more (Press, 1959:77), but concentrated aqueous calcium thiocyanate (Hall, 1969:67) are used to produce Courttelle. When heated, the molecules combine and form long, flexible chains. The copolymer is now dissolved in a suitable solvent to give a spinning solution (Collier, 1974:56). The polymer solution is then degassed and filtered (Hall, 1969:67).

Wet process:

The solution is forced by metering pumps through spinneret which has between 1000 to 12000 holes that is 0.06 to 0.11mm in diameter (Press, 1959:77). Then the solution is extruded into a coagulating bath (Collier, 1974:56). The baths used for acrylic fibre coagulation include glycerine, petroleum, a solution of calcium chloride, water-dimethylformamide, etc. at temperatures ranging from 0 to 150°C (Press, 1959:77). A loss of lustre and a decrease in density has been found with rising spin bath temperatures (Knudsen, 1963:16). Reduced bath temperature leads to improved fibre structure and is related to coagulation rates. Coagulation is retarded at low temperatures which lead to more available time for internal adjustment of osmotic stresses, which causes a denser fibre. A decrease in coagulation temperature will also cause a change in cross-sectional shape.

At a temperature of 50°C or above, the cross-section is usually round, but when the coagulation temperatures are dropped, the cross-section becomes progressively more bean shaped. However, reduced spin bath temperatures doesn't only change the rate but also the character of coagulation. At higher temperatures coagulation takes place by counter diffusion of solvent and nonsolvent, in equal volumes across the fibre surface. When the coagulation temperatures are lowered, the outward diffusion of solvent predominates and leads to cross-sections that are not round, as well as higher fibre density. The lowered bath temperature leads to increased breaking tenacity and abrasion resistance improves, but breaking elongation decreases (Knudsen, 1963: 17). However, abrasion resistance involves longitudinal strength and lateral strength and there are differences in lateral strength between fibres spun at high and low spin bath temperatures (Knudsen, 1963:20).

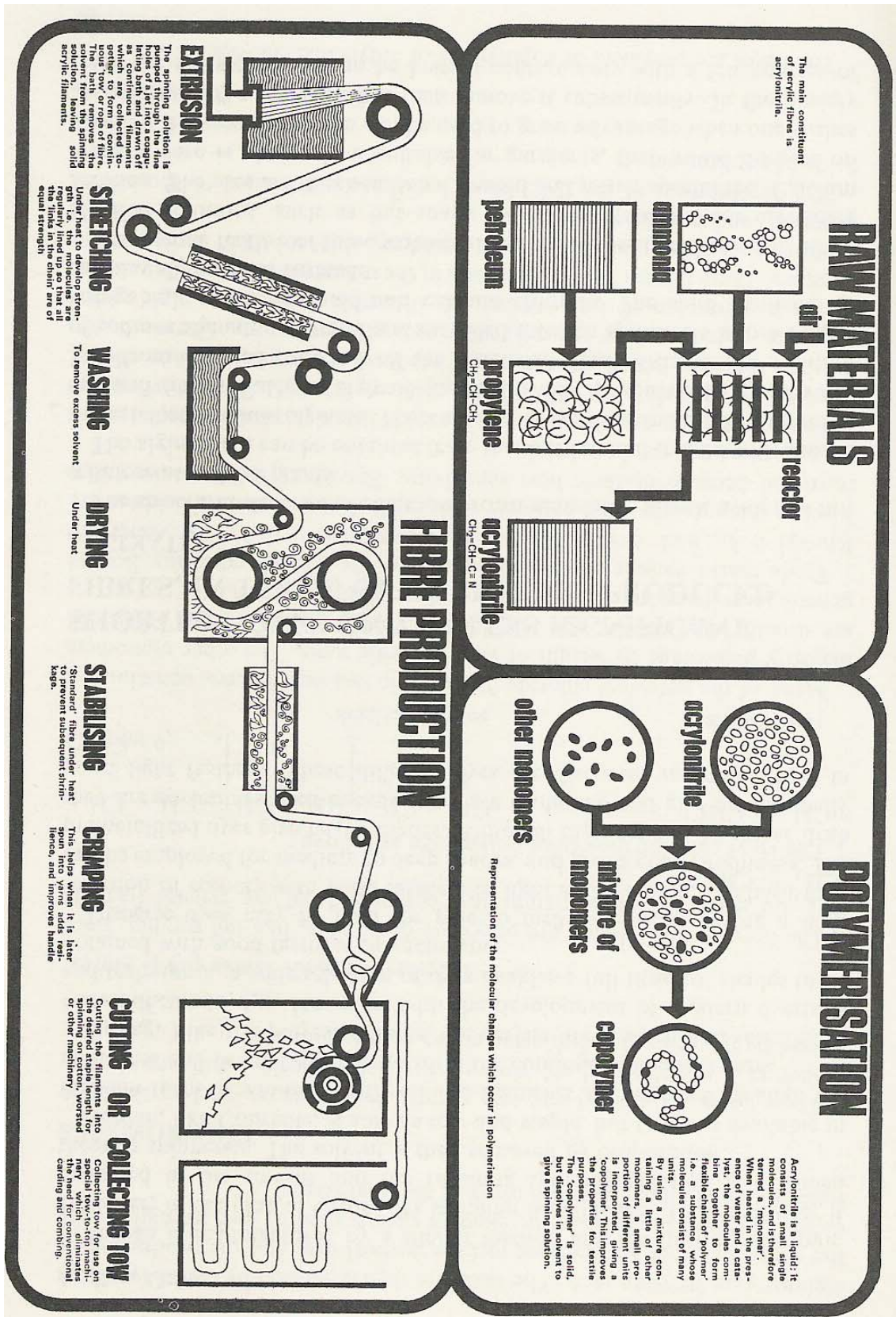
The baths are strengthened by the addition of nonsolvents, to maintain constant concentrations and aid in the recovery of solvents (Press, 1959:77). During coagulation supermolecular and morphological structures are formed (Jian *et al*, 1995: 570). A concentrated and highly viscous polymer solution is transformed into protofibres, which will acquire textile properties after receiving further processing (Knudsen, 1963:13). The crystallinity, orientation and porosity of a fibre depend on coagulation conditions such as temperature, concentration, duration, and viscosity of coagulant (Jian *et al*, 1995: 570). Knudsen (1963:14) also includes density, internal surface, cross-sectional shape, and homogeneity of the fibre structure to the list of factors that depend on coagulation temperatures.

After coagulation, the solidified filaments are collected together to form a tow.

It is stretched under heat to orientate the molecular structure so that the molecular chains are aligned parallel to the finer axis and improve the mechanical properties of the fibre (Phillips, 1987:127).

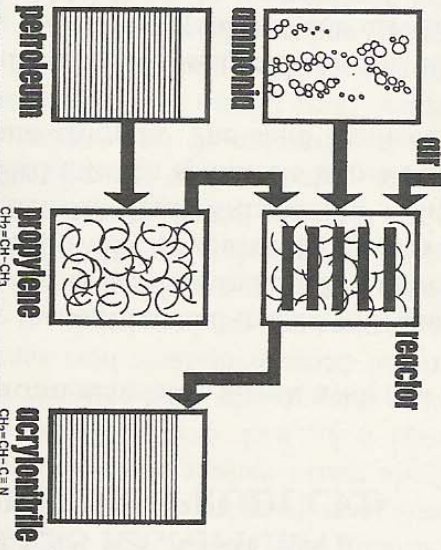
The improved properties after stretching can be attributed to the orientation of the fibrils, not to an increase in crystallinity or molecular order. A deformation process occurs during the stretching phase of the acrylic production process. The fibrils slip relative to one another and create viscosity, and a new network is formed with junctures at the fibril ends which leads to high elasticity (Bell and Dumbleton, 1971: 202). The material is washed to remove excess solvent and then dried (Collier, 1974:56).

The tow is stabilized by heat; this is a crucial exothermic process to prevent the standard fibre from shrinking (Bashir, 1991:1081). This is followed by crimping, which adds resilience and improved handle to the finished yarn (Collier, 1974:56). The tow is ready for delivery either in the form of tow for direct conversion from tow-to-top, or in staple form for use on the textile equipment (Press, 1959:77).

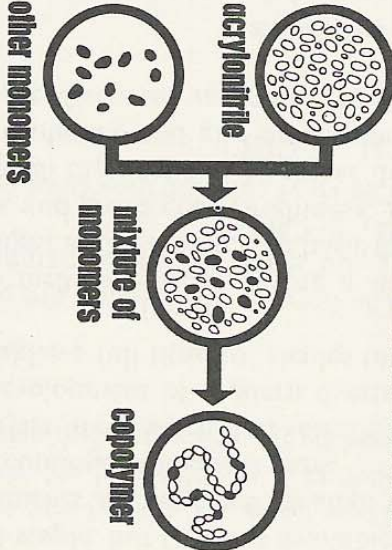


## RAW MATERIALS

The main constituent of acrylic fibres is acrylonitrile.



## POLYMERISATION



Representation of the molecular changes which occur in polymerisation

Acrylonitrile is a liquid: it consists of small single molecules, and is therefore termed a 'monomer'. When heated in the presence of water and a catalyst, the molecules combine together to form a copolymer. This is a substance whose molecules consist of many units. By using a mixture containing a little of other monomers, a small proportion of different units is incorporated into the copolymer. This gives a 'copolymer' with the properties for textile purposes. The 'copolymer' is solid, but dissolves in solvent to give a spinning solution.

## FIBRE PRODUCTION



Production of Courtelee (Courtaulds Ltd., as cited in Collier, 1974:57).

### **2.3.2 Chemical composition of acrylic:**

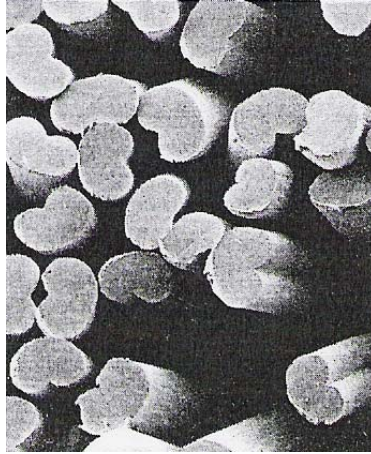
Courtelle contains at least 85% acrylonitrile (Hall, 1969:67). The chemical structure of acrylic fibres consists essentially of the repeating unit (-CH<sub>2</sub>-CH(CN)-) (Carter, 1971:114).

The molecular arrangement of polyacrylonitrile is described as paracrystalline, laterally ordered, extended, and rod-like crystals in a random matrix. In the polymer the molecules are grouped together in fibrils, which form a three-dimensional fibrillar network. The fibrillar elements will remain intact through coagulation, hot-stretching and drying, although network junctures are destroyed and reformed (Bell and Dumbleton, 1971:196).

Up to 15% by weight of the polymer consists of one or two other monomeric units (Carter, 1971: 114). Courtelle is a copolymer of a mixture of acrylonitrile with vinyl acetate and methacrylate (Hall, 1969:67). As comonomers, vinyl acetate and methacrylate is used to vary the properties of the polymer for ease of processing into a fibre and for improved fibre properties (Carter, 1971:114).

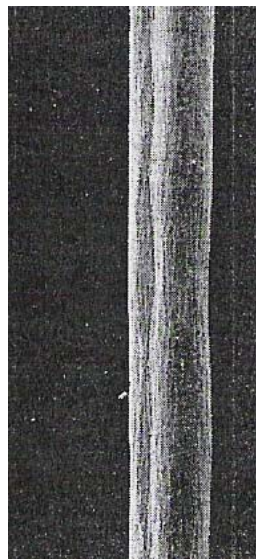
### **2.3.3 Physical structure of acrylic:**

Wet spun fibres usually have a round or kidney-bean shaped cross-section (Cook, 1984:405). Courtelle fibres have a coarse fibrillar form (Morton and Hearle, 1975:69).



Cross-sectional view of acrylic (Jones, 1990: 64).

Courtelle fibres are not round, but bean shaped. The characteristics of acrylic fibres can be varied by controlling the spinning conditions and after treatment to which the fibre is subjected (Cook, 1984:405).



Longitudinal view of acrylic (Jones, 1990: 64).

The longitudinal appearance show smooth uniform diameters with several fine or one heavy marking (Joseph, 1986:127). There are also small specks which can be caused by delustrants (Smith and Block, 1982:137).

Acrylic fibres are slightly wavy, which provides bulkiness to their yarns (Gohl and Vilensky, 1983:90)

Acrylics are man-made fibres and can therefore be controlled in terms of length and diameter. The fibres are marketed in staple or tow form. The natural colour of acrylics ranges from white to cream (Joseph, 1986:127). Acrylics are soft and bulky, as well as low in weight (Wingate and Mohler, 1984:375).

### **2.3.4 Physical properties of acrylic:**

#### **2.3.4.1 Lustre:**

Acrylic fibres are produced with bright, semi-dull and dull lustre, depending on the end-use (Joseph, 1986:127; Gohl and Vilenski, 1983:118). Lustre is created by reflections from the outer surface, therefore fibres with a circular cross-section appear more lustrous than fibres with irregular cross-sections such as triangles (Wynne, 1997:13), and acrylics have different cross-sections.

#### **2.3.4.2 Strength:**

The strength of a yarn is dependent on the fibres in the rupture region and the denier of the weakest fibre (Hurley *et al*, 1968:1174). The strength of acrylics is high and range from 2.0 to 3.5 g/d. This can be attributed to the crystalline nature of the polymer systems and the length of the polymers (Gohl and Vilensky, 1983:95). The strength of fibres is affected by conditions like temperature, rate of extension, and humidity (Hurley *et al*, 1968: 1174).

There is a slight decrease in strength when wet (Tortora, 1978:126). This indicates that the fibres are slightly amorphous, which enables the water molecules to enter and reduce the van der Waals' forces between polymers (Gohl and Vilensky, 1983:95).

Weathering is the result of the action of atmospheric gasses, light and moisture. This has little effect on the acrylics (Miller, 1992:51). Acrylic is very durable with a high resistance to abrasion damage (Corbman, 1983:468). These fibres also have strong resistance to breaking and sudden weight stresses (Cowan and Jungerman, 1969:89).

#### **2.3.4.3 Elasticity:**

According to Corbman (1983:470) acrylic fibres have little elasticity and it is in general lower than in most other synthetic fibres (Tortora, 1978:127), but according to Kadolph and Langford (2002:116) acrylics have a breaking elongation of 35% and Gohl and Vilenski (1983:119) reported breaking elongation between 20 and 50%.

At a 2% extension, most acrylics will recover, but recovery drops sharply as elongation is increased (Joseph, 1986:127). In woven fabrics, acrylic yarn may be extended beyond their ability to recover (Smith and Block, 1982:138).

#### **2.3.4.4 Resilience:**

Acrylics have very good resilience, which is enhanced by the crimp of the fibres (Corbman, 1983:471). Acrylic fabrics resist wrinkling and creases will hang out quickly (Joseph, 1986:127). The wrinkle recovery of acrylic fabrics can be improved by heating under constant shape at 200 to 220°C.

Setting can also be accomplished by the application of a swelling agent like alkylamides and cyanoalkylamides, before or after the desired deformation (Carter, 1971:121).

#### **2.3.4.5 Absorption and moisture regain:**

The standard moisture regain for acrylic is set at 1.0 to 2.5% (Joseph, 1986:128; Tortora, 1978:127). According to Labarthe (1975:143) Courtelle has a moisture regain of 2.0%.

The water absorption of acrylics is relatively low because the polymer system is highly crystalline (Gohl and Vilensky, 1983:95), but is still comfortable when worn next to the skin because these fibres will remove water by wicking (Cook, 1984:407). Wicking is the transfer of moisture from the inside surface of the fibre to the outside surface where it can evaporate (Smith and Block, 1982:137). Courtelle fibres are not as hydrophobic as many other acrylic fibres (Hall, 1969:67). Water tends to cling to the surface of the fibres which causes the water to penetrate between the fibres of the yarn and leads to very slow drying (Corbman, 1983:474).

#### **2.3.4.6 Dimensional stability:**

Acrylics do not shrink if the yarn and fabrics have been properly constructed and processed (Corbman, 1983:478). Heat setting will produce good dimensional stability in acrylic fabrics (Tortora, 1978:127). Therefore with proper care the acrylic fibre show little dimensional change, but high temperatures and steam should be avoided (Joseph, 1986:128). A copolymer of acrylonitrile and vinyl acetate will shrink only 5% at 120°C (Ham, 1954: 597).

#### **2.3.4.7 Pilling:**

Pilling has been a problem with acrylic yarns (Stout, 1970), this is related to yarn and fabric construction (Lyle, 1976:44). Pilling is a three-stage process. The first process is fuzz formation, where loose fibres form on the surface of the fabric. The second stage is pill formation, where the loose fibres tangle and form bundles that are attached to the fabrics by the fibres that are still partially part of the fabric structure. The final stage is pill wear-off. The bundles are now pulled away by mechanical action (Baker, 2002:1314).

#### **2.3.5 Thermal properties:**

Acrylic fibres are thermoplastic (Cowan and Jungerman, 1969:89). This causes the fibre to soften and melt when high temperatures are reached. In this state the fibre is plastic and the molecules can move which causes the shape to be altered by external forces (Collier, 1974:187). When acrylic fibres are heated, the modulus falls and they can be stretched easily. If this is done carefully, it is a reversible process, caused by the increased orientation of the polymer molecules.

When the fibre is cooled before tension is released, it remains in its stretched form. If the fibre is heated again, it will relax and return to its original length (Cook, 1984:408).

Acrylic fibres ignite and burn easily (Gohl and Vilensky, 1983:95). It burns with a yellow flame and form a gummy residue that drips from the burning fibre. The cold residue is hard, black and irregular in shape (Joseph, 1986:128). When burning, there is a chemical aromatic odour (Hollen and Saddler, 1973:76), and black smoke (Miller, 1992:52).

The melting point of the fibre is 232 to 255°C, depending on the type of fibre. Exposure to dry heat above 160°C can cause yellowing and discoloration (Joseph, 1986:128).

The flammability of acrylic fibres can be controlled by the comonomers. Vinyl bromide can be used to improve flame redundancy, or chemicals such as an aromatic chloro or bromo compound with an organic phosphorous compound, which is water insoluble, can be dispersed in the polymer solution before spinning. Other flame resistance formulations use a polybromocyclohexane or a brominated phosphonate and a water-insoluble calcium phosphate suspended in the polymer solution.

## **2.3.6 Chemical properties of acrylic:**

### **2.3.6.1 Effect of alkalis:**

Acrylic fibres have good resistance to weak alkalis (Baikeriar *et al.*, 1981). The mechanical properties of acrylic fibres are not influenced by dilute solutions of caustic soda or all solutions of sodium carbonate and bicarbonate. The fibres are attacked by strong concentrations of alkalis, which cause rapid degradation (Cook, 1984:408; Joseph, 1986:128).

### **2.3.6.2 Effect of acids:**

Acrylic fibres have good resistance to weak and diluted mineral and organic acids (Joseph, 1986:128). Concentrated solutions of strong mineral acids will damage the fibre when immersed for prolonged periods, but acrylic fibres are unaffected by dilute solutions (Cook, 1984:408). According to Tortora (1978:127) acrylic fibres will dissolve in nitric acid.

#### **2.3.6.3 Effect of bleach:**

Acrylics are not harmed by household bleaches (Tortora, 1978:127; Joseph, 1986:128), such as oxidizing and reducing bleaches that are used for stain removal (Lyle, 1976:44)

#### **2.3.6.4 Effect of sunlight:**

Acrylic fibres are not damaged by the effects of sunlight (Miller, 1992:51). After exposure of 600 hours, the fibre still has 96% of the original tenacity (Cook, 1984:408).

#### **2.3.6.5 Effect of perspiration:**

Acrylic fibres have excellent resistance to perspiration as it is resistant to weak alkalis (Corbman, 1983:484; Carter, 1971:116).

#### **2.3.6.6 Effect of water:**

Water affects the tensile properties of acrylic fibres. The tenacity can be reduced to 75 to 95% of the dry tenacity (Cook, 1984:407). Corbman (1983:469) found that acrylics lose up to 20% in strength when wet, but according to Press (1959:123) water has little effect on acrylic fibres.

#### **2.3.6.7 Effect of organic solvents:**

Acrylic fibres are resistant to most organic substances, but dimethyl formamide,  $\alpha$ -butyrolactone, dimethylsulphoxide and ethylene carbonate are solvents for acrylic fibres. Concentrated salt solutions like sodium and calcium thiocyanate, zinc chloride are also solvents for acrylic fibres (Cook, 1984:408).

### **2.3.7 Biological properties of acrylic:**

Insects are not attracted to acrylic fibres (Corbman, 1983:481). Acrylic fibres are not attacked by moth larvae (Cook, 1984:409) as long as it is not stored while contaminated by food stains (Cowan and Jungerman, 1969:89). Acrylic fibres are not attacked by micro-organisms (Cook, 1984:409; Cowan and Jungerman, 1969:89). If the fibre appears to get mouldy it is the finish on the fibre that forms mildew, and it will wash off readily without leaving a stain or damage (Corbman, 1983:481).

### **2.3.8 Care:**

Acrylic can be dry cleaned without damage, as long as the finish can't be removed by the chemicals used during dry cleaning procedures (Kadolph, 2002; Cook, 1984:419). Acrylics are sensitive to heat, therefore tumble drying is not recommended and pressing temperatures should be kept low (Tortora, 1978: 130).

## **2.4 Mixed Yarn Fabrics:**

A mixed fabric is a fabric that has yarn of one fibre content in the warp and yarn of different fibre content in the filling (Corbman, 1983:303).

When fibres are mixed it takes advantage of the attributes of each fibre in the blend. It is also economically feasible and influences the cost of the fibres in the blend, which affects the retail price of the final fabric (Azoulay, 2006:27).

Mixed fabrics can be developed to provide consumers with special performance characteristics or end-use requirements like appearance; to combine appearance and performance; easy care; to attract consumers who want to buy luxury fabrics for prestige or to reduce cost (Joseph, 1986).

Silk is blended with many fibres. When silk is blended, silk noils (short, tangled fibres) are used to make spinning possible because all the fibres are of staple length. The properties of these yarn and fabrics depend on the ratio of the blended fibres.

When silk is blended with another fibre it usually contributes a soft, smooth hand, lightness of weight with strength, resilience, comfort and good colouring possibilities. When silk and wool are blended, a worsted system is used. These fabrics have a soft sheen. They are lightweight, resilient, and durable, with good draping qualities (Corbman, 1983:303).

Acrylic forms part of blends for various reasons. Acrylic can provide the same warmth as wool, but with less weight and hairiness (Bogaty *et al*, 1953:538).

An acrylic blend fabric is resilient and wrinkle resistant but will retain creases and pleats. The acrylic will add strength if the fabric is not too bulky (Corbman, 1983: 407). The use of synthetic fibres in mixed fabrics increases the ease of wetting and the wicking rate of fabrics (Bogaty *et al*, 1953:539). The use of higher denier acrylic fibres offer advantages in yielding thicker, warmer and fuzzier blends which exhibit some degree of resistance to surface wetting by water (Bogaty *et al*, 1953:539).

When wool is blended with other fabrics, it contributes to warmth, resilience, abrasion resistance and drapability (Corbman, 1983:283).

Combining synthetic fibres with natural fibres will improve the care properties and durability of the fabric, while it reduces felting of the fibres, add lustre and reduces costs (Down, 1999).

# Chapter 3: Experimental Approach

## 3.1 Test materials:

All test methods were conducted on three sets of woven textile materials:

Fabric 1: *Gonometa postica* silk textile fabric:

The weft yarns of this fabric were hand spun *Gonometa postica* silk yarns, while the warp yarns were machine spun from *Gonometa postica* silk.

The fabric was hand woven using a plain weave with 44 warp yarns and 55 weft yarns per 100mm<sup>2</sup>. The weight of the fabric was 3.4691 grams per 100mm<sup>2</sup> consisting of 33% machine spun silk and 67% hand spun silk.

Fabric 2: Silk/Wool mixed yarn fabric:

The warp wool yarns are 100% merino wool and machine spun. These wool yarns are commercially available and the fibres have been subjected to chemicals and processes to enable it to be machine washable. The weft yarns were hand spun yarns from the *Gonometa postica* silk.

The fabric was hand woven using a plain weave with 43 warp yarns and 53 weft yarns per 100mm<sup>2</sup>. The weight of the fabric was 3.9424 grams per 100mm<sup>2</sup> consisting of 35% wool and 65% silk.

Fabric 3: Silk/Acrylic mixed yarn fabric:

The warp yarns are 100% Courtelle machine spun yarns. These acrylic yarns are also commercially available and according to the care label it can be machine washed, ironed on a low temperature and steamed. The fabric was hand woven using a plain weave with 43 warp yarns and 44 weft yarns per 100mm<sup>2</sup>. The weight of the fabric was 3.1900 grams per 100mm<sup>2</sup> consisting of 25% acrylic and 75% silk.

## **3.2 Test Methods**

### **3.2.1 Microscopic examination:**

The longitudinal views of the samples were prepared by placing the fibres on a glass microscope plate and covering it with microscope oil. Photos were taken with a Nikon TE 2000 Light microscope.

#### **➤ Photos taken with the SEM**

The samples were cut and glued to the stubs using metal glue. Care was taken to ensure that the samples could not move. The samples were left for 7 hours to ensure that the glue was dry, because any moisture could damage the sample and the machine pump.

The samples were then ready to be sputter coated; an important procedure where the samples are coated with a thin layer of gold to make the samples electrically conductive. The samples were placed in the Bio-rad SEM Sputter Coater and the lid was closed.

The air was pumped to create a vacuum and the argon gas was pumped into the vacuum until a pressure of  $6 \times 10^{-2}$  mBar was reached.

A plasma current was created by a stream of 18 mA which resulted in the gold plate becoming negative and the samples becoming positive. The argon collided with the gold plate releasing negative gold molecules, which were attracted by the positive samples that lead to the sputtering effect. Each sample was then coated with a layer of gold that is approximately 60 nm thick.

These samples were placed in the Scanning Electron Microscope where electrons were brought down onto the samples. The gold reflected the information into the detector, which create an image on the computer.

A Shimadzu SSX 550 Superscan Scanning Electron Microscope was used, as well as a Jeol WINSEM 6400 Scanning Electron Microscope.

### **3.2.2 Abrasion resistance:**

The Martindale wear and abrasion tester was used with ASTM Test Method 4966. This test method determines the abrasion resistance of textiles. The abrasion resistance of textiles is one of the factors contributing to the wear performance or durability of a textile fabric. The Martindale abrasion tester rubs the test samples in numerous directions. The path is circular and changes gradually through a series of narrowing ellipses until the motion is a straight line. The motion develops again through the ellipses until the motion is circular. This type of motion ensures that the test sample is rubbed in all directions, not merely warp or weft way.

The motion also alters continually to ensure that all the fibres are flexed in all directions, and not merely stroked in one direction (Martindale, 1942: 154).

Kalaoglu (2003: 980) found that when circular test samples are abraded under known pressure against a standard abrading fabric, such as the Martindale, very accurate results are provided which closely reflect the changes occurring in actual wear.

Therefore the test procedure was conducted with twelve circular samples with a diameter of 38mm which were punched from the test materials and conditioned at  $21 \pm 1^{\circ}\text{C}$  and  $65 \pm 2\%$  relative humidity for 24 hours.

Before abrasion, the samples were weighed. Four samples at a time were abraded against the standard abrasive material which consists of 100% wool, under a pressure of 9 kPa, until at least two yarns were broken. The standard abrasive material was replaced every 50 000 rubs. Each sample were judged individually to the nearest 1 000 rubs. After abrasion the samples were conditioned for 24 hours and weighed again.

### **3.2.3 Tensile strength:**

The maximum force required to break the samples and elongation at maximum force were determined using the ISO 13934 test method and the Instron Tensile Tester.

Eighteen 5cm x 20cm samples were taken from each of the test fabrics, nine with their long side parallel to the warp yarns and the other nine with their long side parallel to their weft yarns.

The samples were cut carefully ensuring that all the samples contain equal numbers of threads. Test samples were conditioned at  $21 \pm 1^\circ\text{C}$  and  $65 \pm 2\%$  relative humidity for 24 hours.

The gauge length of the testing machine was set at 100mm; the rate of extension was set at 100 mm/min, while the ramp rate was 20 kN/min.

The samples were placed centrally to ensure that the longitudinal centre-line passes through the centre point of the front edges of the jaws of the Instron tester. The clamps are put in motion and it extended the samples to the point of rupture and the following were recorded: a) point of rupture; and, b) the elongation at rupture.

### **3.2.4 Stiffness:**

The Shirley Stiffness tester was used with the British Test Method 3356. The bending length was measured which is an accurate way of expressing stiffness. The bending length is the length a sample is required to overhang to produce a reflection through a predetermined angle.

Twenty 25mm x 150mm samples were taken from each of the test fabric. Ten of the samples were taken with their long side parallel to the weft and the other ten with their long side parallel to the warp. Samples were cut in such a way that all the warp samples didn't contain the same warp yarn and the weft samples so that different weft yarns are contained in each sample. The samples were conditioned at  $21 \pm 1^\circ\text{C}$  and  $65 \pm 2\%$  relative humidity for 24 hours.

The tester was placed horizontally on a table as indicated by the levelling bubble. A sample of the test material was placed on the platform with the weight on top and the leading edges to coincide. The sample was slid along the horizontal platform until it bent to reach the corresponding lines reflected in the mirror.

The numerical value of the bending length is taken in centimetres. The samples had the tendency to twist and therefore the reference point was taken at the centre of the edge.

Four readings were taken from each sample, with each side up, first at the one end and then the other. These readings represent the bending length of the test fabric.

The flexural rigidity ( $G$ ) was also calculated separately for weft and warp directions by the following formulae:

$$G = 0.10 W C^3 \text{ mg cm}$$

Where  $W$  = cloth weight in g/sq m

$C$  = mean bending length

### **3.2.5 Crease recovery:**

The Shirley crease recovery tester was used with the AATCC Test Method 66. The wrinkle recovery is measured as the angle recovered from folding deformations.

Twenty 15mm x 40mm test samples were taken from each test fabric, ten of the samples with their long side parallel to the warp and the other ten with their long side parallel to the weft.

The test samples were conditioned flat and free from wrinkles for 24 hours at  $21 \pm 1^\circ\text{C}$  and  $65 \pm 2\%$  relative humidity.

The sample was folded end to end and held with tweezers, gripping no more than 5mm from the ends. Half of the samples were folded face to face and the other half back to back.

The samples were then placed on the marked area of the lower plate of the loading device and the load applied gently and without delay. The sample was left for five minutes, and then the load was removed quickly and smoothly. The sample was removed with the tweezers and transferred to the sample holder by placing one arm of the sample in the holder while the other end hanged free.

The dial was adjusted to keep the free limb of the sample in a vertical position and in line with the indicator. The reading was taken after five minutes and this is the crease recovery of the sample.

### **3.2.6 Fabric thickness:**

The thickness of the test fabric was determined with the Essdiel thickness gauge using BS Test Method 2544. This method will determine the thickness of a compressible material under pressure.

Ten 15mm x 40mm test samples were taken from each of the test fabrics. The test samples were conditioned for 24 hours at  $21 \pm 1^\circ\text{C}$  and  $65 \pm 2\%$  relative humidity. The presser foot was gently raised and the sample was placed underneath it. The presser foot was then gently lowered onto the sample and left for 30 seconds.

The presser foot was then screwed down until the light came on, the dial reading was then taken, and this represents the thickness of the fabric in mm.

### **3.2.7 Moisture regain:**

The moisture regain was determined by weight-loss using a drying oven and test method ASTM D2654.

Ten 25mm x 100mm test samples were taken from each of the test fabrics, and conditioned at  $21 \pm 1^\circ\text{C}$  and  $65 \pm 2\%$  relative humidity for 48 hours. The test samples were placed in a drying oven at  $105^\circ\text{C}$  and then weighed every hour until no more weight loss occurred. Care was taken not to expose the samples to moisture during the weighing process.

The moisture regain of the samples were then determined using the following calculation:

$$\text{Moisture regain} = \frac{(\text{weight of sample before drying} - \text{weight of oven-dry specimen})}{\text{weight of oven-dry sample}} \times 100$$

### **3.2.8 Dimensional change:**

#### **a) Water:**

Dimensional changes (shrinkage), felting and relaxation were measured using AATCC Test Method 99.

Ten 50mm x 150mm test samples were taken from each of the test fabrics in both warp and weft directions.

For relaxation shrinkage, the test samples were agitated in water at  $38^\circ\text{C}$  with ECE Phosphate Reference Detergent for two hours. The wet samples were removed and excess water distracted.

The test samples being woven fabrics were therefore dried using a flat-bed press at a temperature of 135-149°C, without stretching or distorting the fibres.

The samples were measured after conditioning for 24 hours at  $21 \pm 1^\circ\text{C}$  and  $65 \pm 2\%$  relative humidity. Then the relaxation shrinkage was calculated:

$$\text{Relaxation shrinkage} = \frac{\text{Original measurement} - \text{relaxation measurement}}{\text{original measurement}} \times 100$$

To determine felting or progressive shrinkage the test samples were again agitated in the liquor and dried. After conditioning for 24 hours the samples were measured.

**b) Steam:**

AATCC Test Method 99 was adjusted in order to determine shrinkage caused by steam. Ten 50mm x 150mm test samples were taken from each of the test fabrics in both warp and weft directions and conditioned at  $21 \pm 1^\circ\text{C}$  and  $65 \pm 2\%$  relative humidity for 24 hours. The test samples were exposed to steam for 30 seconds using a steam iron. The samples were then dried using a flat-bed press at a temperature of 135-149°C, without stretching or distorting the fibres. The samples were measured after conditioning for 24 hours, and the relaxation shrinkage was calculated. This process was repeated to determine progressive shrinkage.

### **3.3 Statistical analysis**

Statistical analysis was done to support the interpretation of the results that were obtained. Analysis of variance (ANOVA) was used as it uncovers the main and interaction effects of categorically independent variables (factors) on an interval dependent variable. The ANOVA analysis determined whether the difference in sample means was big enough to conclude that a significant difference exists between the groups. A “sig.” or probability value of 0.05 or less leads to the conclusion that the effect is significant and not due to a change in sampling (Viljoen and Van der Merwe, 2000:12-1).

## Chapter 4: Results and Discussion

The *Gonometa postica* silk possesses a unique combination of properties resulting in a very desirable fabric. Unfortunately silk fabrics are very expensive as the processes of gathering the cocoons, sorting, degumming and reeling are all labour intensive actions and the yarns and fabric still needs to be manufactured. Therefore to make this fabric more affordable, mixed yarn fabrics were created: a *Gonometa postica* silk weft/wool warp fabric and a *Gonometa postica* silk weft /acrylic warp fabric. These two fabrics are being compared to the *Gonometa postica* silk fabric by identifying important properties of the three fabrics and then evaluating it. It is important that the fibre, with which the silk are mixed to make it more affordable, doesn't impair on the silks' properties.

The literature shows that silk possesses a unique combination of beauty and strength, but unfortunately very little is known about the properties of *Gonometa postica* silk. Therefore it is important to determine the properties of the *Gonometa postica* silk, and that these properties should not be influenced negatively in the mixed yarn fabric. This highlights the importance in determining which tests to be conducted. This project will evaluate the abrasion resistance, as it portrays the fibres' ability to resist deterioration by everyday wear. Tensile strength is also important because silk is reported as the strongest natural textile fibre, but the tensile strength of the *Gonometa postica* silk is unknown. The thickness of a fabric will influence its behaviour, for instance crease recovery.

Crease recovery is a very important property as this will influence the aesthetic properties and desirability of the fabric. Stiffness will also influence the aesthetic property of the fibre in terms of bending and draping qualities.

The moisture regain of each fabric will also be determined as no literature could be found on what the moisture regain of the *Gonometa postica* silk is, or the *Gonometa postica* silk weft/wool warp fabric and *Gonometa postica* silk weft/acrylic warp fabric. The results obtained from the tests are expressed graphically and where possible with Scanning Electron Microscope photos.

The longitudinal view and cross-sectional view of the fibres were examined and compared to what is expressed in the literature.

## 4.1 Microscopic examination

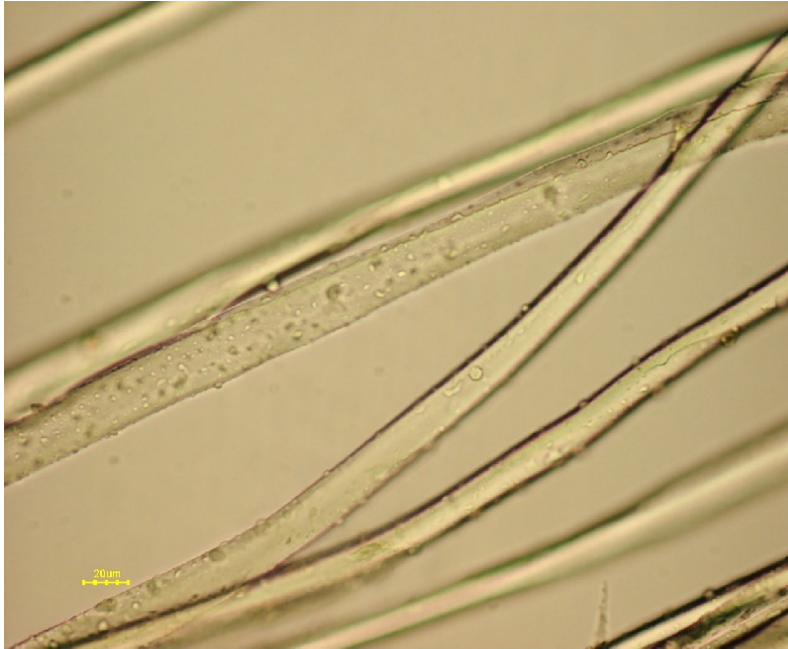


Photo 1: The longitudinal view of the *Gonometta postica* silk as seen under a light microscope.

A smooth surface is observed with no shadows indicative of individual filaments. One of the fibres shows a flattened area which can be due to the triangular form of the fibres.

The fibres shown in photo 1 vary in size which can be attributed to the fact this it is a natural fibre. This aligns with the literature which indicates that the longitudinal view of wild silk shows a slightly coarse fibre, with an irregular diameter and slight striations (Kadolph and Langford, 2002:62).

This variation in diameter can also be seen in Photo 2(a) and (b) showing the diameter of the *Gonometta postica* silk fibres varying between 15 to 25 $\mu\text{m}$ .



Photo 2(a): The cross-sectional view of the *Gonometta postica* silk as seen under a light microscope.

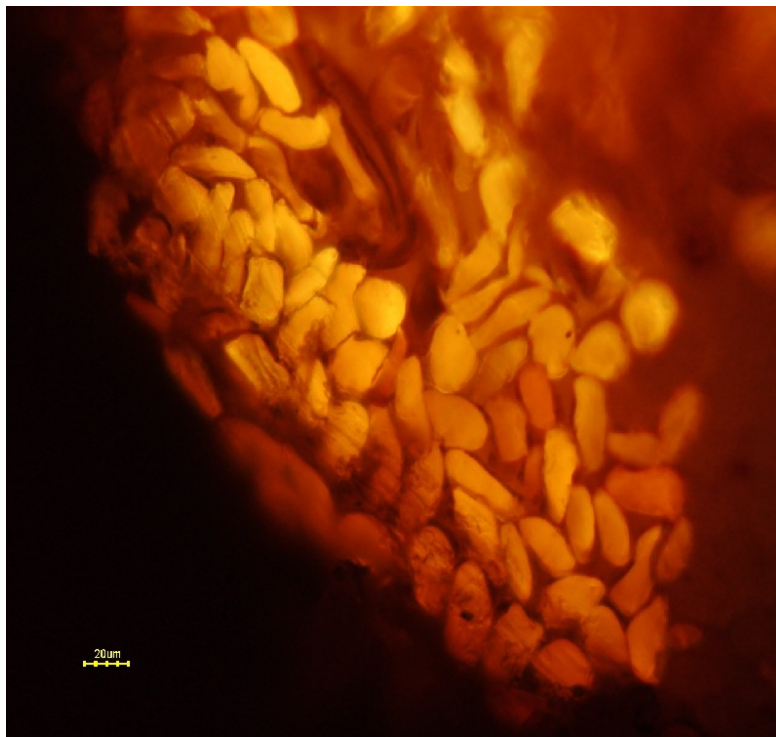


Photo 2(b): The cross-sectional view of the *Gonometta postica* silk as seen under a light microscope.

The cross-section of the *Gonometa postica* silk in photos 2a and 2b shows a variety of flattened and triangular shapes. This could be due to the softness of the fibres when emerging from the spinnerets, and also could have been flattened when the cocoon was shaped as Brick (1975:785) explained. This result agrees with the literature that indicates that the degummed cross-section of silk fibres appear triangular with rounded angles (Cook, 1984:159). According to Kadolph and Langford (2002:63) Tussah silk is less regular in cross-section than cultivated silks.

As seen in photo 2a the colour of the *Gonometa postica* silk are shades of yellow, gold and brown. The colour of the silk in photo 2b can be described as tan. This is also in accordance with literature that indicates that Tussah silk is darker in colour than cultivated silks (Kadolph and Langford, 2002:63) According to Corbman (1983:301) it is the tannin in the leaves that the wild silkworms eat that gives the wild silk a tan colour.

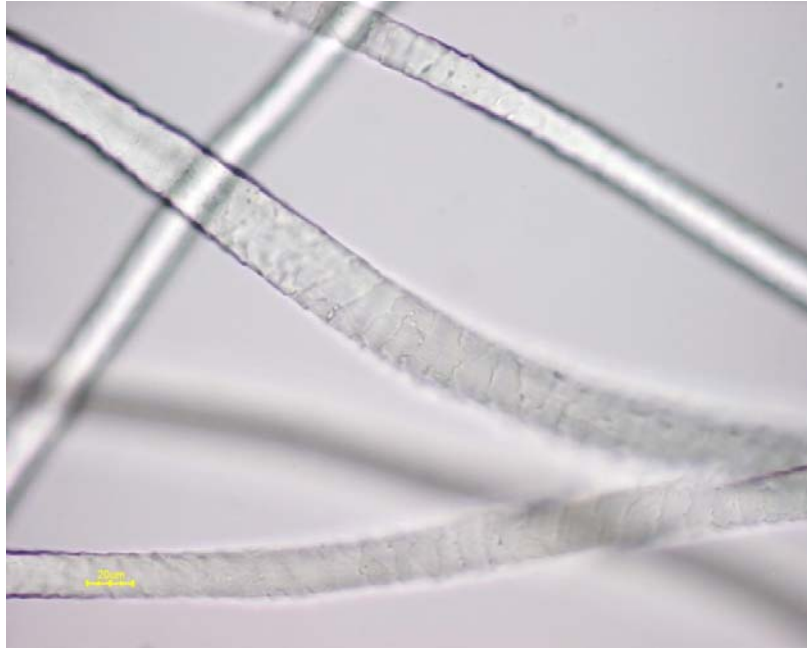


Photo 3: The longitudinal view of the wool fibre as seen under a light microscope.

The scale structure of the wool fibres is seen in photo 3, and indicates that the scales are irregular in shape and overlap each other. The scales seem to have been flattened and it is not as clear as was expected. Irregular widths are seen as can be expected from a natural fibre. This is in accordance with the literature that indicates that the wool fibre is a cylindrical shape, tapered from root to tip and covered with scales (Ito *et al*, 1994:440). The scales are irregular in shape and they overlap each other while facing to the tip of the fibre (Silva *et al*, 2006:634).

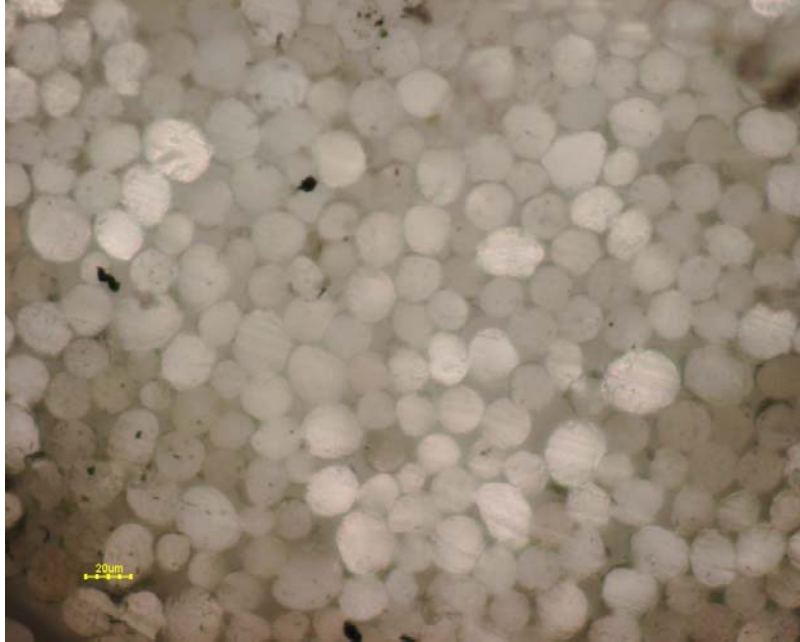


Photo 4: The cross-sectional view of the wool fibres as seen under the light microscope.

The cross-section of the wool fibres as seen in photo 4 is circular to oval in shape. The cross-section shows the varying diameters of the fibres. This agrees with the literature that suggests that the cross-section of the wool fibre is nearly circular and in some cases even oval in shape (Joseph, 1986:49).

According to the literature these fibres could be described as mostly fine (Joseph, 1986:50) because 15 to 17 $\mu\text{m}$  is classified as fine, while 24 to 34 $\mu\text{m}$  is described as medium quality wool, and these wool fibres range from 15 to 20 $\mu\text{m}$ .



Photo 5: The longitudinal view of the acrylic Courtelle fibre as seen under a light microscope.

The Courtelle fibres have a smooth appearance and all the fibres are the same size. The ridge formed by the bean shape of the fibres can also be seen on the longitudinal view on photo 5. This is in accordance with the literature as it indicates that the longitudinal appearance of acrylic shows a smooth surface and uniform diameter (Joseph, 1986:127).

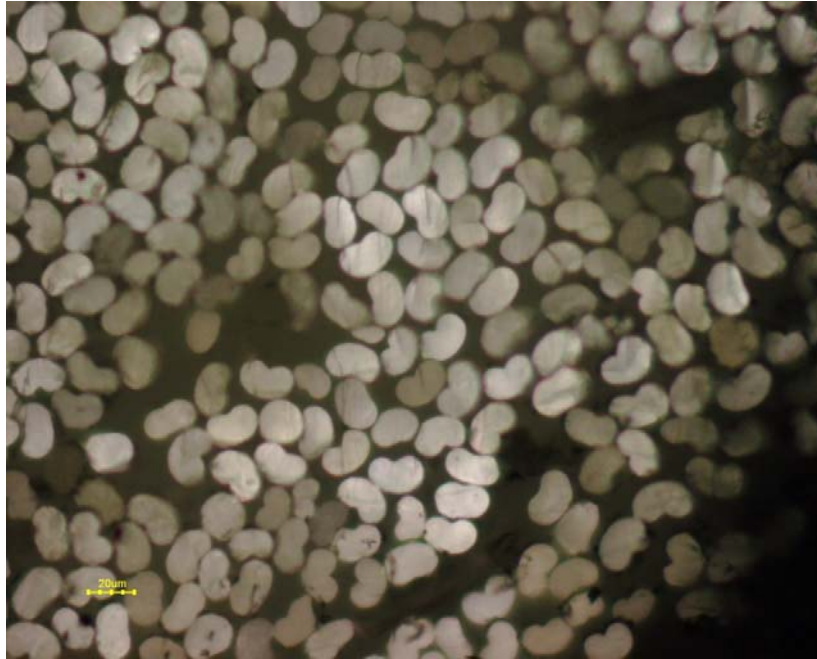


Photo 6: The cross-sectional view of the Courtonne acrylic as seen under the light microscope.

Photo 6 clearly shows that the Courtonne has a bean shaped cross-section. All the fibres are nearly the same size, about 20  $\mu\text{m}$ , due to the fact that it is a man-made fibre. This is in accordance with the literature that indicates that the cross-sectional shape of acrylic fibres vary as a result of the production process that was used. The wet spinning process leads to round or bean shaped fibres (Kadolph and Langford, 2002:113) Courtonne fibres are not round, but bean shaped. The characteristics of acrylic fibres can be varied by controlling the production process and the shape of the cross-section (Cook, 1984:405).

## **4.2 Abrasion resistance**

According to Alpay *et al.* (2005:607) abrasion is “the mechanical deterioration of fabric components by rubbing against another surface”.

Abrasion is a result of deformations due to compression, tension, bending, shear and cutting (Susich, 1954:210). The wear of a test sample is a consequence of interaction between the abrading surface, the geometry of yarn and fabric structure, the normal load and the material properties of the fibres (Varela *et al.*, 1975:303).

Anderson *et al.* (1972:115) found that with Martindale abrasion testing there is a close similarity between the changes occurring during actual wear and testing. Loss in weight and fabric thinning during testing is caused by the production and removal of short fibres. Besides loss of weight, the structure is disturbed, resulting in area shrinkage of the fabric (Ukponmwan, 1987: 445).

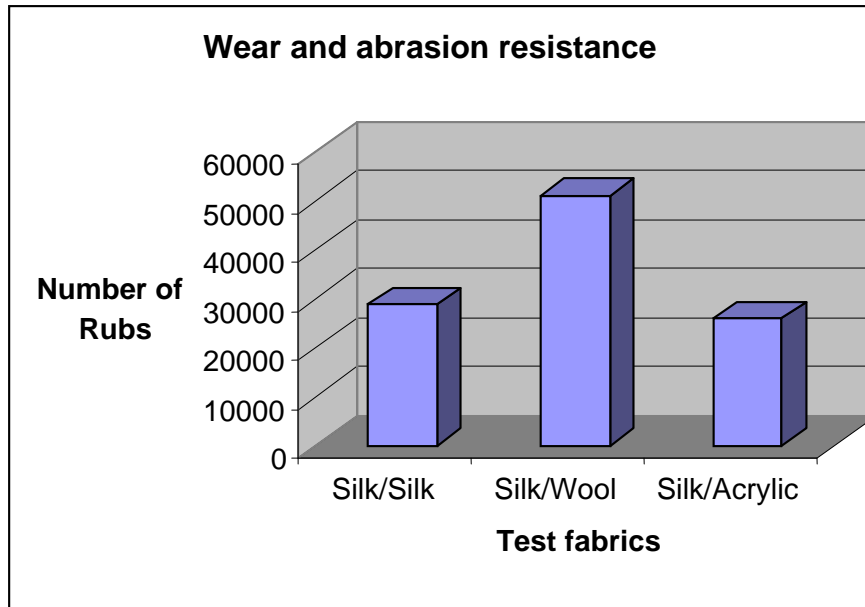


Figure 1: The abrasion resistance of the *Gonometa postica* silk fabric, *Gonometa postica* silk weft/wool warp fabric and *Gonometa postica* silk weft/acrylic warp fabric using the Martindale wear and abrasion tester.

Figure 1 illustrates the difference in the number of rubs with the Martindale wear and abrasion tester that were needed to break two yarns in the test samples. It is clearly shown in figure 1 that the *Gonometa postica* silk weft/wool warp mixed yarn fabric required the highest number of rubs to break. The *Gonometa postica* silk fabric and the *Gonometa postica* silk weft/acrylic warp mixed yarn fabric required a lot less rubs to break.

#### The *Gonometa postica* silk test fabric:

The *Gonometa postica* silk textile fabric had relatively good abrasion resistance, with a mean value of 28 750 rubs necessary to break two yarns. This was expected as wild silk has good abrasion resistance that can be attributed to the smooth surface of the filaments (Potter and Corbman, 1967).

The harsh methods of sericin removal can cause fibre degradation which result in a loss of strength (Freddi *et al*, 2003:103). The sericin is a glue-like protein that assists the yarn to resist abrasion (Textile Institute, 1991:12), but all the sericin was removed from these samples and it still withstood 28 750 rubs.

The molecular arrangement of silk is highly oriented, which gives the fibre high strength, but the strength of silk fabrics is affected by construction and finish (Potter and Corbman, 1967:272).

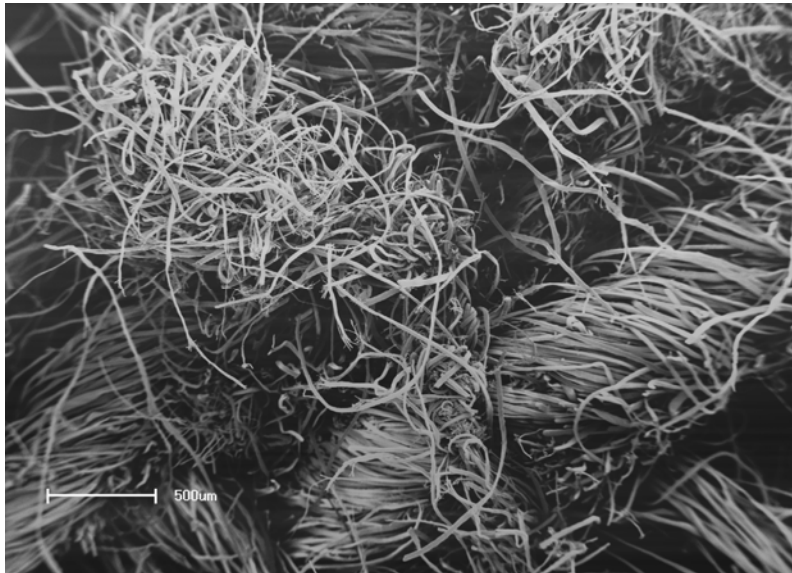


Photo 7(a): A scanning electron micrograph of the entanglement of fibres on the surface of the *Gonometa postica* silk test fabric that was caused by abrasion by the Martindale wear and abrasion tester.

Photo 7(a) shows that abrasion lead to the gathering and entanglement of the fibres on the fabric surface. These entangled fibres then formed balls or pills that stood up on the surface of the fabric.

It is due to the curling of loosened fibre ends which with wear and abrasion form pills on the fabric surface (Dennison & Leach, 1952:489).

Gintis and Mead (1959:580) found that for a fibre end to pull out of the yarn construction it has to overcome interfibre frictional forces and it has to bend to work its way under and over cross-yarns of the fabric. Fibres which resist this bending have increased frictional restraining forces. When the restraining force exceeds fibre breaking strength, the fibre will rather break than pull out. Silk has a high tenacity and therefore will rather pull out than break.

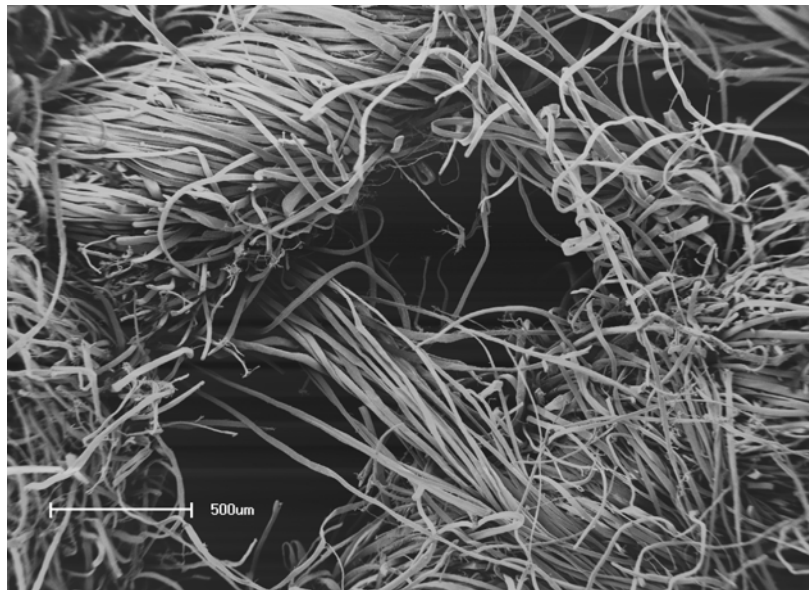


Photo 7(b): A scanning electron micrograph of the fabric structure of the *Gonometa postica* silk test fabric after being abraded with the Martindale wear and abrasion tester until two threads were broken.

The fabric structure of the broken *Gonometa postica* silk test sample is shown in Photo 7(b). It clearly shows the yarn that is abraded until there is only a small strand of fibres left.

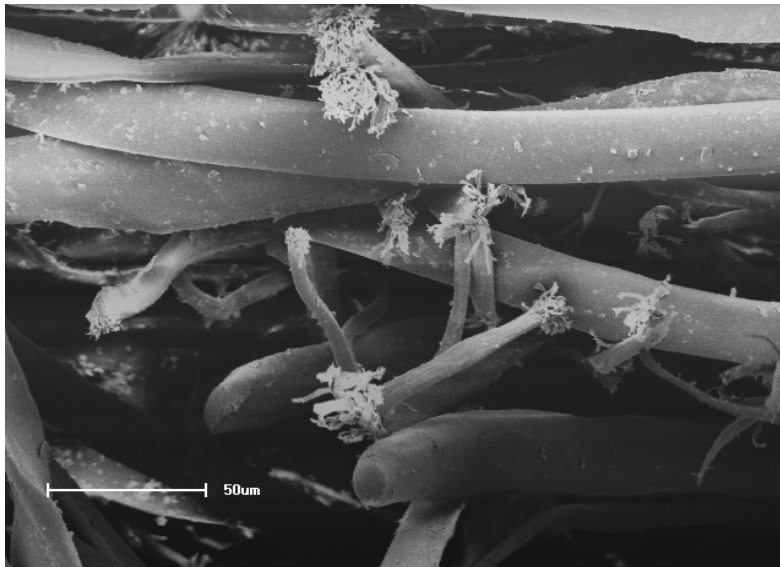


Photo 7(c): A scanning electron micrograph of the broken *Gonometta postica* silk fibre ends that appear between the strong unbroken fibres.

The loose broken fibres that cause fuzz are shown in Photo 7(c). Cooke (1985: 409) indicated that fuzz like this causes pilling as a result of the brushing up of free fibre ends, and the conversion of fibre loops into free fibre ends by pulling it out.



Photo 7(d): A scanning electron micrograph of a broken *Gonometta postica* silk fibre end showing the fibrillar structure.

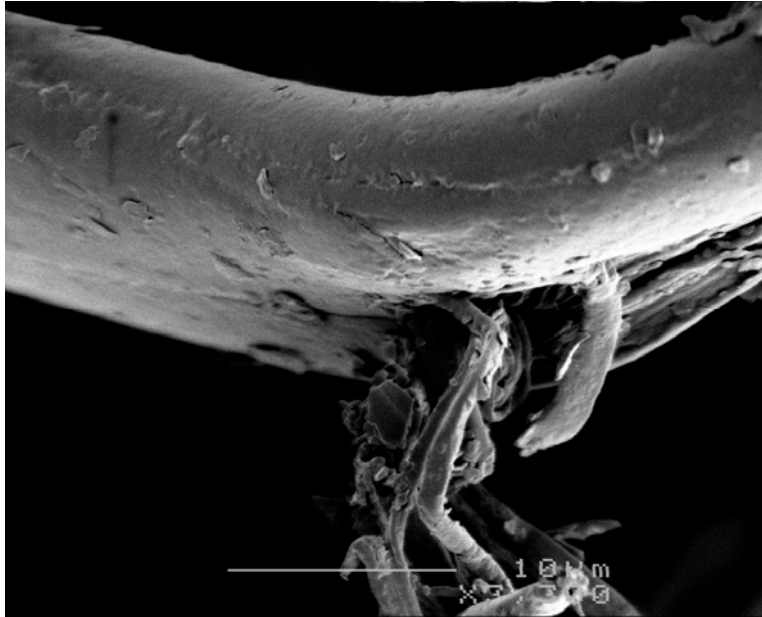


Photo 7 (e): A scanning electron micrograph of a damaged *Gonometa postica* silk fibre as a result of the abrasion.

The abrasion caused the fibres in photo7 (d) and (e) to break and fibrils are shown on the broken edge. Silk has a layered structure with a cross angle between the nanofibrils in different layers. The geometric mean fibril widths is between 90-170nm (Putthanarat *et al*, 2000:7735). The fibrils of wild silks are less closely held together than in cultivated silk (Cook, 1984:158). Such a multifibrillar fibre has mechanical advantages over a solid fibre of the same cross-sectional area. The fibre has greater flexibility and requires less energy to bend. The fibre can also be bent to a smaller minimum radius before failure occurs on the outside of the bend or compression on the inside of the bend. This is due to the shear involved in bending, which can be accommodated with little stress in the weakly bonded inter-fibril boundaries of a nanofibrillar fibre like silk (Putthanarat *et al*, 2000:7746).

This explanation of Putthanarat further explains the number of rubs necessary to break the silk fibres.

The *Gonometa postica* silk weft/wool warp test fabric:

As illustrated in figure 1, the *Gonometa postica* silk weft/wool warp test fabric showed very good abrasion resistance with a mean value of 51 000 rubs required to break two yarns. This was also expected as it is well known that wool fibres possess very good abrasion resistance because of the irregular, overlapping scales which resist deteriorating influences (Joseph, 1986; Hall, 1969:15). According to Smith and Block (1982:93) the scale structure of wool gives the fibre excellent abrasion resistance. Manich *et al.* (2001:470) reports between 11 000 and 71 000 rubs to break two yarns in wool fabrics.

Therefore, it is not surprising that the statistical analysis indicates, as shown in table 1, that there was a significant difference between the number of rubs to break two yarns of the *Gonometa postica* silk fabric and the *Gonometa postica* silk weft/wool warp fabric, with the p-value < 0.05.

Table 3: Anova of the number of rubs needed to break the silk/silk fabric and the *Gonometa postica* silk weft/wool warp fabric.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	12	28750	6454.385	1863.221	
Silk/wool	12	51000	5608.435	1619.016	.000

Wool requires higher work input to cause rupture, despite its low tenacity. Its elastic behaviour is excellent and no appreciable loss in work absorption occurs in the repeated tensioning of wool. This explains the low abrasion damage of wool (Susich, 1954:210).

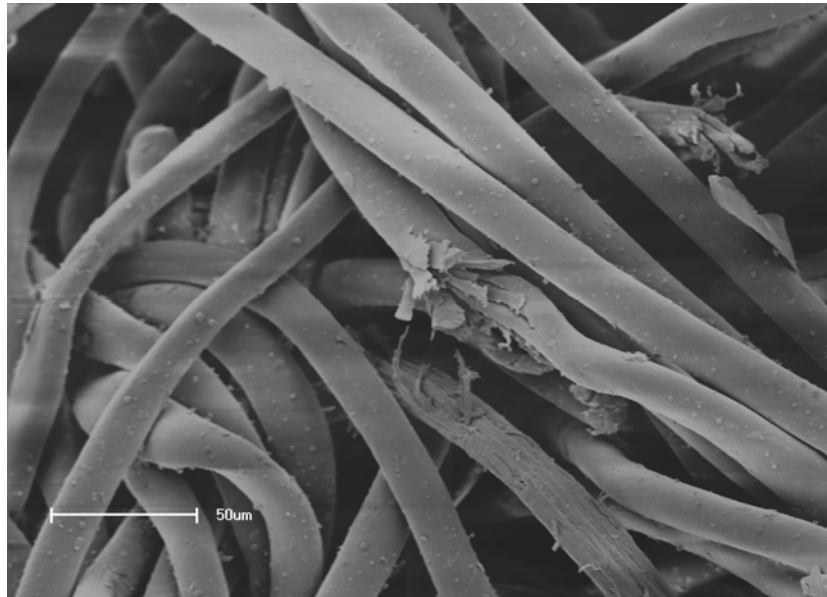


Photo 8(a): A scanning electron micrograph of the beginning of damage caused to silk and wool fibres as a result of abrasion.

There are still lots of undamaged fibres while it is clear to see some of the fibres that have been damaged by the abrasion.

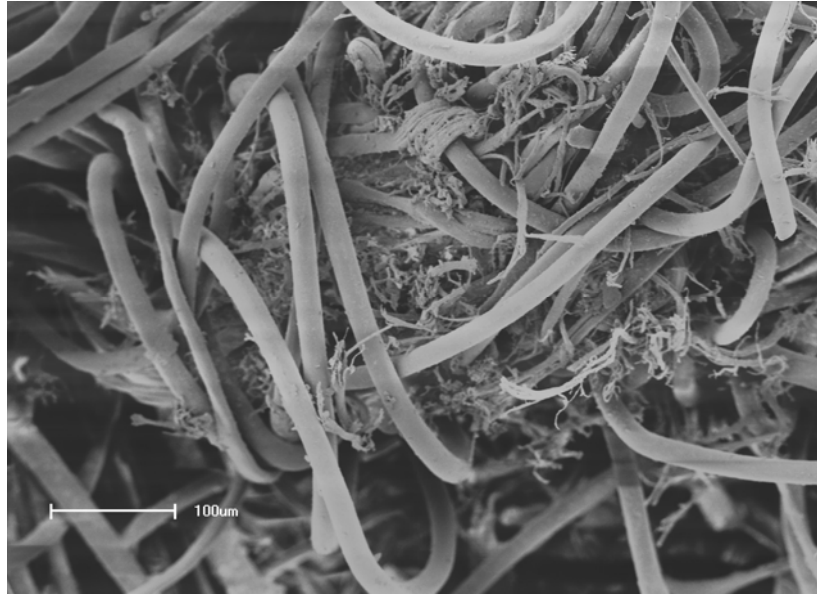


Photo 8(b): A scanning electron micrograph of the formation of fuzz by the broken and worn yarns in the *Gonometta postica* silk weft/wool warp test fabric as a result of the Martindale abrasion.

This photo shows the damage caused to the yarn by abrasion. The worn, damaged fibres are forming fuzz between the less damaged fibres in the yarn structure. Anderson *et al.* (1972:115) found that during wear and machine-testing of wool fabrics some morphological changes occurred such as scale removal, fibrillation of fibres and rounding of fibre ends. The failure of wool fibres during wear or Martindale flat abrasion initially occurs along the intercellular boundaries. It is suggested that the intercellular regions influence mechanical properties such as abrasion resistance and torsion fatigue (Feldtman and Leeder, 1984:26).

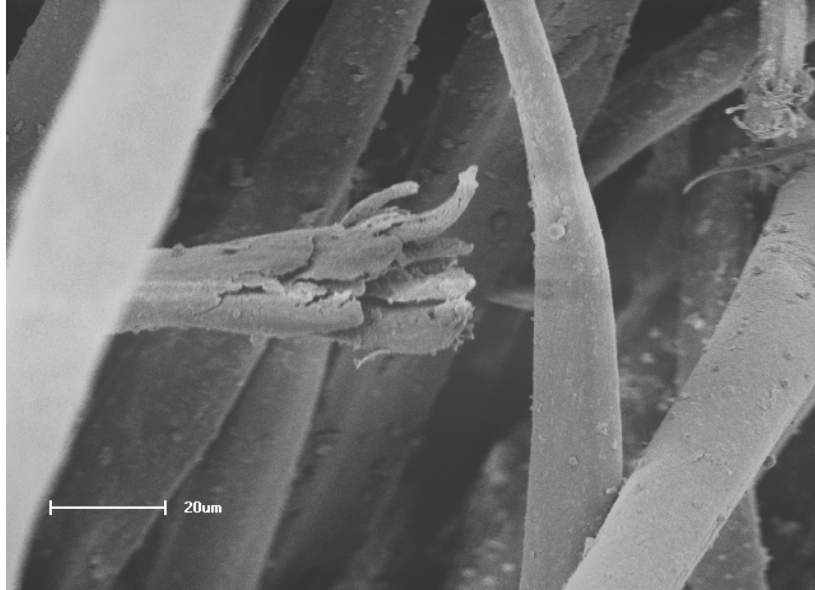


Photo 8(c): A scanning electron micrograph of a broken wool fibre end caused to break by the abrasion.

This broken wool fibre shows a fibrillar network. These results were expected as literature reports similar results by Anderson *et al.* (1972:115) who found morphological changes like fibrillation of fibres and rounding of fibre ends, as a result of the abrasion.

The *Gonometa postica* silk weft/acrylic warp test fabric:

The *Gonometa postica* silk weft/acrylic warp test fabric also showed relatively good abrasion resistance with a mean value of 25917 rubs although it was lower than the other test fabrics.

The statistical analysis indicates, as shown in table 2, that there was no significant difference between the number of rubs needed to break two yarns of the *Gonometa postica* silk fabric and the *Gonometa postica* silk weft/acrylic warp fabric, with the p-value  $> 0.05$ .

Table 4: Anova of the number of rubs needed to break the *Gonometa postica* silk fabric and the *Gonometa postica* silk weft/acrylic warp fabric.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	12	28750	6454.385	1863.221	
Silk/acrylic	12	25916.67	2998.737	865.661	.424

Acrylic is a synthetic fibre and therefore the filaments are of uniform diameter and have a smooth surface (Joseph, 1986:127). This smooth surface contributes to abrasion resistance. Acrylic is durable with a high resistance to abrasion damage (Corbman, 1983:468).

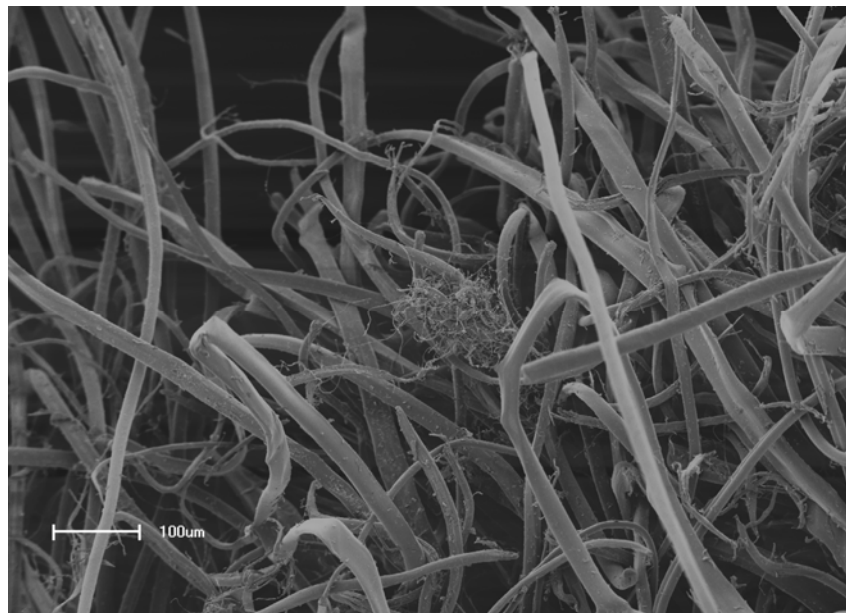


Photo 9(a): A scanning electron micrograph of broken fibres of the *Gonometa postica* silk weft/acrylic warp test material that was caused by abrasion.

It is clear to see in photo 9(a) that the signs of fuzz formation are there. During abrasion some of the fibres broke quickly, while others were bent and flattened to resist the abrasion. This was expected as literature indicates that pilling is a problem with acrylics (Stout, 1970). The first process of pilling is fuzz formation, where loose fibres form on the surface of the fabric (Baker, 2002: 1314).

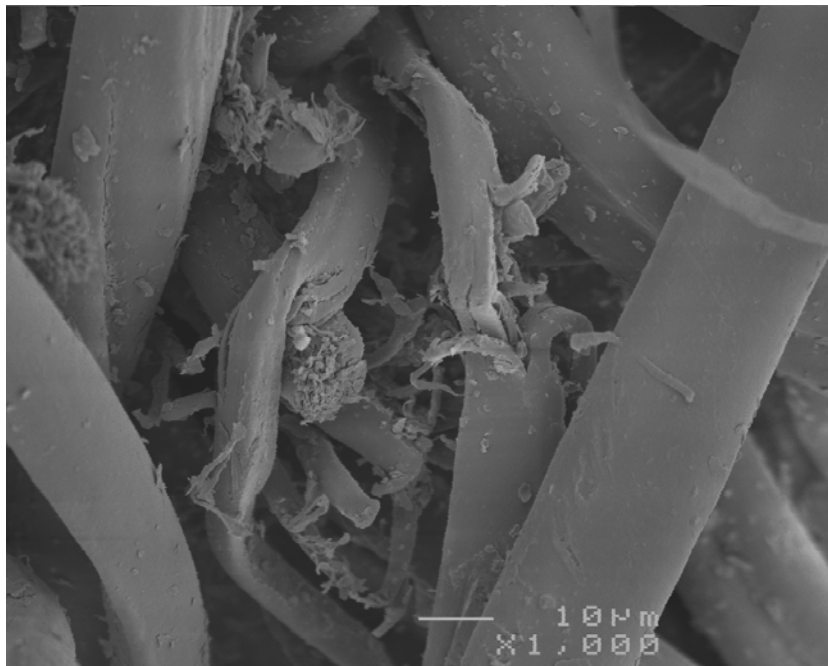


Photo 9 (b): A scanning electron micrograph of damaged fibres of the *Gonometa postica* silk weft/acrylic warp test fabric as a result of the abrasion.

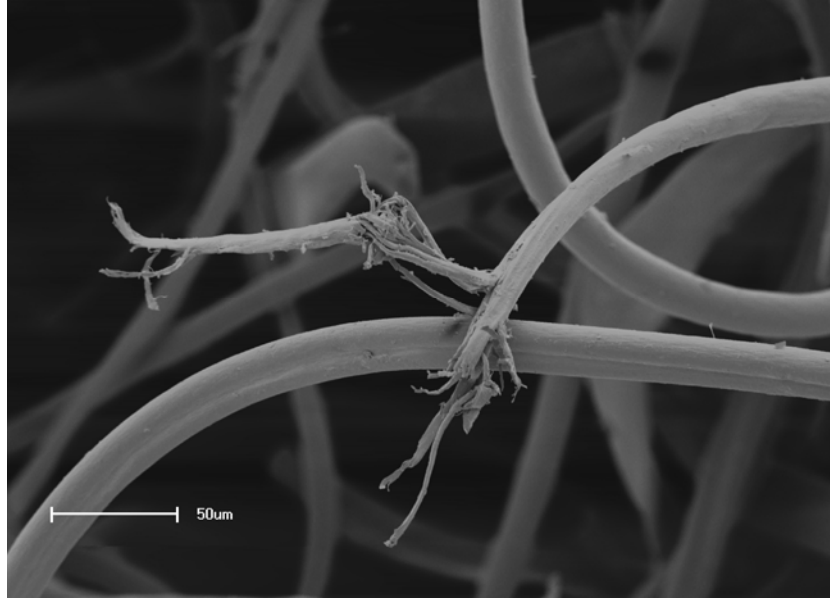
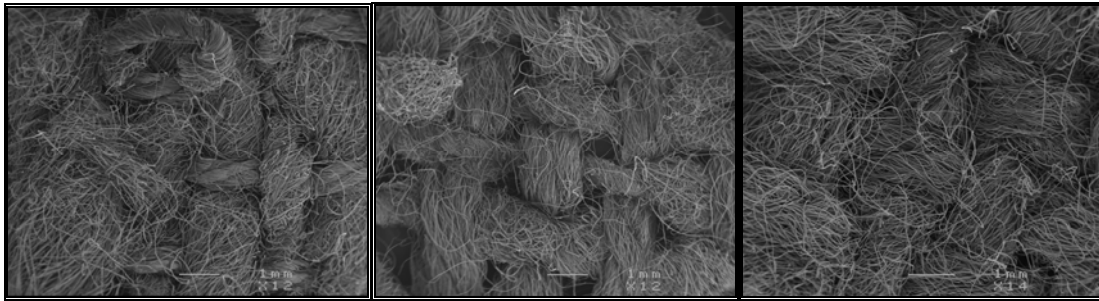


Photo 9(c): A scanning electron micrograph of a damaged and broken acrylic fibre as a result of abrasion.

The scanning electron microscope is a powerful tool in the study of surface features of fibres (Varela *et al*, 1975:303). All of the fibres showed fibrillation on the broken fibre end, as was illustrated in photos 7d, 8c and 9b, which shows that they all have a fibrillar network in their construction, but yet, they all had different behaviour.

To make it possible to compare the *Gonometa postica* silk test fabrics with the *Gonometa postica* silk/wool warp fabric and *Gonometa postica* silk weft/acrylic warp fabric, it was necessary to see and evaluate these fabrics after the same amount of abrasion.

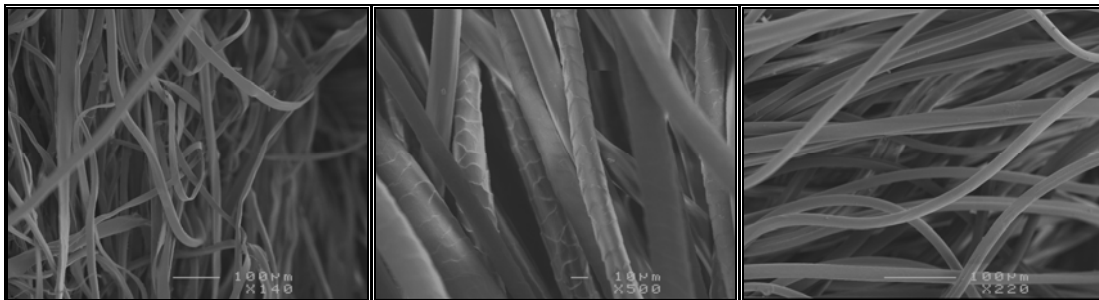


(a)Silk/silk fabric

(b)Silk/wool fabric

(c)Silk/acrylic fabric

Photos 10(a-c): Scanning electron micrographs of the test fabrics before any abrasion.



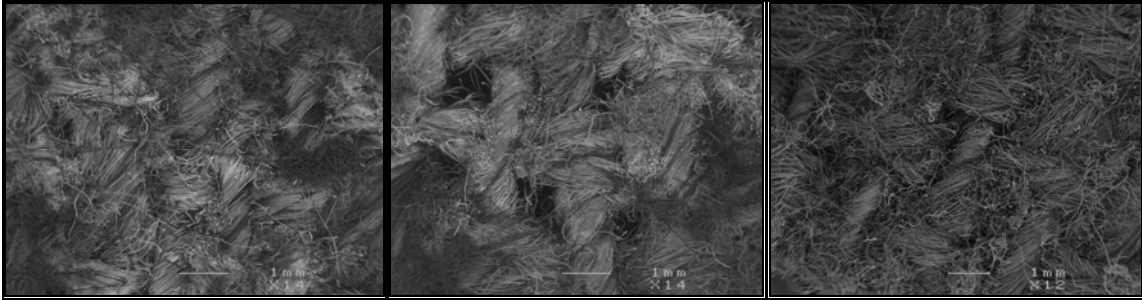
(a)Silk/silk fabric

(b)Silk/wool fabric

(c)Silk/acrylic fabric

Photos 11(a-c): Scanning electron micrographs of the undamaged fibres of the test fabrics.

Photos 10 and 11 show the test fabrics before any cycles by the Martindale wear and abrasion tester, with no damage caused to these fibres by abrasion and all the yarns are still in tact.



(a)Silk/silk fabric                      (b)Silk/wool fabric                      (c)Silk/acrylic fabric

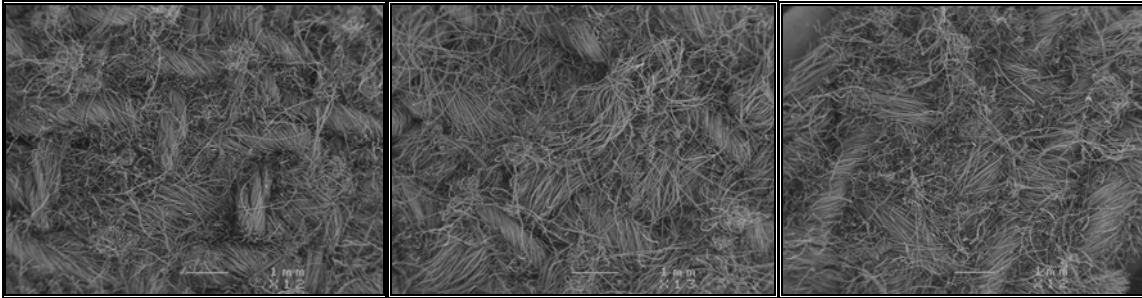
Photos 12(a-c): Scanning electron micrographs of the test fabrics after 10 000 rubs with the Martindale wear and abrasion tester.



(a)Silk/silk fabric                      (b)Silk/wool fabric                      (c)Silk/acrylic fabric

Photos 13(a-c): Scanning electron micrographs of the damaged fibres of the fabrics after 10 000 rubs.

After 10 000 rubs the *Gonometa postica* silk fabric showed some damage as there are gathering of fibres on the surface of the fabric and the *Gonometa postica* silk weft/wool warp fabric only showed minor damage and hairiness on the fabric surface. This could be expected as Manich *et al.* (2001:469) found that abrasion modifies the fabric surface first and then affects the internal structure of the fabric. The *Gonometa postica* silk weft/acrylic warp fabric showed the most damage and it also indicated entangling and fuzz formation. This is in accordance with the literature that indicates that pilling can be a problem with acrylic fibres (Stout, 1970).



(a)Silk/silk fabric                      (b)Silk/wool fabric                      (c)Silk/acrylic fabric

Photos 14(a-c): Scanning electron micrographs of the test fabrics after 20 000 rubs with the Martindale wear and abrasion tester.



(a)Silk/silk fabric                      (b)Silk/wool fabric                      (c)Silk/acrylic fabric

Photos 15(a-c): Scanning electron micrographs of the damaged fibres of the test fabrics after 20 000 rubs with the Martindale wear and abrasion tester.

Photos 14 and 15 illustrate that the *Gonometa postica* silk weft/acrylic warp fabric had the most damage and fuzz formation between the yarns, while the wool still showed only slight damage and the silk a moderate amount of damage. The difference between the test samples are less prominent than it was after 10 000 rubs.

After visual evaluation of the *Gonometa postica* silk fabric, *Gonometa postica* silk weft/wool warp fabric and *Gonometa postica* silk weft/acrylic warp fabric in photos 10-12, it can be concluded that the *Gonometa postica* silk weft/acrylic warp fabric showed the worst abrasion resistance and the *Gonometa postica* silk fabric moderate resistance, while the silk/wool fabric showed superior abrasion resistance.

Weight loss as a result of abrasion:

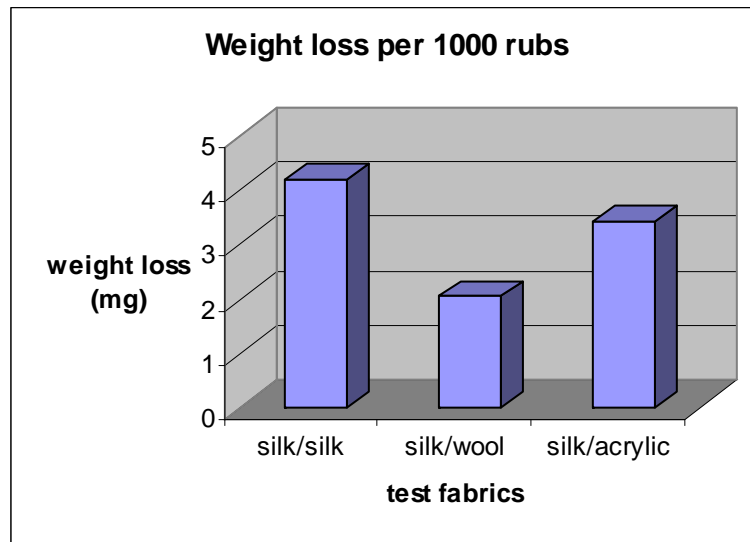


Figure 2: Weight loss of the *Gonometa postica* silk fabric samples, *Gonometa postica* silk weft/wool warp samples and *Gonometa postica* silk weft/acrylic warp samples during abrasion with the Martindale wear and abrasion tester.

From figure 2 it is clear that the *Gonometa postica* silk test fabric had the largest weight loss, while the *Gonometa postica* silk weft/wool warp had the smallest weight loss.

The statistical analysis indicates, as shown in table 3, that there was a significant difference between the weight loss of the *Gonometa postica* silk fabric and the *Gonometa postica* silk weft/wool warp fabric, with the p-value < 0.05.

Table 5: Anova of the weight loss of the *Gonometa postica* silk fabric compared to the *Gonometa postica* silk weft/wool warp fabric.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	12	0.00417975	0.000571241	0.000164903	
Silk/wool	12	0.00204142	0.000241556	0.000069731	0.000

The statistical analysis also indicates, as shown in table 4, that there was a significant difference between the weight loss of the *Gonometa postica* silk fabric and the *Gonometa postica* silk weft/acrylic warp fabric, with the p-value < 0.05.

Table 6: Anova of the weight loss of the *Gonometa postica* silk fabric compared to the *Gonometa postica* silk weft/acrylic warp fabric.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	12	0.00417975	0.000571241	0.000164903	
Silk/acrylic	12	0.00342475	0.000467505	0.000134957	.001

The weight loss could be due to the forming of pills on the surface of the fabric, which then abraded off.

The *Gonometa postica* silk fabric contained hand spun weft yarns, which was quite hairy, and hairy yarns lose fibres more easily.

These results are in agreement with known research that suggests that the abrasion of textiles can be quantitatively measured by the progressively diminishing thickness, weight loss, strength, energy absorption and the number of reciprocating action (cycles) to cause partial or total failure (Susich, 1954:210). Abrasion results in the loss of performance characteristics and it affect the appearance of the fabric (Alpay *et al*, 2005:607).

### **4.3 Tensile strength**

Textile fibres are subjected to repeated stresses and strains in their practical use that may substantially affect their tensile properties.

The Instron tensile tester incorporates a sensitive electronic weighing system to detect and record the load applied to the sample under test (Hindman & Burr, 1949:789).

The results of the Instron tensile tester of the *Gonometa postica* silk fabric, the *Gonometa postica* silk weft/wool warp fabric and *Gonometa postica* silk weft/acrylic warp fabric are shown in both weft and warp directions.

*Gonometa postica* silk fabric in the weft direction:

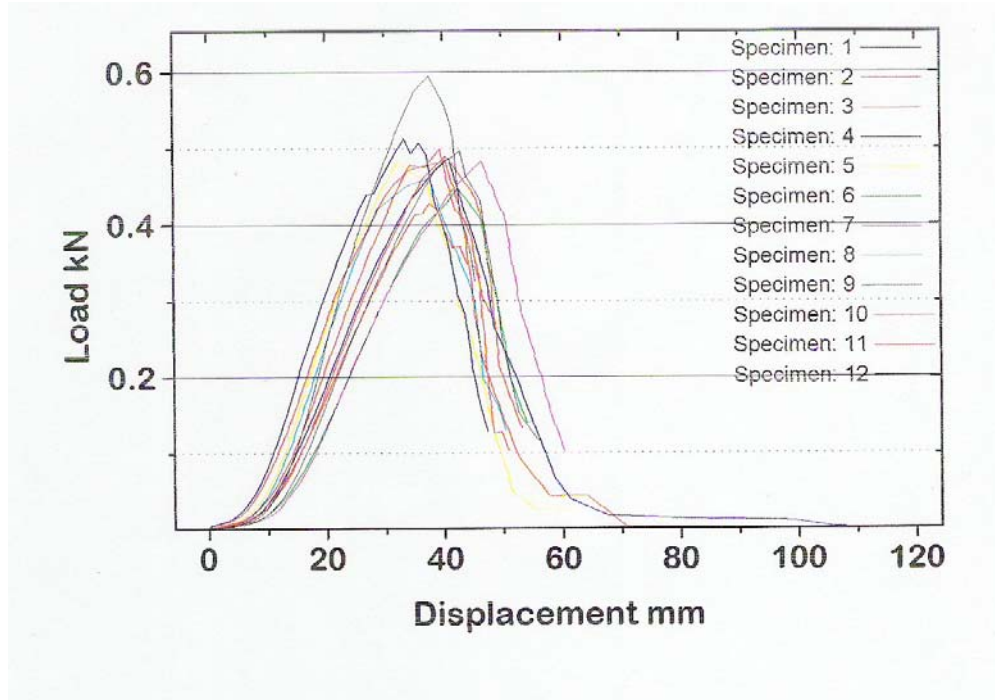


Figure 3: The displacement and maximum load of the *Gonometa postica* silk fabric in the weft direction at breaking point.

According to figure 3 the mean maximum load necessary to break the silk weft yarns was 492.317 N and the mean displacement at maximum load was 39.048 mm.

*Gonometa postica* silk fabric in the warp direction:

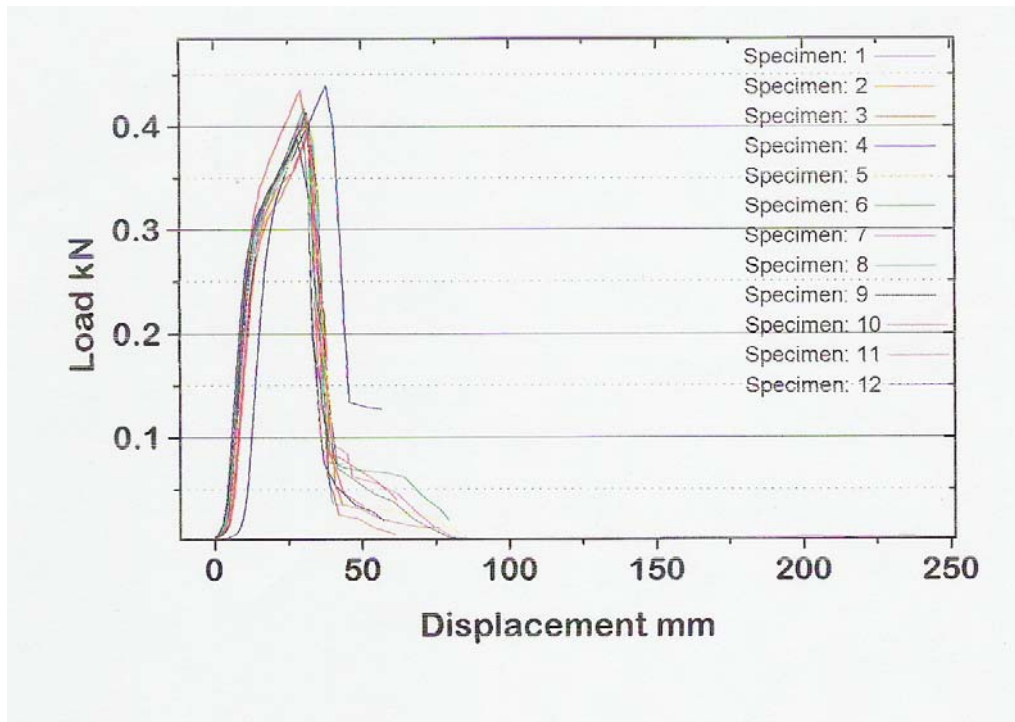


Figure 4: The displacement and maximum load of the *Gonometa postica* silk fabric in the warp direction at breaking point.

According to figure 4 the mean maximum load to break the *Gonometa postica* silk fabric was 412.750 N and the mean displacement was 31.764 mm.

The difference between the maximum load carried by the silk weft and the silk warp is due to the fact that the weft yarns were hand spun while the warp yarns were machine spun. It is surprising that the hand spun yarns could carry a bigger load than the smooth machine spun yarns.

An explanation might be that the machine spun yarn was thinner and didn't contain as many fibres in the yarn cross-section as the hand spun yarn that could carry the load.

The shape of the warp and weft stress-strain curves differs and the machine spun warp yarns show relatively little variation compared to the hand spun weft yarns. A yield point is found in the stress-strain curve and could be explained by the unfolding of the long fibrous chains in the amorphous regions (Freddi *et al*, 1994:778).

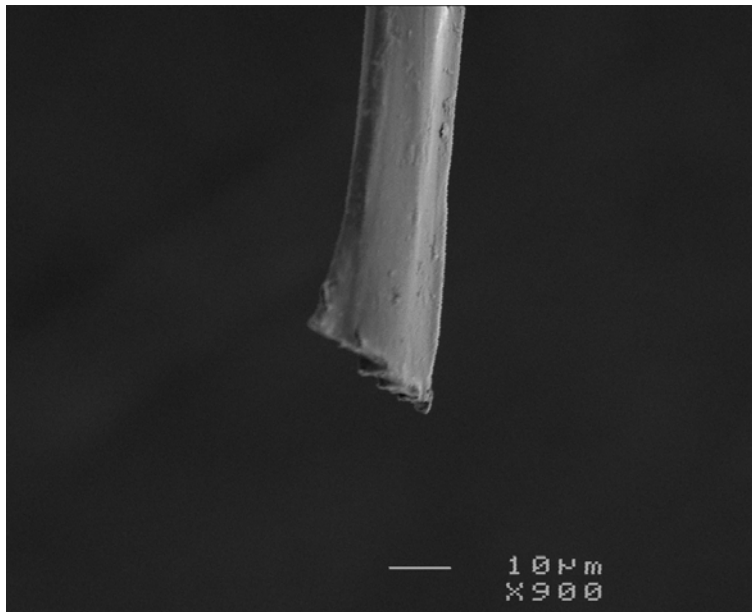


Photo 16 (a): A scanning electron micrograph of a *Gonometa postica* silk fibre that was broken by the Instron tensile tester.

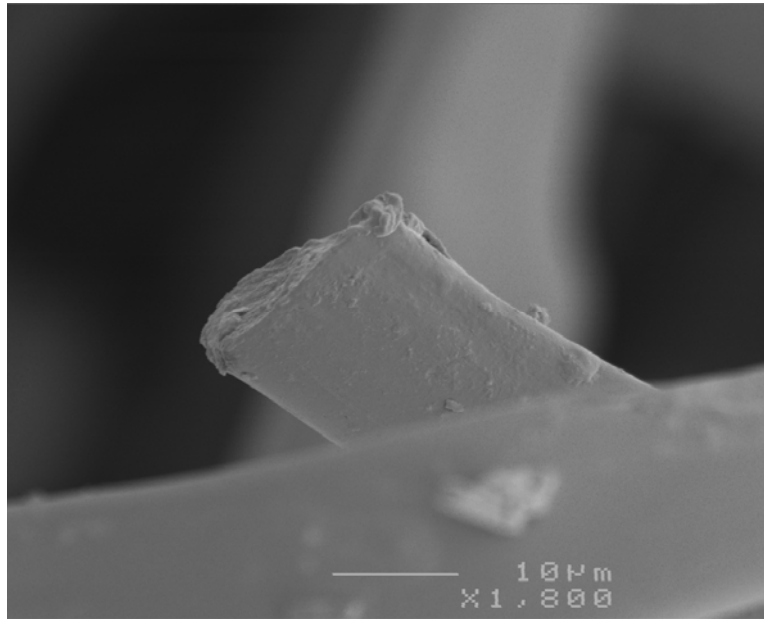


Photo 16 (b): A scanning electron micrograph of a *Gonometa postica* silk fibre that broke during testing with the Instron tensile tester.

According to photos 16 (a) and (b) the *Gonometa postica* silk fibres left a blunt point where it broke as a result of the strain caused by the Instron tensile tester.

*Gonometa postica* silk weft/wool warp fabric in the weft direction:

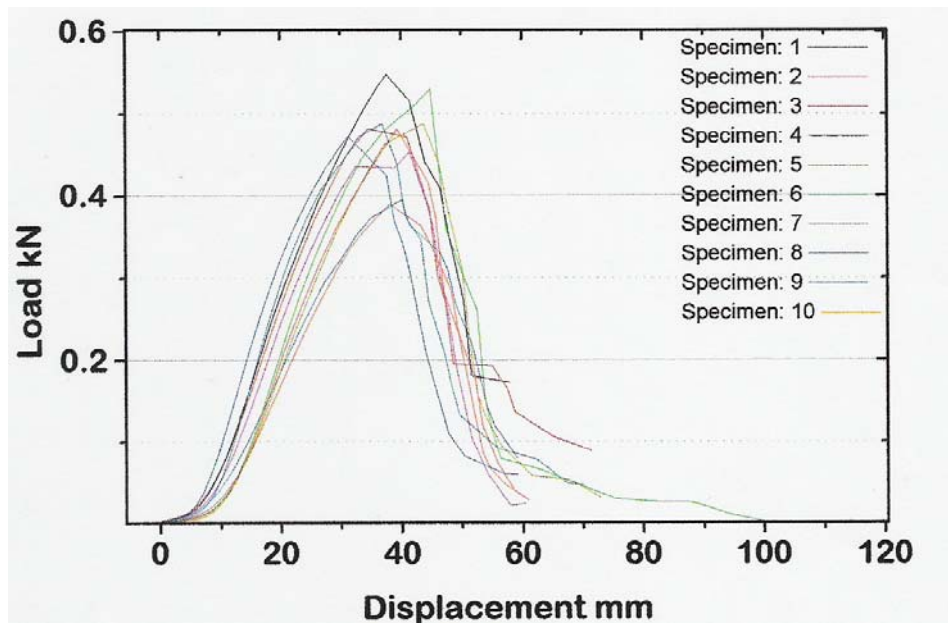


Figure 5: The displacement and maximum load of the *Gonometa postica* silk weft/wool warp fabric in the weft direction at breaking point.

According to figure 5 the mean maximum load that the silk weft yarns could carry was 475.970 N and the mean maximum displacement was 39.442 mm.

The statistical analysis indicates, as shown in table 5, that there was not a significant difference between the maximum load required to break the *Gonometa postica* silk fabric and the *Gonometa postica* silk weft/wool warp fabric, in the weft direction, with the p-value  $> 0.05$ .

Table 7: Anova of the maximum load required to break the *Gonometa postica* silk fabric in weft direction compared to the *Gonometa postica* silk weft/wool warp fabric in weft direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	9	486.87778	17.610350	5.870117	
Silk/wool	9	475.31111	52.939056	17.646352	0.815

*Gonometa postica* silk weft/wool warp fabric in the warp direction:

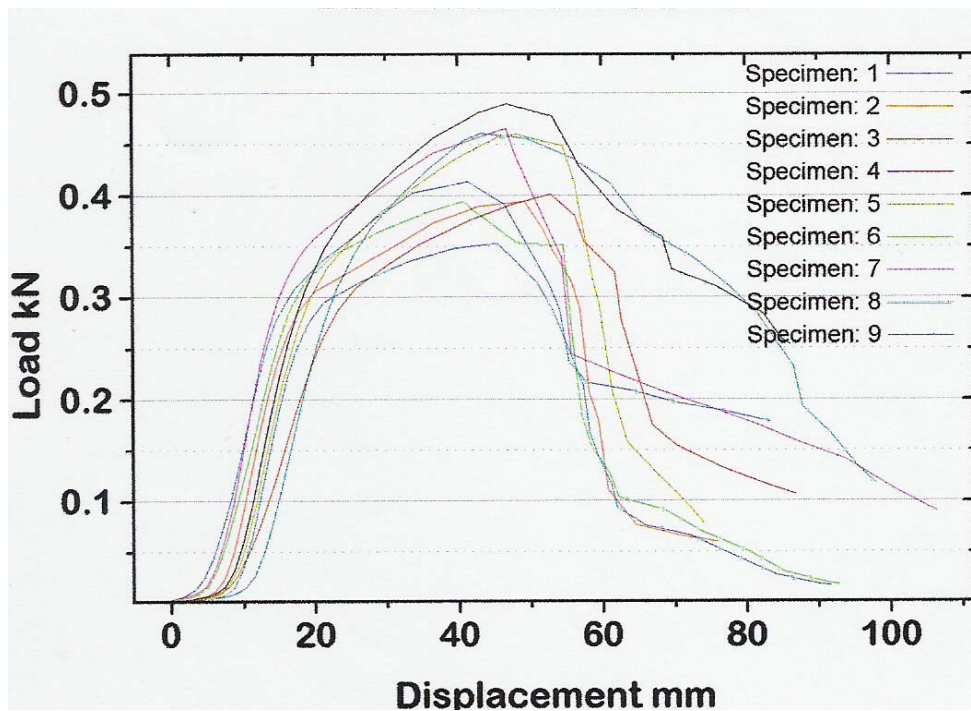


Figure 6: The displacement and maximum load of the *Gonometa postica* silk weft/wool warp fabric in the warp direction at breaking point.

According to figure 6 the mean maximum load that the wool warp yarns could carry was 426.011 N and the mean displacement was 46.448 mm.

The statistical analysis indicates, as shown in table 6, that there was not a significant difference between the maximum loads required to break the *Gonometa postica* silk fabric in warp direction compared to the *Gonometa postica* silk weft/wool warp fabric in warp direction, with the p-value > 0.05.

Table 8: Anova of the maximum load required to break the *Gonometa postica* silk fabric in the warp direction compared to the *Gonometa postica* silk weft/wool warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	9	416.15556	17.081943	5.693981	
Silk/wool	9	426.01111	44.912761	14.970920	0.766

The lower tenacity of wool can be explained by the large amorphous areas containing bulky molecules that can't be packed close enough together to form strong hydrogen bonds, therefore wool has many weak bonds and less strong cystine linkages which makes the fibre weak (Hollen and Saddler, 1973:20). Lang (1952:246) reports that tensile strength is independent of the shape and proportional to the size of the cross-section. Therefore, wool has a good correlation between fibre weight per unit length and breaking load. It is also reported that the extension at breaking point increases slightly with decreasing fineness. This may explain the differences in the slope as shown in figure 6.

Figure 6 indicates that wool has high elongation, which could be attributed to the spiral structure (Gohl and Vilensky, 1983:75), because when the fibre is stretched it tends to unfold its polymers (Kadolph, 2002:54).

The shape of the wool warp yarn stress-strain curve shows three regions as was indicated by the literature as a “Hookean region” up to 2% elongation, a yield region up to 30% elongation and a post-yield region above 30% elongation (Maclared and Milligan, 1981:289). As is indicated in figure 6, the curve of a dry fibre is not as clearly defined.

The shape of the curve is distinctly different from the *Gonometa postica* silk curves seen in figure 3, 4 and 5.

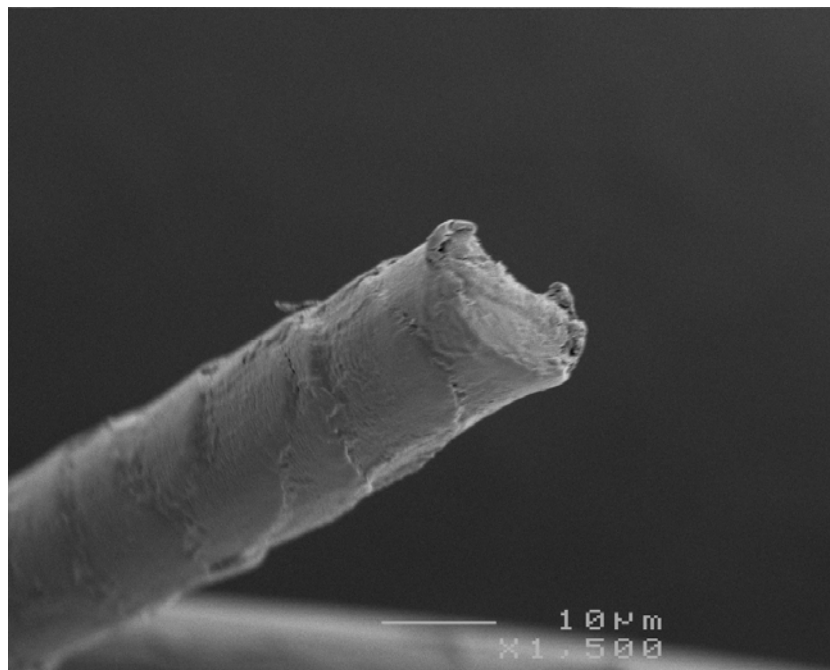


Photo 17: A scanning electron micrograph of a wool fibre that broke during testing with the Instron tensile tester.

*Gonometa postica* silk weft/acrylic warp fabric in the weft direction:

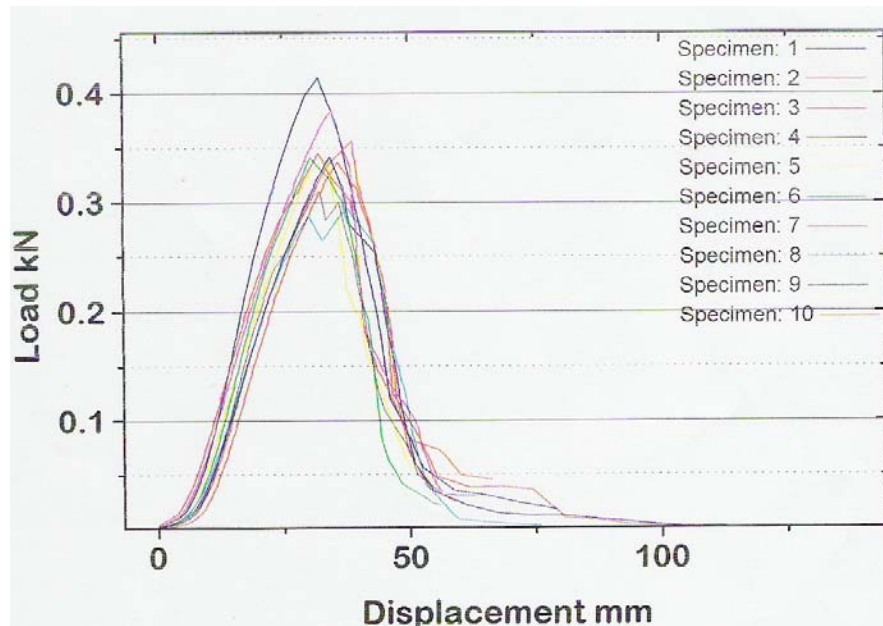


Figure 7: The displacement and maximum load of the *Gonometa postica* silk weft/acrylic warp fabric in the weft direction at breaking point.

According to figure 7 the mean maximum load that the silk weft yarns could carry before breaking was 347.910 N and the displacement was 34.465 mm.

The stress-strain curves of the three silk weft directions show the same shape as was expected, but the load it could carry before break varies between 347.9 and 492.317 N. This could be due to the fabric construction, as all the hand spun yarns were not of the exact same diameter.

The statistical analysis indicates, as shown in table 7, that there was a significant difference between the maximum loads required to break the *Gonometa postica* silk fabric in weft direction compared to the *Gonometa postica* silk weft/acrylic warp fabric in the weft direction, with the p-value < 0.05.

Table 9: Anova of the maximum load required to break the *Gonometa postica* silk fabric in weft direction compared to the *Gonometa postica* silk weft/acrylic warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	9	486.87778	17.610350	5.870117	
Silk/acrylic	9	349.08889	35.615391	11.871797	0.000

*Gonometa postica* silk weft/acrylic warp fabric in the warp direction:

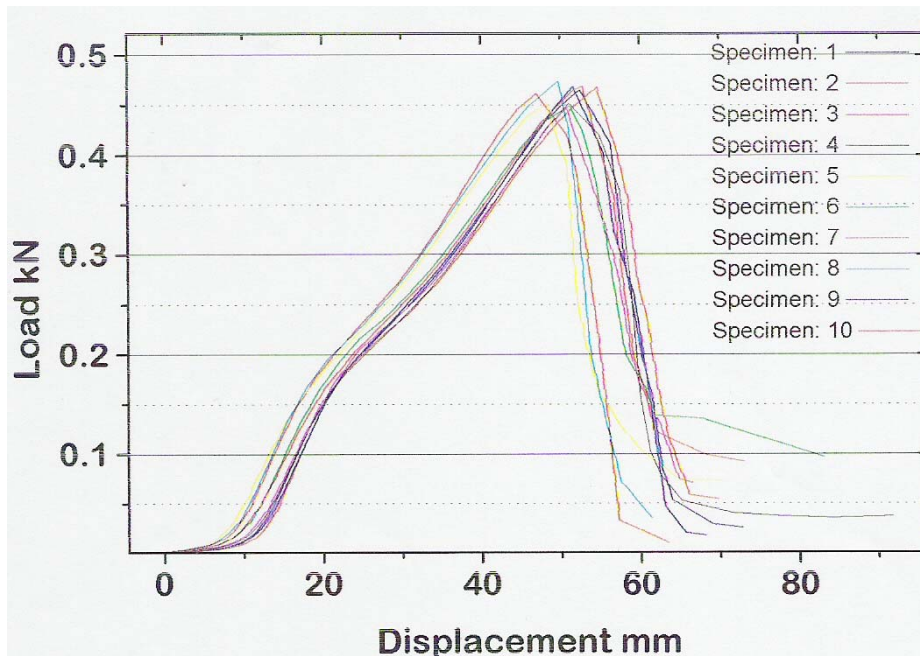


Figure 8: The displacement and maximum load of the *Gonometa postica* silk weft/acrylic warp fabric in the warp direction at breaking point.

According to figure 8 the mean maximum load that the acrylic warp yarns could carry was 462.840 N and the maximum displacement was 51.447 mm.

The statistical analysis indicates, as shown in table 8, that there was a significant difference between the maximum loads required to break the *Gonometa postica* silk fabric in the warp direction and the *Gonometa postica* silk weft/acrylic warp fabric in the same direction, as the p-value < 0.05.

Table 10: Anova analysis of the maximum load required to break the *Gonometa postica* silk fabric in the warp direction compared to the *Gonometa postica* silk weft/acrylic warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	9	416.15556	17.081943	5.693981	
Silk/acrylic	9	461.92222	11.352618	3.784206	0.009

The stress-strain curves of the acrylic warp yarns differ from those of the silk and wool warp yarns. Bell and Dumbleton (1971: 200) found the same shape acrylic stress-strain curve and explained that a deformation process occurs during the stretching phase of the acrylic production process. The fibrils slip relative to one another and create viscosity, and a new network is formed with junctures at the fibril ends which give the fibre its elasticity.

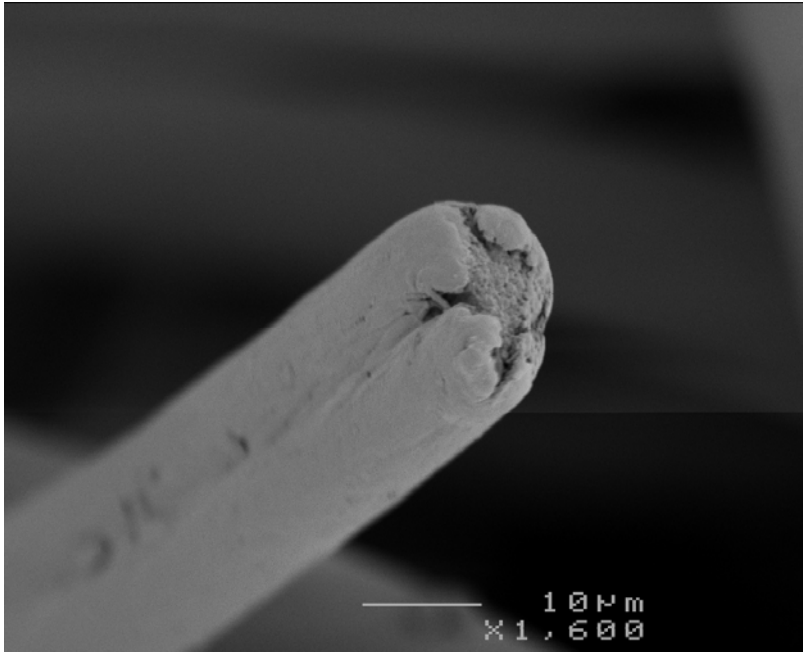


Photo 18: A scanning electron micrograph of an acrylic fibre that broke during testing with the Instron tensile tester.

The shape of the broken fibre end suggests that the fibre became thinner as it was stretched and then broke. It differs completely from the fibre ends of the silk and wool.

## Maximum loads:

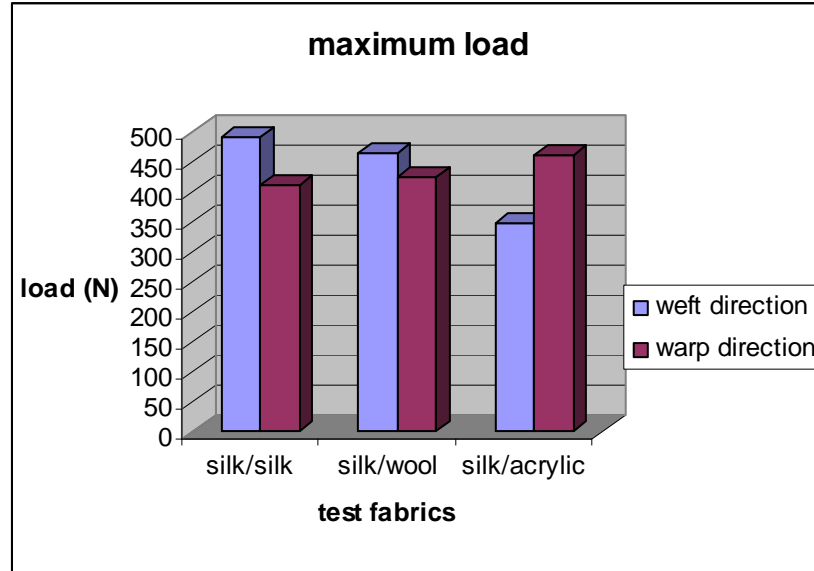


Figure 9: The maximum loads of the *Gonometa postica* silk fabric, *Gonometa postica* silk weft/wool warp fabric and *Gonometa postica* silk weft/acyrylic warp fabric in weft and warp directions, at break.

Figure 9 indicates that the weft direction of the *Gonometa postica* silk fabric was the strongest and the weft direction of the *Gonometa postica* silk weft/acyrylic warp fabric was the weakest, while both consists of hand spun silk. The difference in thickness of yarns might be responsible for the discrepancy, although the analysis of the results shows no significant difference in the tenacity of the weft yarns. According to Kadolph and Langford (2002:63) silk is a very strong fibre, while wool has poor tenacity and acrylic has moderate tensile strength. The tenacity and elongation at break of silk are different from other protein fibres because of the chemical differences – fibroin consists mainly of four amino acids without bulky side-chains, cross-linked by hydrogen bonds – and structural differences – high crystallinity and orientation (Susich and Zagieboylo, 1953: 405).

Hand spun silk has a lower tenacity than filament silk (Potter and Corbman, 1967) and the harsh removal of sericin causes fibre degradation (Freddi *et al*, 2003). These might be the causes of the lower tenacity of the silk weft yarns.

### Displacement at maximum load:

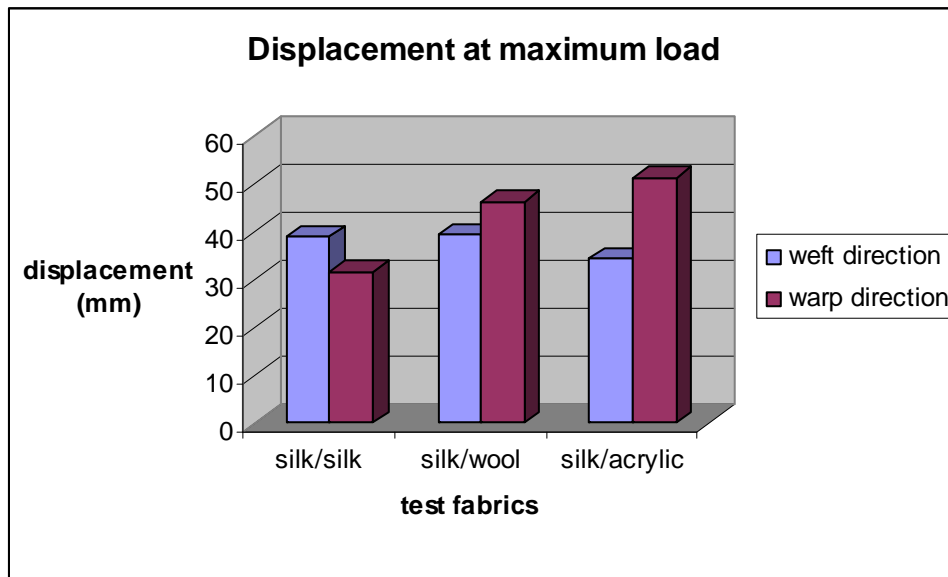


Figure 10: The displacement of the *Gonometa postica* silk fabric, *Gonometa postica* silk weft/wool warp fabric and *Gonometa postica* silk weft/acrylic warp fabric at break in weft and warp directions.

According to figure 10 the *Gonometa postica* silk weft/acrylic warp fabric showed the most displacement in the warp direction, while the *Gonometa postica* silk fabric showed the least displacement in the same direction.

The statistical analysis indicates, as shown in table 9, that there was not a significant difference between the displacement at maximum load of the *Gonometa postica* silk fabric in the weft direction and the *Gonometa postica* silk weft/wool warp fabric in the same direction, with the p-value > 0.05.

Table 11: Anova of the displacement at maximum load of the *Gonometa postica* silk fabric in the weft direction, compared to the *Gonometa postica* silk weft/wool warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	9	39.26778	5.135834	1.711945	
Silk/wool	9	39.25667	4.439124	1.479708	1.000

Table 12: Anova of the displacement at maximum load of the *Gonometa postica* silk fabric in the warp direction, compared to the *Gonometa postica* silk weft/wool warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	9	31.93222	2.601071	0.867024	
Silk/wool	9	46.44778	3.656018	1.218673	0.000

The statistical analysis indicates that there was a significant difference between the displacements at maximum load of the *Gonometa postica* silk fabric in the warp direction and the *Gonometa postica* silk weft/wool warp fabric in the same direction, with the p-value < 0.05.

Table 13: Anova of the displacement at maximum load of the *Gonometa postica* silk fabric in the weft direction compared to the *Gonometa postica* silk weft/acrylic warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	9	39.26778	5.135834	1.711945	
Silk/acrylic	9	34.26444	2.954290	0.984763	0.064

The analysis indicates that there was not a significant difference between the displacements at maximum load of the *Gonometa postica* silk fabric in the weft direction and the *Gonometa postica* silk weft/acrylic warp fabric in the same direction, with the p-value > 0.05.

Table 14: Anova of the displacement at maximum load of the *Gonometa postica* silk fabric in the warp direction compared to the *Gonometa postica* silk weft/acrylic warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	9	31.93222	2.601071	0.867024	
Silk/acrylic	9	51.16000	2.499825	0.833275	0.000

The analysis indicates that there was a significant difference between the displacements at maximum load of the *Gonometa postica* silk fabric in the warp direction and the *Gonometa postica* silk weft/acrylic warp fabric in the same direction, with the p-value < 0.05.

These results were expected as the warp yarns were of different origin. The acrylic warp yarns show the most displacement before breaking and this is in agreement with the literature which indicate 35% elongation for acrylic, 25% elongation for wool and 20-30% elongation for silk (Kadolph and Langford, 2002:116).

The *Gonometa postica* silk showed a significant lower breaking elongation compared to those of wool and acrylic, and this was not expected but could be explained by the fact that silks' elasticity varies as may be expected of a natural fibre (Potter and Corbman, 1967:272).

Although Kadolph and Langford (2002:63) found that silk has a 20-30% breaking elongation, the wild silks contain more amino acid residues with bulky side groups that enable molecular chains in non-crystalline regions to slip easily when stretched and show higher elongation at break (Kushal and Muruges, 2004:1105).

According to the literature acrylic has good elasticity (Lyle, 1976:44) with a breaking elongation between 20 and 50 % (Gohl and Vilenski, 1983:119).

According to Kadolph and Langford (2002:53) wool has a breaking elongation of 25 % and acrylic 35 % but Krasny and Sookne (1955:495) found that wool had a 41.4 % elongation at break at 65 % humidity. Wool fibres are very elastic (Smith and Block, 1982:92), due to the crimp of the fibre which enables it to be stretched out. The molecules are in a folded state and become straightened when stretched (Collier, 1974:27).

## 4.4 Stiffness:

The bending length is a characteristic property of a textile fabric and is dependent upon the energy required to produce a given bending deformation under its own weight (Brenner and Britt, 1964:754). A fabric's bending properties are important because they contribute towards drape and handle and it influences the mechanisms of fabric deformation. The places where deformations occur are in the individual fibres and the yarns, which are both capable of movement within the fabric structure (Cooper, 1960: 317).

The following results describe the stiffness of the *Gonometa postica* silk fabric, *Gonometa postica* silk weft/wool warp fabric and *Gonometa postica* silk weft/acrylic warp fabric.

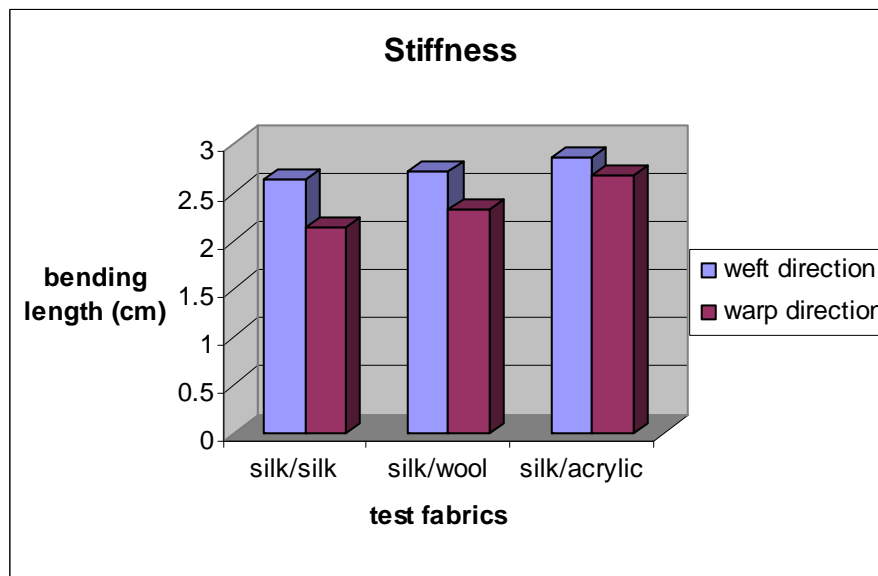


Figure 11: The bending length of the *Gonometa postica* silk fabric, *Gonometa postica* silk weft/wool warp fabric and *Gonometa postica* silk weft/acrylic warp fabric, measured with the Shirley stiffness tester.

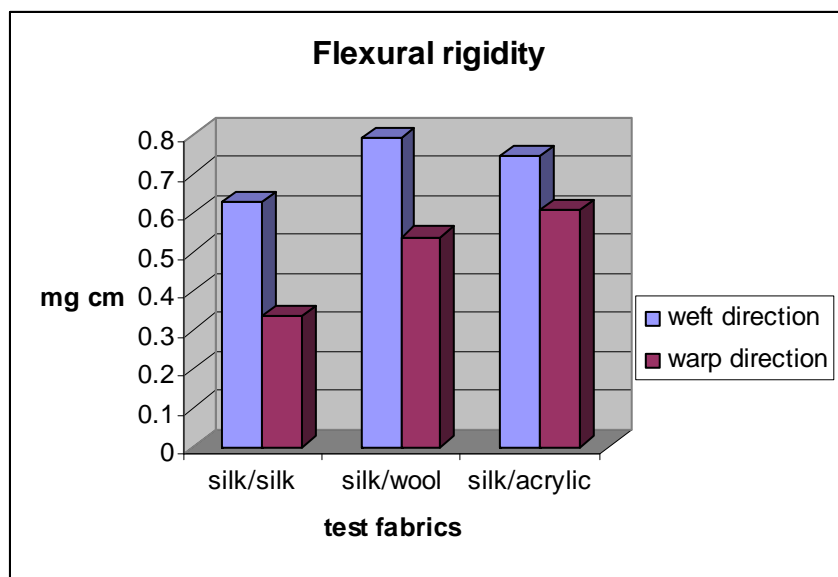


Figure 12: The flexural rigidity of the *Gonometa postica* silk fabric, *Gonometa postica* silk weft/wool warp fabric and *Gonometa postica* silk weft/acrylic warp fabric.

Figure 11 and 12 indicate the stiffness of the test fabrics, in weft and warp directions, in terms of bending length and flexural rigidity. The bending lengths of all the samples were small enough to indicate that it has good draping qualities, considering the thickness of the fabrics. It is clear to see that the weft direction of the *Gonometa postica* silk weft/acrylic warp fabric was the stiffest, which could be expected as this fabric was the thickest and most bulky and therefore couldn't bend easily. The silk was degummed completely before spinning and weaving, therefore these results were not unexpected as the literature shows that the degumming process of silk influences the bending properties of the fibre and there is a decrease in fabric bending length as a result of the degumming process (Sharma *et al*, 1999:293).

The *Gonometa postica* silk fabric showed less stiffness in the warp direction which could be due to the fact that it was a thinner and smoother yarn that was machine spun and therefore softer. Wool and acrylic both have moderate bending qualities, which could have decreased as a result of the finishing processes it has undergone (Corbman, 1983:273). In this case, probably, the finishing process made the fibres machine washable.

Statistical analysis was done to be clear about the significance of the differences.

Table 15: Anova of the stiffness of the *Gonometa postica* silk fabric in the weft direction compared to the *Gonometa postica* silk weft/wool warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	2.6275	0.16644	0.5263	
Silk/wool	10	2.7175	0.13897	0.04395	0.439

The statistical analysis indicates that there was not a significant difference between the stiffness of the *Gonometa postica* silk fabric in the weft direction and the *Gonometa postica* silk weft/wool warp fabric in the same direction, with the p-value > 0.05.

Table 16: Anova of the stiffness of the *Gonometa postica* silk fabric in the warp direction compared to the *Gonometa postica* silk weft/wool warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	2.1350	0.12202	0.03859	
Silk/wool	10	2.3900	0.08913	0.02819	0.000

According to the statistical analysis there was a significant difference between the stiffness of the *Gonometa postica* silk fabric in the warp direction and the *Gonometa postica* silk weft/wool warp fabric in the same direction, with the p-value < 0.05.

Table 17: Anova of the stiffness of the *Gonometa postica* silk fabric in the weft direction compared to the *Gonometa postica* silk weft/acrylic warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	2.6275	0.16644	0.5263	
Silk/acrylic	10	2.8625	0.15646	0.04948	0.008

The analysis indicated that there was a significant difference between the stiffness of the *Gonometa postica* silk fabric in the weft direction and the *Gonometa postica* silk weft/acrylic warp fabric in the same direction, with the p-value < 0.05.

Table 18: Anova of the stiffness of the *Gonometa postica* silk fabric in the warp direction compared to the *Gonometa postica* silk weft/acrylic warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	2.1350	0.12202	0.03859	
Silk/acrylic	10	2.6675	0.09283	0.02936	0.000

According to the analysis there was a significant difference between the stiffness of the *Gonometa postica* silk fabric in the warp direction and the *Gonometa postica* silk weft/acrylic warp fabric in the same direction, with the p-value < 0.05.

#### **4.5 Crease Recovery:**

The ability of a fabric to recover after creasing is very desirable, and wool leads among natural fibres possessing this characteristic. Recovery from creasing can be expressed by the angle to which the fabric returns after having been folded and held under a controlled pressure for a fixed period of time. Perfect recovery would be 180 ° (Dennison and Leach, 1952:473).

The following results of the test fabrics were obtained:

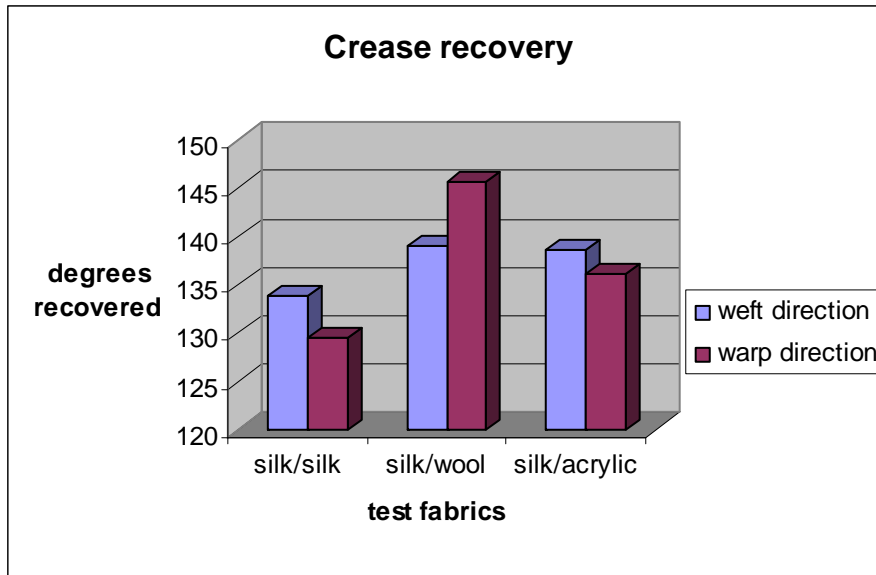


Figure 13: The crease recovery of the *Gonometa postica* silk fabric, *Gonometa postica* silk weft/wool warp fabric and *Gonometa postica* silk weft/acrylic warp fabric in both weft and warp directions.

Figure 13 clearly illustrates that the *Gonometa postica* silk weft/wool warp fabric exhibited the best crease recovery especially in the warp direction, while the *Gonometa postica* silk fabric had the worst crease recovery especially in the warp direction. The best crease recovery of the *Gonometa postica* silk weft/wool warp fabric in the warp direction was expected, as the warp yarns were wool yarns which shows excellent recovery from creasing. Protein fibres are more resistant to creasing due to their flexible molecules and their existence in the form of a network, secured by strong chemical forces or primary bonds (Meredith, 1952: 790).

The molecular chains in the polymer system of silk are not coiled, but are layers of folded linear polymers; therefore silk is estimated to be about 65-70 % crystalline and 30-35 % amorphous (Kadolph & Langford, 2002:63), which results in more rigid and less flexible fibres.

According to Krasny and Sookne (1955:502) crease recovery is improved by the use of symmetrical weaves as the fabric construction influences the crease recovery, this could explain why the *Gonometa postica* silk had the smallest recovery as the weave wasn't balanced. The bulkiness of the wool yarn gives it good crease recovery, while the warp *Gonometa postica* silk yarn was machine spun and thinner than any of the other yarns that made it more difficult for these yarns to resist and recover from creasing. According to Dennison and Leach (1952:473) wool improves crease recovery in mixed fabrics.

The small difference in crease recovery in the weft direction was expected as the weft yarns of all three test fabrics were hand spun silk yarns.

Statistical analysis was done to determine the significance of the differences.

Table 19: Anova of the crease recovery of the *Gonometa postica* silk fabric in the weft direction compared to the *Gonometa postica* silk weft/wool warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	133.80	10.358	3.275	
Silk/wool	10	139.10	7.370	2.331	0.345

The analysis and this table shows that there wasn't a significant difference between the crease recovery of the *Gonometa postica* silk fabric in the weft direction and the *Gonometa postica* silk weft/wool warp fabric in the same direction, with the p-value > 0.05.

Table 20: Anova of the crease recovery of the *Gonometa postica* silk fabric in warp direction compared to the *Gonometa postica* silk weft/wool warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	129.50	12.599	3.984	
Silk/wool	10	145.70	9.044	2.860	0.006

According to the analysis there was a significant difference in the crease recovery of the *Gonometa postica* silk fabric in the warp direction and the *Gonometa postica* silk weft/wool warp fabric in the same direction, with the p-value < 0.05.

Table 21: Anova of the crease recovery of the *Gonometa postica* silk fabric in the weft direction compared to the *Gonometa postica* silk weft/acrylic warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	133.80	10.358	3.275	
Silk/acrylic	10	138.60	5.337	1.688	0.415

The analysis clearly indicated that there wasn't a significant difference between the crease recovery of the *Gonometa postica* silk fabric in the weft direction and the *Gonometa postica* silk weft/acrylic warp fabric in the same direction, with the p-value > 0.05.

Table 22: Anova of the crease recovery of the *Gonometa postica* silk fabric in the warp direction compared to the *Gonometa postica* silk weft/acrylic warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	129.50	12.599	3.984	
Silk/acrylic	10	136.10	8.425	2.664	0.364

The analysis indicated that there wasn't a significant difference in the crease recovery of the *Gonometa postica* silk fabric in the warp direction and the *Gonometa postica* silk weft/acrylic warp fabric in the same direction, with the p-value > 0.05.

## 4.6 Fabric thickness:

Thickness can be explained as the space occupied by a fabric subjected to a barely perceptible pressure (Ukponmwan, 1994: 756).

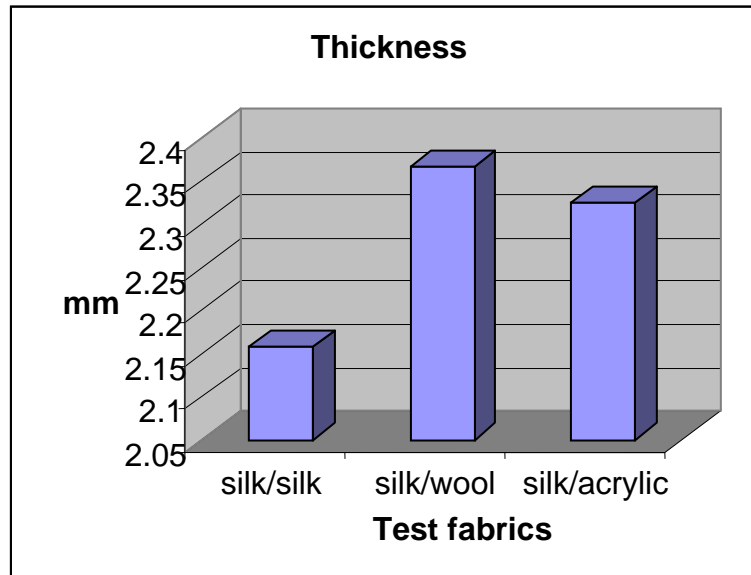


Figure 14: The difference in thickness of the *Gonometa postica* silk fabric, *Gonometa postica* silk weft/wool warp fabric and *Gonometa postica* silk weft/acrylic warp fabric.

Figure 14 clearly shows that the *Gonometa postica* silk fabric was thinner than the *Gonometa postica* silk weft/wool warp fabric and the *Gonometa postica* silk weft/acrylic warp fabric.

The statistical analysis indicates, as shown in table 21, that there wasn't a significant difference between the thickness of the *Gonometa postica* silk fabric and the *Gonometa postica* silk weft/wool warp fabric, with the p-value  $> 0.05$ .

Table 23: Anova of the thickness of the *Gonometa postica* silk fabric compared to the *Gonometa postica* silk weft/wool warp fabric.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	2.158	0.26515	0.08385	
Silk/wool	10	2.366	0.15013	0.04747	0.083

The statistical analysis also indicates, as shown in table 22, that there wasn't a significant difference between the thickness of the *Gonometa postica* silk test fabric and the *Gonometa postica* silk weft/acrylic warp test fabric, with the p-value > 0.05.

Table 24: Anova of the thickness of the *Gonometa postica* silk fabric compared to the *Gonometa postica* silk weft/acrylic warp fabric.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	2.158	0.26515	0.08385	
Silk/acrylic	10	2.324	0.16112	0.05095	0.195

The results were expected as silk doesn't create bulky yarns like wool and acrylic, whose physical structure contributes loft and body to fabrics (Kadolph and Langford, 2002:115). According to Sharma *et al.* (1999:293) after degumming there is a decrease in fabric thickness.

## 4.7 Moisture regain:

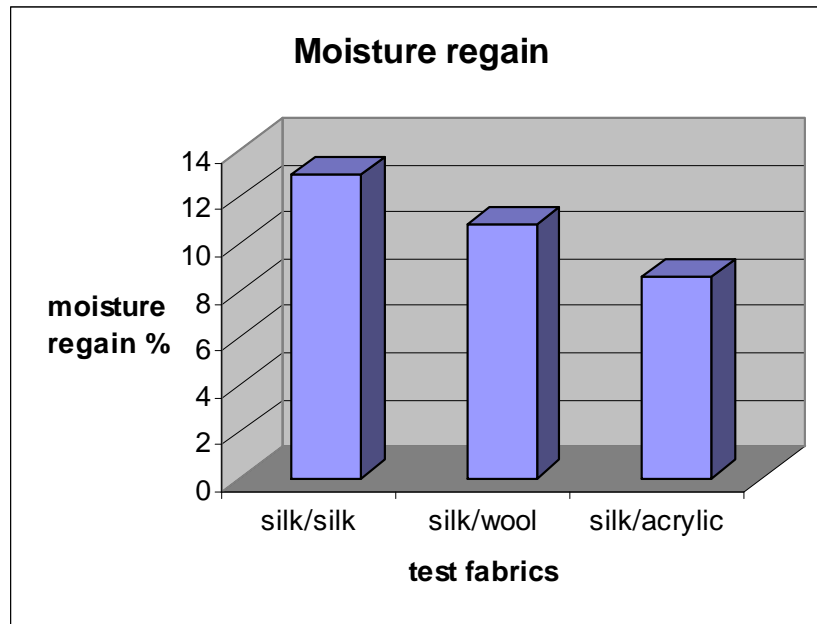


Figure 15: The moisture regain of the *Gonometa postica* silk fabric, *Gonometa postica* silk weft/wool warp fabric and *Gonometa postica* silk weft/acrylic warp fabric.

Figure 15 indicates that the *Gonometa postica* silk fabric had the largest moisture regain, while the *Gonometa postica* silk weft/acrylic warp fabric had the smallest moisture regain.

The statistical analysis indicates, as shown in table 23, that there wasn't a significant difference between the moisture regain of the *Gonometa postica* silk fabric and *Gonometa postica* silk weft/wool warp fabric, with the p-value  $> 0.05$ .

Table 25: Anova of the moisture regain of the *Gonometa postica* silk fabric compared to the *Gonometa postica* silk weft/wool warp fabric.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	12.9308	2.39730	0.75809	
Silk/wool	10	10.8117	1.62089	0.51257	0.128

However, the statistical analysis also indicates, as shown in table 24, that there was a significant difference in moisture regain of the *Gonometa postica* silk fabric and *Gonometa postica* silk weft/acrylic warp fabric, with the p-value < 0.05.

Table 26: Anova of the moisture regain of the *Gonometa postica* silk fabric compared to the *Gonometa postica* silk weft/acrylic warp fabric.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	12.9308	2.39730	0.75809	
Silk/acrylic	10	8.5958	2.60313	0.82318	0.001

The results were supported by the literature because according to Kadolph and Langford (2002:64) silk has a moisture regain of 11%, but according Cooke (1949:161) Tussah silk has a higher moisture regain than mulberry silk, therefore it wasn't unexpected to find the moisture regain of the *Gonometa postica* silk fabric to be 13%.

In the literature there is some dispute on the moisture regain of wool and according to Cowan and Jungerman (1969:9) and Joseph (1986) the moisture regain of wool is 13 to 16%, while Hollen and Saddler, (1973:22) set it at 16 to 30%, and according to Lyle (1976:29) it is 15 %.

The *Gonometa postica* silk weft/wool warp fabric had a moisture regain of 11%, maybe due to the fact that the wool had undergone some finishing processes, which could have influenced its moisture regain.

The standard moisture regain for acrylic is set at 1.0 – 2.5 % (Joseph, 1986:128), while Hunter (1978:48) found it to be between 1.2 – 2 % and according to Labarthe (1975:143) Courtelle has a moisture regain of 2.0 %. It was therefore expected that the moisture regain of the silk/acrylic fabric would be higher than that of the Courtelle. The moisture regain of the *Gonometa postica* silk weft/acrylic warp fabric was calculated as 8.6%.

#### **4.8 Dimensional change (shrinkage):**

According to Cookson *et al* (1991) relaxation shrinkage occurs in finished fabrics because of strain imposed during finishing processes, which is then released when the fabric is exposed to conditions of high relative humidity.

## Shrinkage with exposure to water:

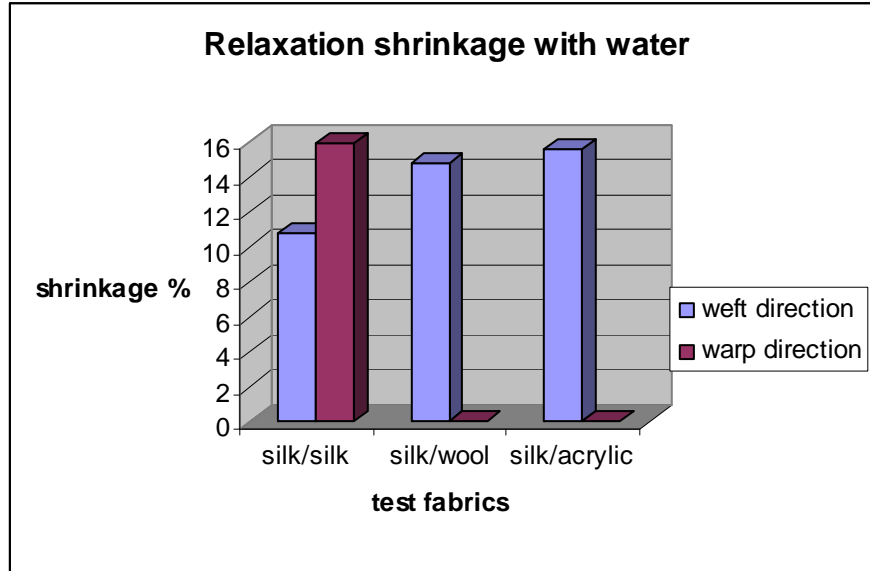


Figure 16: The relaxation shrinkage of the *Gonometa postica* silk fabric, *Gonometa postica* silk weft/wool warp fabric and *Gonometa postica* silk weft/acrylic warp fabric with exposure to water.

Figure 16 clearly shows that the *Gonometa postica* silk weft/wool warp fabric and the *Gonometa postica* silk weft/acrylic warp fabric had no shrinkage in the warp directions. This could be due to the fact that the wool had a finish that made it washable and acrylic doesn't shrink as a result of exposure to water. The *Gonometa postica* silk fabric showed more shrinkage in the warp direction than in the weft direction. This could be because the warp yarns were machine spun and had more tension imparted that relaxed, where the weft yarns were hand spun and not twisted and stretched as much.

Statistical analysis was done to determine the significance of the differences in the relaxation shrinkage.

Table 27: Anova of the relaxation shrinkage of the *Gonometa postica* silk fabric in the weft direction compared to the *Gonometa postica* silk weft/wool warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	10.8000	5.00666	1.58325	
Silk/wool	10	14.8000	3.29309	1.04137	0.086

The analysis indicates that there wasn't a significant difference between the relaxation shrinkage of the *Gonometa postica* silk fabric in the weft direction and the *Gonometa postica* silk weft/wool warp fabric in the same direction, with the p-value > 0.05.

Table 28: Anova of the relaxation shrinkage of the *Gonometa postica* silk fabric in the warp direction compared to the *Gonometa postica* silk weft/wool warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	16.0000	4.61880	1.46059	
Silk/wool	10	0.0000	0.0000	0.0000	0.000

The analysis indicates that there was a significant difference between the relaxation shrinkage of the *Gonometa postica* silk fabric in the warp direction and the *Gonometa postica* silk weft/wool warp fabric in the same direction, with the p-value < 0.05.

Table 29: Anova of the relaxation shrinkage of the *Gonometa postica* silk fabric in the weft direction compared to the *Gonometa postica* silk weft/acrylic warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	10.8000	5.00666	1.58325	
Silk/acrylic	10	15.6000	2.95146	0.93333	0.03

The analysis indicates that there was a significant difference between the *Gonometa postica* silk fabric in the weft direction and the *Gonometa postica* silk weft/acrylic warp fabric in the same direction, with the p-value < 0.05.

Table 30: Anova of the relaxation shrinkage of the *Gonometa postica* silk fabric in the warp direction compared to the *Gonometa postica* silk weft/acrylic warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	16.0000	4.61880	1.46059	
Silk/acrylic	10	0.0000	0.00000	0.00000	0.000

The analysis indicates that there was a significant difference between the relaxation shrinkage of the *Gonometa postica* silk fabric in the warp direction and the *Gonometa postica* silk weft/acrylic warp fabric in the same direction, with the p-value < 0.05.

The procedure was repeated to determine whether the shrinkage was progressive, but no residual shrinkage was found, therefore it is concluded that the shrinkage was only relaxation shrinkage.

### **Shrinkage with exposure to steam:**

A test was conducted to determine if the test fabrics would exhibit any shrinkage after being exposed to steam.

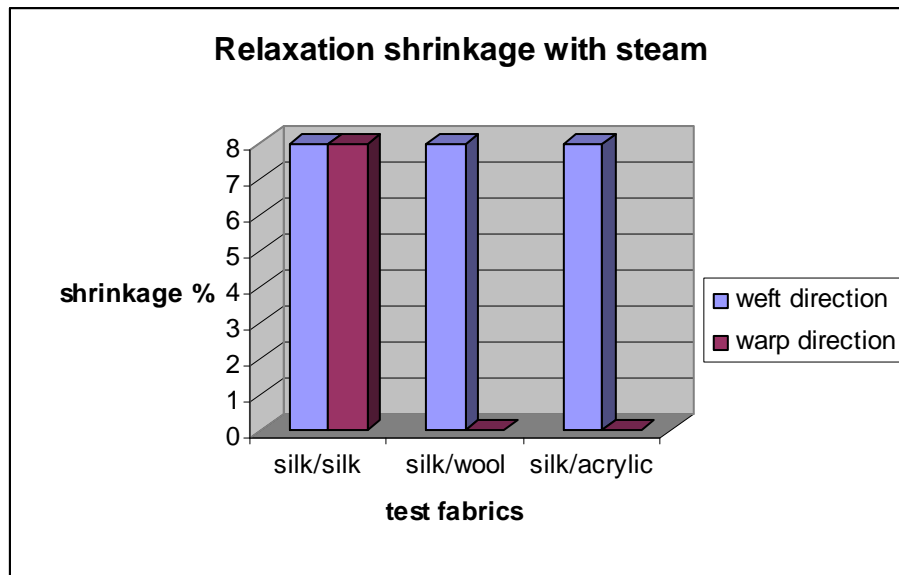


Figure 17: The relaxation shrinkage of the *Gonometa postica* silk fabric, *Gonometa postica* silk weft/wool warp fabric and *Gonometa postica* silk weft/acrylic warp fabric with steam.

Again there was no shrinkage in the warp directions of the *Gonometa postica* silk weft/wool warp fabric and *Gonometa postica* silk weft/acrylic warp fabric.

It was interesting that the *Gonometa postica* silk fabric showed the same amount of shrinkage in both directions with the steam, and the silk yarns of the *Gonometa postica* silk weft/wool warp fabric and the *Gonometa postica* silk weft/acrylic warp fabric also showed the same amount of shrinkage. The shrinkage of 8% with exposure to steam was much less than the 15% with water.

Statistical analysis was done to determine any significance.

Table 31: Anova of the relaxation shrinkage with steam of the *Gonometa postica* silk fabric in weft direction compared to the *Gonometa postica* silk weft/wool warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	8.0000	0.0000	0.0000	
Silk/wool	10	8.0000	0.0000	0.0000	

The analysis indicated that there was no significant difference between the relaxation shrinkage of the *Gonometa postica* silk fabric in the weft direction compared to the *Gonometa postica* silk weft/wool warp fabric in the same direction, as the mean values are the same.

Table 32: Anova of the relaxation shrinkage of the *Gonometa postica* silk fabric in the warp direction compared to the *Gonometa postica* silk weft/wool warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	8.0000	0.0000	0.0000	
Silk/wool	10	0.0000	0.0000	0.0000	0.000

The analysis indicates that there was a significant difference between the relaxation shrinkage of the *Gonometa postica* silk fabric in the warp direction and the *Gonometa postica* silk weft/wool warp fabric in the same direction, with the p-value < 0.05.

Table 33: Anova of the relaxation shrinkage with steam of the *Gonometa postica* silk fabric in the weft direction compared to the *Gonometa postica* silk weft/acrylic warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	8.000	0.0000	0.0000	
Silk/acrylic	10	8.000	0.0000	0.0000	

The analysis indicates that there was no significant difference between the *Gonometa postica* silk fabric in the weft direction and the *Gonometa postica* silk weft/acrylic warp fabric in the same direction, as the mean values are the same.

Table 34: Anova of the relaxation shrinkage with steam of the *Gonometa postica* silk fabric in the warp direction compared to the *Gonometa postica* silk weft/acrylic warp fabric in the same direction.

Test group	N	Mean	Std. Deviation	Std. Error	P-value
Silk/silk	10	8.0000	0.0000	0.0000	
Silk/acrylic	10	0.0000	0.00000	0.00000	0.000

The analysis indicates that there was a significant difference between the relaxation shrinkage of the *Gonometa postica* silk fabric in the warp direction and the *Gonometa postica* silk weft/acrylic warp fabric in the same direction, with the p-value < 0.05.

# Chapter 5: Conclusion and recommendation

## 5.1 Conclusion

The aim of this study was to establish if the *Gonometa postica* silk could be mixed with wool or acrylic without losing its unique properties, in order to make the *Gonometa postica* silk fabric more affordable. This was achieved by the evaluation of certain properties of the *Gonometa postica* silk weft/wool warp mixed yarn fabric and *Gonometa postica* silk weft/acrylic warp mixed yarn fabric, and comparing those with the properties of the *Gonometa postica* silk fabric.

From the results obtained from the tests, conclusions are drawn based on the hypotheses and aims relating to the properties of the test fabrics.

According to hypothesis 1 there will be a significant difference between the number of rubs needed to break two yarns of the *Gonometa postica* silk fabric and the number required by the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics, when measured with the Martindale wear and abrasion tester. The results showed that the *Gonometa postica* silk weft/wool warp fabric had the best abrasion resistance, while the *Gonometa postica* silk weft/acrylic warp fabric and *Gonometa postica* silk fabric showed a closer relation in abrasion resistance.

A significant difference was found in the number of rubs needed to break the *Gonometa postica* silk fabric and the *Gonometa postica* silk weft/wool warp fabric, while there was not a significant difference in the number of rubs needed to break the *Gonometa postica* silk fabric and the *Gonometa postica* silk weft/acrylic warp fabric.

Therefore hypothesis 1 is only accepted for on the *Gonometa postica* silk weft/wool warp fabric and rejected for the *Gonometa postica* silk weft/acrylic warp fabric as no significant difference was found between the number of rubs needed to break two yarns in the *Gonometa postica* silk fabric and *Gonometa postica* silk weft/acrylic warp fabric.

Hypothesis 2 stated that there will be a significant difference in weight loss of the *Gonometa postica* silk fabric, as opposed to that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics, when abraded with the Martindale wear and abrasion tester. The results showed that the *Gonometa postica* silk fabric had the largest weight loss, while the *Gonometa postica* silk weft/wool warp fabric had the smallest weight loss. There was a significant difference in the weight loss of the *Gonometa postica* silk and *Gonometa postica* silk weft/wool warp fabric, as well as in the weight loss of the *Gonometa postica* silk fabric and *Gonometa postica* silk weft/acrylic warp fabric. Therefore hypotheses 2 are proven to be true for the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics.

According to hypothesis 3 there will be a significant difference between the maximum load required to break the *Gonometa postica* silk fabric in the weft direction and that required to break the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the same direction, when measured with the Instron tensile tester. The weft direction of the *Gonometa postica* silk fabric required the highest maximum load to break the fabric, while the *Gonometa postica* silk weft/acrylic warp fabric in the weft direction required the lowest maximum load to break. There isn't a significant difference in maximum loads needed to break the *Gonometa postica* silk fabric and the *Gonometa postica* silk weft/wool warp fabric in weft direction, but there is a significant difference between the maximum loads required to break the *Gonometa postica* silk fabric in weft direction compared to the *Gonometa postica* silk weft/acrylic warp fabric in weft direction.

Therefore hypothesis 3 is rejected for the *Gonometa postica* silk weft/wool warp fabric, but it is true for the *Gonometa postica* silk weft/acrylic warp fabric.

Hypothesis 4 stated that there will be a significant difference in the maximum load required to break the *Gonometa postica* silk fabric in the warp direction and that required to break and the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the same direction, when measured with the Instron tensile tester. The *Gonometa postica* silk weft/acrylic warp fabric required the highest maximum load in the warp direction to break, while the *Gonometa postica* silk fabric required the lowest maximum load in the warp direction to break.

No significant difference was found in the maximum loads required to break the *Gonometa postica* silk fabric and *Gonometa postica* silk weft/wool warp fabric in the warp direction, but there is a significant difference between the maximum loads required to break the *Gonometa postica* silk fabric in the warp direction compared to the *Gonometa postica* silk weft/acrylic warp fabric in the warp direction. Therefore hypothesis 4 is only applicable to the *Gonometa postica* silk weft/acrylic warp fabric, and rejected for the *Gonometa postica* silk weft/wool warp fabric.

According to hypothesis 5 there will be a significant difference between the displacement at maximum load of the *Gonometa postica* silk fabric in the weft direction, at maximum load, and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the same direction, when measured with the Instron tensile tester. The *Gonometa postica* silk fabric and the *Gonometa postica* silk weft/wool warp fabric had almost the same displacement in the weft direction, while the *Gonometa postica* silk weft/acrylic warp had less displacement in the weft direction. There wasn't a significant difference between the displacement at maximum load of the *Gonometa postica* silk fabric in the weft direction and the *Gonometa postica* silk weft/wool warp fabric or the *Gonometa postica* silk weft/acrylic warp fabric in weft direction. Therefore hypothesis 5 is rejected as it isn't true for any of the test fabrics.

Hypothesis 6 stated that there will be a significant difference between the displacement at maximum load of the *Gonometa postica* silk fabric in the warp direction, at maximum load, and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the same direction, when measured with the Instron tensile tester. The *Gonometa postica* silk weft/acrylic warp fabric showed the most displacement in the warp direction, while the *Gonometa postica* silk fabric showed the least displacement in the warp direction. There is a significant difference between the displacements at maximum load of the *Gonometa postica* silk fabric in the warp direction and the *Gonometa postica* silk weft/acrylic warp fabric in the warp direction. Therefore hypothesis 6 is accepted and true for the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp fabrics.

According to hypothesis 7 there will be a significant difference between the stiffness of the *Gonometa postica* silk fabric and the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the weft direction, when measured with the Shirley stiffness tester. The test fabrics had very close bending lengths in the weft direction, but the *Gonometa postica* silk weft/acrylic warp fabric had the largest bending length in weft direction, while the *Gonometa postica* silk fabric had the smallest bending length in the weft direction. The *Gonometa postica* silk weft/wool warp fabric had the highest flexural rigidity in the weft direction and the *Gonometa postica* silk fabric had the lowest flexural rigidity in weft direction.

There wasn't a significant difference in stiffness between the stiffness of the *Gonometa postica* silk fabrics' weft direction and the *Gonometa postica* silk weft/wool warp fabrics' weft direction, but there was a significant difference between the stiffness of the *Gonometa postica* silk fabrics' weft and the *Gonometa postica* silk weft/acrylic warp fabrics' weft direction. Therefore hypothesis 7 is accepted for the *Gonometa postica* silk weft/acrylic warp fabric as it is true, but rejected for the *Gonometa postica* silk weft/wool warp fabric.

Hypothesis 8 stated that there will be a significant difference between the stiffness of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the warp direction, when measured with the Shirley stiffness tester. The *Gonometa postica* silk fabric had the smallest bending length in the warp direction and the *Gonometa postica* silk weft/acrylic warp fabric had the largest bending length in the warp direction. There is a significant difference between the stiffness of the *Gonometa postica* silk fabrics' warp direction and the *Gonometa postica* silk weft/wool warp fabrics' and *Gonometa postica* silk weft/acrylic warp fabrics' warp direction.

Therefore hypothesis 8 is accepted as it is found to be true for the *Gonometa postica* silk weft/wool warp fabric and the *Gonometa postica* silk weft/acrylic warp fabric.

According to hypotheses 9 there will be a significant difference between the crease recovery of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the weft direction, when measured with the Shirley crease recovery tester. The *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp fabrics showed nearly the same crease recovery in the weft direction, while the *Gonometa postica* silk fabric showed less recovery in the weft direction. There isn't a significant difference between the crease recovery of the *Gonometa postica* silk fabrics' weft direction and the *Gonometa postica* silk weft/wool warp fabrics' weft direction or the *Gonometa postica* silk weft/acrylic warp fabrics' weft direction. Therefore hypothesis 9 is rejected as it wasn't found to be true for either of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp fabrics.

Hypothesis 10 stated that there will be a significant difference between the crease recovery of the *Gonometa postica* silk fabric and that of the silk/wool and silk/acrylic mixed yarn fabrics in the warp direction, when measured with the Shirley crease recovery tester. The *Gonometa postica* silk weft/wool warp fabric had by far the best crease recovery in the warp direction, while the *Gonometa postica* silk fabric had the least recovery in the warp direction.

A significant difference was found in the crease recovery of the *Gonometa postica* silk fabrics' warp direction and the *Gonometa postica* silk weft/wool warp fabrics' warp direction, but no significant difference was found in the crease recovery of the *Gonometa postica* silk fabrics' warp direction and the *Gonometa postica* silk weft/acrylic warp fabrics' warp direction. Therefore hypothesis 10 is rejected for the *Gonometa postica* silk weft/acrylic warp fabric as it was not found to be true, but accepted for the *Gonometa postica* silk weft/wool warp fabric as it was shown to be true.

According to hypothesis 11 there will be a significant difference between the thickness of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics, when measured with the Essdiel thickness gauge. The *Gonometa postica* silk weft/wool warp fabric was the thickest, while the *Gonometa postica* silk fabric was the thinnest. There isn't a significant difference in thickness of the *Gonometa postica* silk fabric and the *Gonometa postica* silk weft/wool warp fabric or between the thicknesses of the *Gonometa postica* silk test fabric and the *Gonometa postica* silk weft/acrylic warp test fabric. Therefore hypothesis 11 is rejected as it wasn't found to be true for the *Gonometa postica* silk weft/wool warp fabric or the *Gonometa postica* silk weft/acrylic warp fabric.

According to hypothesis 12 there will be a significant difference between the moisture regain of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics, when measured by weight-loss using a drying oven.

The *Gonometa postica* silk fabric had the highest moisture regain, while the *Gonometa postica* silk weft/acrylic warp fabric had the lowest moisture regain. No significant difference was found between the moisture regain of the *Gonometa postica* silk fabric and the *Gonometa postica* silk weft/wool warp fabric, but there is a significant difference between the moisture regains of the *Gonometa postica* silk fabric and the *Gonometa postica* silk weft/acrylic warp fabric. Therefore hypothesis 12 is accepted for the *Gonometa postica* silk weft/acrylic warp fabric as it was found to be true, but rejected for the *Gonometa postica* silk weft/wool warp fabric as it wasn't found to be true.

According to hypothesis 13 there will be a significant difference between the shrinkage of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the weft direction, when exposed to water. The *Gonometa postica* silk weft/acrylic warp fabric showed the most shrinkage in the weft direction, while the *Gonometa postica* silk fabric showed the least shrinkage in the weft direction. There isn't a significant difference between the relaxation shrinkage of the *Gonometa postica* silk fabrics' weft direction compared to the *Gonometa postica* silk weft/wool warp fabrics' weft direction, but there was a significant difference between the *Gonometa postica* silk fabrics' weft direction and the *Gonometa postica* silk weft/acrylic warp fabrics' weft direction. Therefore hypothesis 13 is accepted for the *Gonometa postica* silk weft/acrylic warp fabric as it was shown to be true, but rejected for the *Gonometa postica* silk weft/wool warp fabric as it was not found to be true.

Hypothesis 14 stated that there will be a significant difference between the shrinkage of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the warp direction, when exposed to water. There was no shrinkage found in the warp directions of the *Gonometa postica* silk weft/wool warp fabric and *Gonometa postica* silk weft/acrylic warp fabric, but the *Gonometa postica* silk fabric did shrink in the warp direction. There was a significant difference between shrinkage of the *Gonometa postica* silk fabrics' warp direction and the *Gonometa postica* silk weft/wool warp fabrics' and the *Gonometa postica* silk weft/acrylic warp fabrics' warp directions. Therefore hypothesis 14 is accepted as it was found to be true for both the *Gonometa postica* silk weft/wool warp fabric and the *Gonometa postica* silk weft/acrylic warp fabric.

According to hypothesis 15 there will be a significant difference between the shrinkage of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the weft direction, when exposed to steam. All of the test fabrics showed the same amount of shrinkage in the weft direction, and therefore there wasn't a significant difference in shrinkage of the *Gonometa postica* silk fabric and *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp fabrics in weft direction. Hypothesis 15 is rejected as it was not found to be true for neither the *Gonometa postica* silk weft/wool warp fabric nor *Gonometa postica* silk weft/acrylic warp fabric.

Hypothesis 16 stated that there will be a significant difference between the dimensional stability of the *Gonometa postica* silk fabric and that of the *Gonometa postica* silk weft/wool warp and the *Gonometa postica* silk weft/acrylic warp mixed yarn fabrics in the warp direction, when exposed to steam. Only the *Gonometa postica* silk fabric showed shrinkage in the warp direction, and there is a significant difference between the relaxation shrinkage of the *Gonometa postica* silk fabrics' warp direction and the *Gonometa postica* silk weft/wool warp fabrics' and the *Gonometa postica* silk weft/acrylic warp fabrics' warp direction. Therefore hypothesis 16 is accepted as it was shown to be true for both the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk weft/acrylic warp fabrics.

## **5.2 Recommendation**

In order to reach the recommendation it was necessary to carefully review the results that were obtained from the various tests executed.

The *Gonometa postica* silk weft/acrylic warp fabric showed better tensile strength with a higher maximum load and larger displacement than the *Gonometa postica* silk weft/wool warp and *Gonometa postica* silk fabrics.

The *Gonometa postica* silk weft/wool warp fabric had the best abrasion resistance and crease recovery, which are both very desirable characteristics of a textile fabric.

When comparing the stiffness of the fabric it was the *Gonometa postica* silk weft/wool warp fabric that showed the closest relation to the *Gonometa postica* silk fabric, and the same was found with the moisture regain.

Therefore it is recommended that the *Gonometa postica* silk be mixed with wool, rather than acrylic as it was found that the wool will improve important properties, with no negative impact on the other properties of the silk. It will also still lower the price of the textile fabric, which was one of the objectives.

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## **Abstract**

Silk occupies a unique position as a textile fibre with a rare combination of beauty and strength. Production and processing of silk is labour intensive which leads to high cost and limited production of the silk fibre. Unfortunately the high cost of silk makes it unaffordable for many consumers; therefore mixed yarn fabrics could be constructed in order to lower the price of the fabric, without changing the unique properties of the silk negatively.

The aim of this study was to evaluate and compare the properties of *Gonometa postica* silk fabric with the properties of mixed yarn fabrics consisting of *Gonometa postica* silk weft on a wool warp, and *Gonometa postica* silk weft on an acrylic warp. This is done in order to determine which of the wool or the acrylic create a more suitable mixed yarn fabric with the *Gonometa postica* silk.

Standard methods were used to evaluate the abrasion resistance (ASTM 4966), tensile strength and elongation (ISO 13934), stiffness (BS 3356), crease recovery (AATCC 66), fabric thickness (BS 2544), dimensional change (AATCC 99) and moisture regain (ASTM 2654). Analysis of variance supported the interpretation of the results of the tests.

The *Gonometa postica* silk textile fabric has relatively good abrasion resistance, with a mean value of 28 750 rubs necessary to break two yarns.

The *Gonometa postica* silk weft/wool warp test fabric showed very good abrasion resistance with a mean value of 51 000 rubs required to break two yarns. And the *Gonometa postica* silk weft/acrylic warp test fabric also showed relatively good abrasion resistance, although it was lower than the other test fabrics with a mean value of 25 197 rubs needed to break two yarns. The *Gonometa postica* silk test fabric had the largest weight loss, while the *Gonometa postica* silk weft/wool warp fabric had the smallest weight loss.

Tensile strength and displacement were measured and the *Gonometa postica* silk fabric had the highest mean maximum load necessary to break the silk weft yarns of 492.317 N and the mean displacement at maximum load was 39.048 mm. The *Gonometa postica* silk weft/acrylic warp fabric had the lowest mean maximum load that the silk weft yarns could carry before break at 347.910 N and the displacement was 34.465 mm.

The bending lengths of all the samples were small enough to indicate that it has good draping qualities, considering the thickness of the fabrics.

The *Gonometa postica* silk weft/wool warp fabric showed the best crease recovery especially in the warp direction (145°), while the *Gonometa postica* silk fabric had the worst crease recovery especially in the warp direction (128°).

The *Gonometa postica* silk weft/*Gonometa postica* warp fabric was thinner than the *Gonometa postica* silk weft/wool warp fabric and the *Gonometa postica* silk weft/acrylic warp fabric.

The moisture regain of the *Gonometa postica* silk fabric was found to be 13%, while the *Gonometa postica* silk weft/wool warp fabric had a moisture regain of 11% and the *Gonometa postica* silk weft/acrylic warp fabric had a moisture regain of 8.6%.

The *Gonometa postica* silk weft/wool warp fabric and the *Gonometa postica* silk weft/acrylic warp fabric had no shrinkage in the warp directions. The *Gonometa postica* silk fabric showed more shrinkage in the warp direction than in the weft direction. No residual shrinkage was found.

This lead to the conclusion that the wool would be the best fibre to mix with the *Gonometa postica* silk as it enhanced some of the properties of the silk, without influencing the properties negatively.

**Key terms:** *Gonometa postica* silk, wool, acrylic, mixed yarn fabrics, abrasion resistance, tensile strength, stiffness, moisture regain, crease recovery, shrinkage.

## Opsomming:

Sy beslaan 'n unieke posisie as tekstielvesel met 'n skaars kombinasie van skoonheid en sterkte. Produksie en prosessering van sy is arbeids-intensief en dit lei tot hoë koste en beperkte produksie van sy. Ongelukkig lei hierdie hoë pryse daartoe dat dit onbekostigbaar is vir baie verbruikers, daarom kan gemengde garing stowwe gemaak word om die prys van die tekstielstof te verlaag, sonder om die unieke eienskappe van die sy negatief te beïnvloed.

Die doel van hierdie studie was om die eienskappe van die tekstielstowwe wat bestaan uit *Gonometa postica*-sy-inslag op wol-skering en *Gonometa postica*-sy-inslag op akriel-skering te evalueer en dit dan met *Gonometa postica*-sy-tekstielstof te vergelyk. Dit word gedoen om te kan bepaal watter van die wol of akriel geskik sal wees om met die *Gonometa postica*-sy te meng.

Standaard metodes was gebruik om slytweerstand (ASTM 4966), breek sterkte (ISO 13934), styfheid (BS3356), kreukelherstel (AATCC 66), materiaal dikte (BS2544), krimpings (AATCC 99) en vogbyslag (ASTM 2654) te evalueer. Variansie analise was aangewend met die interpretasie van die resultate.

Die *Gonometa postica*-sy-inslag/*Gonometa postica*-sy-skering tekstielstof het goeie slytweerstand getoon, met 'n gemiddeld van 28 750 vrywe nodig om twee drade te breek.

Die *Gonometa postica*-sy-inslag/wol-skering tekstielstof toon baie goeie slytweerstand met 'n gemiddeld van 51 000 vrywe nodig om twee drade te breek. Die *Gonometa postica*-sy-inslag/akriel-skering tekstielstof het ook goeie slytweerstand alhoewel dit laer as die ander tekstielstowwe was met 'n gemiddeld van 25 197 vrywe voor twee drade gebreek het. Die *Gonometa postica*-sy-tekstielstof het die meeste gewigsverlies gehad terwyl die *Gonometa postica*-sy-inslag/wol-skering tekstielstof die minste gewigsverlies gehad het.

Breeksterkte en verplasing was geëvalueer en die *Gonometa postica*-sy-tekstielstof het die grootste gemiddelde maksimum vrag van 492.317 N gedra voordat dit gebreek het, met 'n verplasing van 39.048 mm. Die *Gonometa postica*-sy-inslag/akriel-skering tekstielstof het die kleinste gemiddelde maksimum vrag gedra van 347.910 N voordat dit gebreek het, met 'n verplasing van 34.465 mm.

Die buiglengtes van al drie die tekstielstowwe was klein genoeg om aan te dui dat dit goeie drapeervermoë het, veral as die dikte van die tekstielstowwe in ag geneem word.

Die *Gonometa postica*-sy-inslag/wol-skering tekstielstof het die beste kreukelherstel getoon ( $145^\circ$ ) in die skering rigting, terwyl die *Gonometa postica*-sy-tekstielstof die swakste kreukelherstel getoon het ( $128^\circ$ ) in die skering rigting.

Die *Gonometa postica*-sy-tekstielstof was baie dunner die ander tekstielstowwe.

Die vogbyslag van die *Gonometa postica*-sy-tekstielstof was 13%, terwyl die *Gonometa postica*-sy inslag/wol-skering tekstielstof 'n vogbyslag van 11% gehad het en die *Gonometa postica*-sy-inslag/akriel-skering tekstielstof 'n vogbyslag van 8.6% het.

Die *Gonometa postica*-sy-inslag/wol-skering tekstielstof en die *Gonometa postica*-sy-inslag/akriel-skering tekstielstof het beide geen krimping in die skering rigting getoon nie. Die *Gonometa postica*-sy-tekstielstof het meer krimping in die skering rigting as in die inslag rigting getoon. Geen residuele krimping is gevind nie.

Hierdie resultate het gelei tot die gevolgtrekking dat die wol die beste vesel sal wees om met die *Gonometa postica*-sy te meng, omdat van die sy se eienskappe verbeter het sonder om 'n negatiewe invloed op ander eienskappe te toon.

**Sleutel terme:** *Gonometa postica*-sy, wol, akriel, gemengde garing-stowwe, slytsterkte, breeksterkte, styfheid, voglobslag, kreukelherstel, krimping.