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THE EFFECT OF REGULAR AND MICRO DETERGENTS ON THE COLOURFASTNESS AND STRENGTH OF DYED COTTON FABRIC

by

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Declaration

I, the undersigned, hereby declare that the work contained in this thesis, is my own original work, and has not previously in its entirety or in part been submitted at any university for a degree.

Signature: WW de Villiers

Date: 25/11/98

OPSOMMING

Die doel met die navorsing was om die effek van *standaard* en *mikro waspoeiers* op die *kleurvastheid* en *sterkte* van *gekleurde katoenstowwe* te bepaal. 'n Eksperimentele studie is uitgevoer om die effek van vier huishoudelike waspoeiers van twee handelsmerke (twee standaard en twee mikro; massa volgens vervaardiers se aanbevelings), te vergelyk tov kleurvastheid en breeksterkte van gekleurde katoen, na herhaalde wasbehandelings (tot 50 wassiklusse) by 60°C. Die tekstielstowwe is in outomatiese, huishoudelike wasmasjiene gewas en mbv binneshuise lyndroging in 'n standaard atmosfeer gedroog. Kleurverlies is mbv 'n spektrofotometer gemeet in terme van kleurgehalte (Delta C), ligweerkaatsing (Delta L) en skakering (Delta H). Totale kleurverlies (Delta E) is ook bepaal. 'n Instron is gebruik om breeksterkte te meet en skandeer elektron mikroskoop (SEM) fotos is geneem.

Resultate toon dat die hoofeffekte (*aantal wassiklusse, kleur van tekstielstof* en *tipe detergent*), asook hulle interaksies, hoogs betenisvol verskil ($p \leq 1\%$). Die "pass/fail" metode (gebaseer op Delta E), wat die persentasie monsters met *kleurverlies* na 50 wasse aandui, het getoon dat slegs 50% monsters aanvaar is met die gebruik van Skip standaard, in vergelyking met Skip mikro (70%), Woolworths standaard (70%) en Woolworths mikro (76%). Die groen tekstielstof het uitermatige kleurverlies getoon met die gebruik van al vier detergente. Skip standaard en Woolworths standaard het die blou tekstielstof negatief beïnvloed. Alhoewel daar nie 'n afname in breek*sterkte* was nie, het die SEM fotos veselfibrillasie getoon, veral in die groen tekstielstof. Die gevolgtrekking word gemaak dat *aantal wassiklusse*, *tipe detergent* en *tekstielstofafwerking* veselfibrillasie beïnvloed. Die minste beskadiging het in die wit en blou tekstielstowwe voorgekom. Beide was gemerceriseer en het 'n kruisbinding afwerking gehad. Skip standaard het die groen tekstielstof (geen afwerking) meer beskadig as die ander drie waspoeiers. Met beide handelsmerke het die standaard waspoeiers die kleurvastheid en sterkte van tekstielstowwe meer negatief beïnvloed as die mikro waspoeiers.

SUMMARY

The aim of this research was to determine the effect of regular and micro detergents on the colourfastness and tensile strength of dyed cotton fabrics. An experimental study was carried out to compare the effect of four household detergents from two brands (two regular and two micro; mass according to manufacturers' recommendations), on the colourfastness and strength of dyed cotton fabrics (white, blue and green), after multiple wash treatments (up to 50 wash cycles) at 60°C. Fabrics were laundered in automatic, drum-type household washing machines and line dried indoors in a standard atmosphere. Colour loss was measured in terms of chroma (Delta C), lightness (Delta L) and hue (Delta H), using a spectrophotometer. Total colour loss in fabrics (Delta E) was computed. An Instron tensile tester was used to measure tensile strength and scanning electron microscope (SEM) photos were taken.

Results indicated that the main effects (*number of wash cycles, fabric colour, detergent type*), as well as their interactions, showed highly significant differences ($p \leq 1\%$). The pass/fail method (based on Delta E), indicating the percentage samples showing *colour loss* after 50 wash cycles, showed that with Skip regular, only 50% of the samples were accepted, compared to Skip micro (70%), Woolworths regular (70%) and Woolworths micro (76%). The green fabric showed extensive colour loss with all four detergents used, whereas Skip regular and Woolworths regular affected the blue fabric negatively. Although there was no loss in fabric tensile *strength*, SEM photos showed considerable fibre fibrillation, especially in the green fabric. It was concluded that *number of wash cycles*, *detergent type* and *fabric finishing* affect fibre fibrillation. The least damage occurred in the white and blue fabrics, which were both mercerised and cross-linked. Skip regular caused more damage to the green fabric (not treated) than the other three washing powders. With both brands, the regular washing powders influenced the colourfastness and strength of fabrics more negatively than the micro powders.

Die krusifiks.

Wees is lewende tekstiel
ononderbroke voelend-gevoelig
selfwewend:Passie; net uitgestrekter
as daardie ander gepersde voorbeeld
ter kras desnoodse illustrasie
van hoe geen stekie bewustheid ooit
sonder Hom is nie. Ek is deurtrek van Hom.
Só, dat ek vandag, ongeduldig met
orals waar ek kerke kry, sy koue corpus,
ń ander ding gedoen het:
my hele webmassa gedompel het opnuut
tot deurtinteling van elke verrafelde vesel
in daardie ontsaglike Son-Hy
wat straal uit my krusifiks se goue kéérsy.

(Cussons, S.1997: ń Engel deur my kop. bls.50)

Dank aan almal wat ń bydrae gelewer

het om hierdie navorsing moontlik te maak

Opgedra aan my vier seuns.

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CHAPTER 1

STATEMENT OF PROBLEM

1. Overview

During the past years various types of synthetic detergents have been developed for household use. These include products containing fluorescent whitening agents, softeners, enzymes, foam regulators and bleaching activators. Two main ingredients in synthetic detergents are surfactants and builders (Brown, Cameron & Meyer, 1993[2]:267). Surfactants are the active ingredients whereas builders such as carbonates, phosphates, zeolites and citrates react with impurities in water such as calcium and magnesium ions and therefore increase the cleansing power of the product (Cameron & Brown, 1995:85). Most present-day detergents have fluorescent and optical brighteners in addition to oxygen bleaches.

Laundry detergents are generally available in two forms, namely heavy duty products, suitable for heavily soiled fabrics and light duty products, developed primarily for hand washing and lightly soiled clothing (Cameron & Brown, 1995:86). Recently so-called combination laundry powders have become available which contain detergents in combination with colour safe bleaches and/or fabric softeners (Cameron & Brown, 1995:87). A major development over the last four years has been the introduction of micro detergents as a response to consumers' desire for "greener" products. These detergents are concentrated, use less packaging than regular detergents and save energy in production, distribution and use (Swaine, 1993:4; Cameron, Brown, 1995:87 & Ford, 1991:3).

The variety of laundry detergents available has lead to research concerning the use of these products. Various researchers have studied the effectiveness of detergents. The effectiveness of laundry powders (Brown, Cameron & Meyer, 1993[1]:145) and laundry liquids (Brown, Cameron & Meyer 1993[2]:267) have been tested. The effectiveness of detergents in cleaning standard soiled fabrics in water of varying hardness has also been evaluated (Brown, Cameron, Meyer & Umber, 1991:215; Umber, Brown, Cameron, Meyer, Powell & Burton, 1992:151; Cameron & Brown, 1995:85). Tinsley, Byrne and Fritz (1991:223) investigated the effect of detergents on fabric handle whereas Sainio (1996:83) discovered that in some cases concentrations of detergent residues are found in textiles, which may lead to skin irritations and allergies. The above research data is of importance to consumers, retailers and manufacturers of textile products.

The effect of laundering on the wear life of cotton fabrics has been investigated extensively. Research indicates that detergent type, number of launderings used, water quality as well as finishes applied to cotton fabrics, are important factors in the deterioration of fabric colour (Krüszmann, 1982:24; Lord, 1971; Ulrich and Mohamed, 1982[1]:39; Mohamed 1982[2]:29; Reinhardt and Graves, 1996:28). It was also established that degradation of fabric strength, due to laundering treatments, include a combined effect of mechanical and chemical damage. Apart from mechanical or chemical degradation, researchers indicate that a number of factors may have an effect on textile degradation during laundering. They include number of wash cycles used, temperature of wash water, fabric finishes and water quality (Jokelainen and Kujala, 1984:333; Hördler, Mizner and Hetzer, 1976:853; Griffioen, 1973:221; Mohamed, 1982[1]:65; Ulrich and Mohamed, 1982:38; Raheel, 1983[1]:639; Rhee, Young and Sarmadi, 1993:403).

1.2 Problem statement

Apart from its ability to clean textile products, the effect of detergents on the degradation of textiles, including colour change and decrease in strength, can be regarded as criteria for measuring its effectiveness.

Recent data on consumer complaints obtained from a well- known retail company in South Africa, show that approximately 85% of all complaints on textile products, relate to colourfastness during care (Thistleton,1996). It is suspected that laundry additives such as detergents, may be the cause of these problems.

However, research regarding the effect of detergents on the colourfastness and strength of fabrics, usually include an investigation into detergency efficiency, and not the effect of detergents on fabrics as such. Also, in establishing the cleaning effectiveness of a detergent on soiled fabrics, may only necessitate one wash cycle. Criteria set for investigating fibre damage and colour change by detergents requires multiple wash cycles e.g., between 25 to 50 washes (Jakobi & Löhr, 1987[1]:397). Elder (1978:5), Higginbotham (1976:43-44), Raheel and Lien (1985:3) and Williams and Horridge (1996:137) reported research data on the above matters.

According to Elder (1978:5), both mechanical and chemical damage was found to have occurred in laundering trials on bed sheets. Higginbotham (1976:43) indicated that in using detergents with sodium perborate, a powerful bleaching agent, chemical damage of cotton fabrics could be greater than mechanical damage (Inglis & Leaver, 1967:998). In a study conducted by Raheel and Lien (1985:23) cotton fabric was subjected to various detergency conditions, including no detergent. It was found that at a temperature of 40°C detergent degraded fabrics more than water alone. Williams and Horridge (1996:144 & 156) found that laundry pretreatments on soiled, naturally coloured cotton immediately before laundering, had altered the inherent colours of the fabrics.

Although the research reported above suggest that detergents may have a degradative effect on the colour and strength of textiles, no information seems to be available on the effect of micro detergents on fabrics. No research in this regard could be found. Apart from the role regular detergents play in this regard, it is suspected that the new micro detergents might react differently on fabrics. According to Swaine (1993:4) micro detergents use 30% less chemicals per wash than regular detergents. It is assumed that these detergents would degrade fabrics to a lesser degree than regular detergents.

On the contrary, manufacturers and retailers have considered the possibility that the use of newly developed micro detergents might bear relation to the rise in consumer complaints on fabric colourfastness (Greenblau, 1996; Thistleton, 1996). If this is the case, laboratory tests carried out by retail companies for quality management which employ regular detergents, will have to be adapted (Thistleton, 1996).

From the above, it is clear that there is a need to investigate whether there is a difference in effect between regular and micro detergents of the same brand on the colourfastness and strength of fabrics. Answers to these questions would be of value to both industry and consumers. The Department of Consumer Studies, at the University of Stellenbosch, was approached by a well-known retail company , Woolworths, to specifically investigate the above- mentioned issue.

1.3 Research objectives

The broad aim of the research was to determine the effect of regular and micro detergents on the colourfastness and tensile strength of woven cotton fabrics, used in everyday wear. This could be established by comparing the effect of repeated laundering on dyed cotton fabrics, using both types of detergents.

More specifically stated, the objectives were:

1.3.1. To assess the effect of repeated laundering with regular and micro detergents on the colourfastness of dyed cotton fabrics.

1.3.2 To assess the long-term effect of repeated laundering with regular and micro detergents on the tensile strength of dyed cotton fabrics.

1.4 Study limitations

This study is viewed as an exploratory investigation into the effect of specific detergent types on dyed cotton fabrics. No evaluation was done regarding the detergency efficiency of the fabrics. It could be expected that research results might differ in using stained fabrics, as would be the case with consumer use of the products investigated.

Experimental fabrics subjected to laundering treatments in this study were evaluated for change in colour and tensile strength. As degradation of fabrics manifests itself in many ways, it is expected that the measurement of additional fabric properties, such as weight loss and handle, will shed more light on the true effect of detergents.

1.5 Variables and hypotheses

1.5.1 Variables

1.5.1.1 Independent Variables

The independent variables were the detergent type (regular and micro), the number of wash cycles used and the colour of experimental fabrics used in this study.

1.5.1.2 Dependent Variables

Colourfastness and strength of dyed cotton fabrics were the dependent variables.

1.5.2 Hypotheses

The null hypotheses were:

$H1_0$: There will be no difference in the influence of regular and micro detergents on the colour of dyed cotton fabrics after multiple laundry treatments.

$H2_0$: There will be no difference in the influence of regular and micro detergents on the strength of dyed cotton fabrics after multiple laundry treatments.

1.6 Conceptual framework

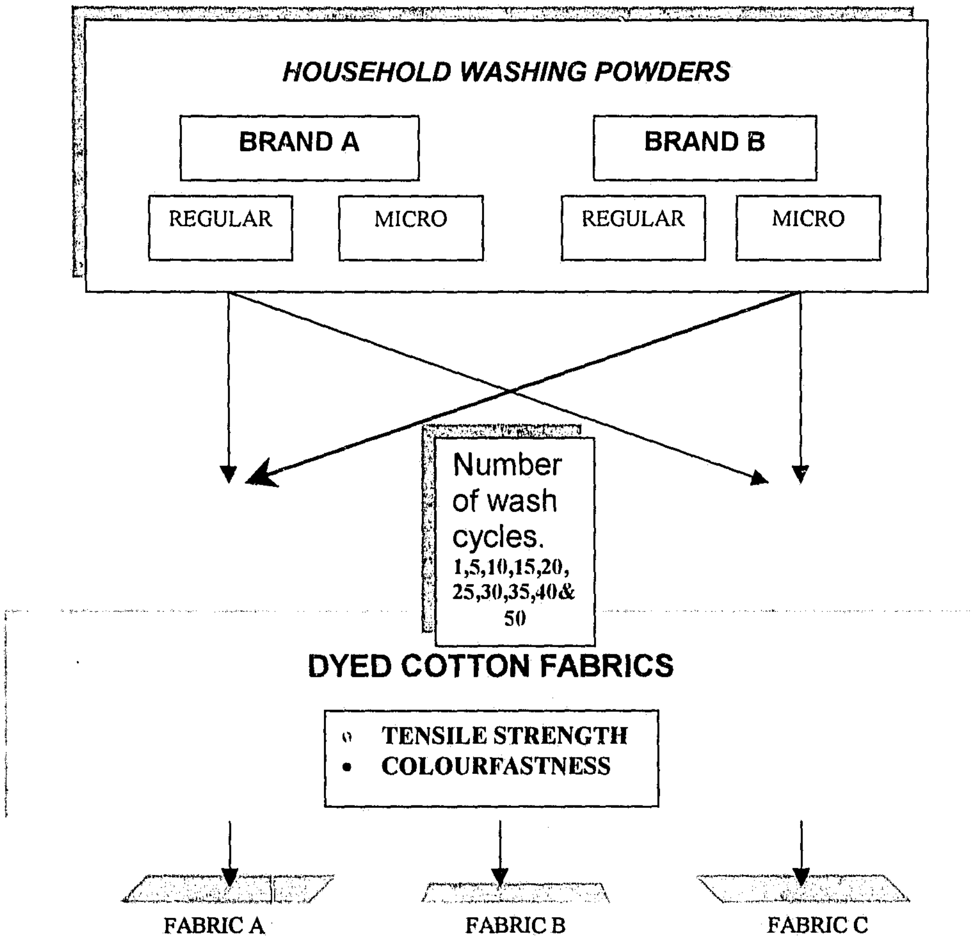

Figure 1: Conceptual framework

The above framework shows that the effect of regular and micro detergents of two different brands on the colourfastness and tensile strength of three different cotton fabrics, will be measured after subjecting the dyed fabrics to multiple wash cycles.

1.7 Operational definitions

1.7.1 Detergent

A chemical compound specially formulated to remove soil or other material from textiles. (Kadolph, SJ, Langford, AL, Hollen, N & Saddler, J, 1993:391).

1.7.2 Regular detergent

For this research regular detergent refers to a synthetic household washing powder specifically developed for use in automatic household washing machines.

1.7.3 Micro detergent

Newly developed environmental friendly, synthetic household washing powder for use in automatic household washing machines.

1.7.4 Wash cycle

One wash cycle refers to a specific experimental fabric being washed once in an automatic household washing machine using a specific detergent, a specific washing programme and one successive line drying period.

1.7.5 Degradation of Cotton Fabrics

Degradation of cotton fabrics refers to the pervasive change in textile structure, reducing its life expectancy (Slater, 1991:2). Mechanical action and chemical damage are the main causes of textile degradation during laundering (Slater, 1991:10). Degradation manifests itself in a variety of ways. Loss or change of colour and change of tensile strength are considered to be the main effects of degradation.

1.7.6 Colourfastness

This is the resistance of a textile fabric to change in any of its colour characteristics, to transfer of its colour(s) to adjacent materials, or both, as results of the exposure of the fabrics to laundering treatment (Merkel, 1991:369).

1.7.7 Measurement of colourfastness

Each colour has its own distinct appearance based on the elements hue, chroma and value. These three elements were used in the study to determine colour loss in experimental fabrics.

1.7.8 Hue

Hue refers to how a fabric's colour is perceived, e.g. white, green, blue, etc. (Datacolor, 1996:6).

1.7.9 Chroma

The vividness or dullness of a colour describes its chroma (Datacolor, 1996:6).

1.7.10 Value

Value describes a colour's luminous intensity or degree of "lightness" (Datacolor, 1996:6).

1.7.11 Tensile Strength

This is the maximum resistance of a textile fabric to deformation in a tensile test carried to rupture; that is, the breaking load or force per unit cross- sectional area of the unstrained specimen (Booth, 1968:353).

1.8 Research report sequence

The purpose and relevance of this study is explained in the first chapter. Establishing interrelationships between the effect of the factors *detergent type* (regular and micro), *number of wash cycles* and the *colour of experimental fabrics* on the *colourfastness* and *strength* of dyed cotton fabrics, was the main objective of the study.

As this research is of an exploratory nature, a literature review (Chapter 2) was conducted to obtain insight into the above mentioned variables. The functions of detergent ingredients as well as their influence on fabric properties are discussed. This is followed by an overview of the structure of the cotton fibre, which could serve as explanation for the mechanism of degradation of cotton during laundering. Where possible, research findings reported in literature, is discussed. The chapter is concluded with a discussion on methods used for assessing colour change and tensile strength in cotton fabrics.

The research procedure followed in this study is described in Chapter 3. A full explanation is given of the types of detergents, fabrics and equipment used. The research procedures used are described in terms of fabric sampling, wash treatments as well as methods used to assess the possible degradation of colour and/or strength of experimental fabrics. The chapter is concluded with a description of the pilot study conducted to test and/or standardise a number of procedures, and methods followed during the main study.

The results of the empirical part of the study are presented in Chapter 4. The effect of regular and micro detergents on dyed cotton fabrics are described in terms of data obtained on change in colourfastness (hue, chroma, value) and tensile strength of experimental fabrics.

In the final chapter, conclusions are drawn and recommendations suggested, based on the findings obtained in the study.

CHAPTER 2

THE EFFECT OF HOUSEHOLD DETERGENTS ON DYED COTTON FABRICS

This chapter is a review of related literature and provides insight into the effect of household detergents on the colour and strength of cotton fabrics. It deals with a discussion of detergent ingredients and their functions, as well as their effect on textile fabrics. This is followed by an overview of the structure of the cotton fibre and its relation to fabric properties, basic cotton finishing processes and the dyeing of cotton, using reactive dyes. Research on laundering degradation is discussed, specifically in terms of the factors involved in the degradation of cotton after multiple laundry treatments. The methods followed to assess fabric degradation through laundering are described, with special reference to the assessment of fabric colourfastness and strength.

2.1 Detergents

The word detergent is derived from the Latin *detergo*, which means clean (Kay, 1995:28). Detergents without soap were developed mainly during the latter part of this century. Detergency refers to the removal of soil in the presence of a chemical substance (detergent) which may lower the adhesion of the soil to the substrate (BASF 1998:1).

In this section, a brief overview is given of the classification of detergents, followed by a description of the main ingredients of detergents and their functions. This information is necessary to understand and explain the chemical degradation of fabrics through detergent use. Although the main reason for detergency is soil removal, the focus of this study is its effect on fabrics. As soiling and its removal bear no relevance to this study, only research pertaining to the effect of detergents on the degradation of fabric colourfastness and strength after laundering, is reported (Bevan, 1979: 69).

2.1.1 Classification of household detergents

Household detergents are generally classified into four groups, namely heavy-duty or all-purpose detergents, speciality detergents, laundry aids and after treatment aids (Jakobi & Löhr, 1987[4]: 103).

In Europe, laundry powders make up 60% of sales of detergents (Brown, Cameron and Meyer, 1993[1]:145). In these countries laundry powders are classified as heavy-duty or all purpose products, suitable for all types of fabrics and light-duty products for delicates and baby clothes. Combination laundry powders have come into use recently, which consist of a detergent, combined with either colour-safe bleach or a fabric softener. Liquid detergents have been in use in the USA for a number of years (Jakobi & Löhr, 1987[4]:107; Lloyd &Adams 1989:80) and have been introduced to the European and South- African markets. However, these detergents have not been accepted widely by the South-African consumer (Hill, 1997).

Brown, Cameron and Meyer (1993[1]: 146) specifically mention the introduction of concentrates in powder form during the past few years. Through these products, detergent manufacturers have succeeded in minimising their environmental impact. These detergents use 30% less chemicals and 30% less packaging per wash than conventional detergents (Swaine, 1993:4). Concentrated (micro) laundry powders have largely replaced conventional or regular powders and liquids. A second generation of more condensed high-density powders has been introduced recently. It is believed that these developments will lead to changes in washing machine design to increase energy efficiency (CEH, 1998[1]:1).

2.1.2 Active detergent ingredients and functions

Detergents for household use are complex formulations and contain the following major groups of substances: surfactants, builders, bleaching agents and auxiliary agents (Jakobi & Löhr, 1987[4]:41). Each of these components has a specific function and may cause a specific problem during the washing process.

2.1.2.1 *Surfactants*

Surfactants are the most important components of detergents and are present in all types of detergents. They are the so-called active ingredients of a detergent (Cameron & Brown, 1995:85). Surfactants can be divided into four classes, depending on the charge present in the molecule after dissociation in an aqueous solution: anionic surfactants, non-ionic surfactants, cationic surfactants and amphoteric surfactants (Jakobi and Löhr, 1987[4]:41). Modern detergents generally contain larger amounts of anionic surfactants than non-ionic surfactants.

Anionic surfactants are widely used in laundry detergents. They are generally comprised of a hydrophobic portion, attached to hydrophilic functional groups (Jakobi & Löhr, 1987[2]:338). The molecules are ampholytic (both water and oil attracting) and consist of long, water-repellent chains, bonded to hydrophilic heads. They dissociate or 'ionise' in an aqueous solution to negatively charged surface active ions. Figure 2 illustrates the molecular structure of a detergent surfactant.

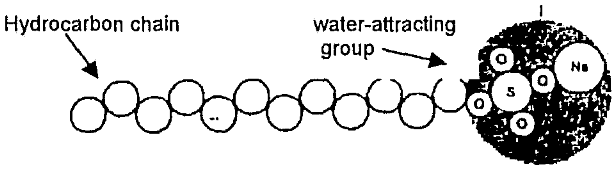

Figure 2: Typical molecular structure of a detergent surfactant (Ford, 1991:3)

Surfactants with little branching in their alkyl chains generally show good wash effectiveness, but poor wetting characteristics, whereas more highly branched surfactants are good wetting agents, but have unsatisfactory detergency.

Anionic surfactants include alkylbenzene sulphonates (LAS), alkane phulfonates (SAS), ą-olefin sulphonates (AOS), ą-sulpha fatty acid methyl esters (SES), fatty alcohol sulphates (FAS) and fatty alcohol ether sulphates (FES). In recent years, there has been a shift from the use of alkylbenzene sulphonates (LAS) to alcohol-based surfactants, including alcohol ethoxylates (AE) and alcohol ether sulphates (AES) (CEH, 1996:1).

Non-ionic surfactants are non-soapy surfactants, which do not dissociate into charged ions in solution. These surfactants have acquired great importance during the past years. Like anionic and cationic surfactants, the non-ionic molecule is water loving at one end, and water hating at the other. Because of its dual nature and its lack of charge, they have very good oil and grease removing properties. They also have good scum dispersing properties and are used in detergents to produce low lather products (Swaine, 1975:13).

The main function of surfactants in household detergents is to improve the wetting ability of the water, to loosen and remove soil and to emulsify or suspend soil in the wash solution. Adsorption and wash effectiveness increase with increasing chain length. Surfactants with little branching in their alkyl chains generally show good wash effectiveness, but relatively poor wetting characteristics, whereas highly branched surfactants are good wetting agents but have unsatisfactory detergency. For compounds containing an equal number of carbon atoms in their hydrophobic residues, wetting power increases markedly as the hydrophilic groups move to the centre of the chain, or as branching increases. However, a simultaneous decrease in adsorption and washing power occurs (Jakobi & Löhr, 1987[4]:42).

Over the past 30 years manufacturers had to devise surfactants with a wide spectrum of action, in response to the major changes in the development of fibres and fabrics. The trend at present is to include surfactant mixtures in detergents, which complement each other. These mixtures have the following characteristics: specific absorption, soil removal, low sensitivity to water hardness, dispersion properties, soil anti-redeposition capability, high solubility, wetting power, storage, good handling characteristics, minimal toxicity to humans, acceptable environmental behaviour and economy (Jakobi and Löhr, 1987[2]:342 and Epps& Leonas, 1996:16).

2.1.2.2 *Builders*

Surfactants are described as the "active" ingredients in detergents, but builders are nearly of equal importance. The function of builders in detergents is to support detergent action and to eliminate calcium and magnesium ions present in water and/or soil and fabrics. Builders enhance the cleaning action of surfactants, by softening the water through counteracting the detrimental effects of hardness ions (Ca^{2+} and Mg^{2+}). It also provides a good level of alkalinity for cleaning, and assist with suspending and preventing soil redeposition (MacKay, Anand & Bishop, 1996:156).

Builders include alkaline substances such as sodium carbonate and sodium silicate (Jakobi & Löhr, 1987^{2}:350). Carbonates are environmentally safe, but have the disadvantage of not suspending soils in solution. This can result in soils re-depositing on fabric surfaces, leading to harshness and greying. Phosphates on the other hand are extremely effective, but are banned in many states of the U.S. America because they are thought to cause eutrophication (Brown *et al.*, 1993:145).

Sodium tri-polyphosphate (STP) is the main builder used in detergents (Connor, 1981:196). Other complex agents such as sodium di-phosphate and nitrilotriacetic acid (NTA), and ion exchangers such as water-soluble poly-carbolic acids and insoluble zeolites, are also used (Jakobi & Löhr, 1987^{2}:350). Zealot was developed as a replacement builder in areas of the world where eutrophication rates led to restrictions of phosphate-containing detergents. zeolites are a group of crystalline aluminosilicates with surface pores, enclosing internal cavities, which permit selective absorption and separation (CEH, 1998^{2}:1).

The main criteria builders in present-day detergents have to fulfil are: elimination of alkaline-earth ions from water, textiles and soil, multiple wash cycle performance, good soil anti-redeposition capability, prevention of incrustations on textiles, human toxicological safety insurance, environmental properties, response to deactivation by biological degradation and economy (Jakobi & Löhr, 1987^{2}:351).

2.1.2.3 *Bleaching agents*

In the washing process, bleaching occurs through mechanical, physical and/or chemical means, specifically through change or removal of dyes as well as soil adhering to the fabric (Jakobi & Löhr, 1987[2]: 357). Mechanical or physical bleaching is effective for the removal of pigmented and greasy soil. Chemical bleaching is used to remove non-washable soils, adhering to fibres.

Only oxidative bleaches are used in the washing process, usually hydrogen peroxide bleaching (Jakobi & Löhr, 1987[2]:358). Sodium perborate hydrolyses in water to form hydrogen peroxide. It is the most important source of hydrogen peroxide in detergents because of its excellent shelf life.

In alkaline medium, hydrogen peroxide is converted to the active intermediate hydrogen peroxide anion (see equation below):

$$H_20_2 + OH^- \leftrightarrow H_2O + HO_2^-$$

Figure 3: Conversion of hydrogen peroxide in an alkaline medium (Jakobi & Löhr, 1987[2]:358)

The concentration of the bleach-active hydrogen peroxide anion increases with pH and temperature. Sodium perborate exhibits significant bleaching power above 60°C but below this temperature the bleaching effect is insufficient. Another development has been the inclusion of bleach activators in household detergents, such as organic peroxy acids and their salts. With these, significant bleaching occurs at temperatures as low as 30°C (Jakobi & Löhr, 1987[2]:358).

Using bleach catalysts also increases the bleaching power of sodium perborate. Traces of ions such as copper, manganese and iron are used as bleaching stabilisers. These ions catalyse the release of oxygen from bleach systems which in turn reduces bleach effectiveness and at the same time causes damage to fabrics. Heavy metal chelates have also been used, although their effectiveness remains controversial (Hill, 1997).

Besides sodium perborate, sodium percarbonate, sodium perphosphate and percarbamide have been used, but with limited success because of their lower shelf life. Recently, various organic peroxy acids and their salts have been combined with sodium perborate in detergents. With these, it is possible to obtain significant bleaching at temperatures as low as 30°C.

2.1.2.4 *Auxiliary agents*

Auxiliary agents are used in small amounts in detergents for a specific purpose. They include enzymes, soil anti-redeposition agents, foam regulators, corrosion inhibitors, fluorescent whitening agents, fragrances, dyes and fillers.

Fluorescent compounds also called fluorescent blues, brighteners, optical bleaches, optical brightening agents (OBA) or optical whites, are colourless substances, giving out a blue light when exposed to ultraviolet radiation. OBA is often blended with synthetic detergents to enhance the whiteness of washed articles (Kay, 1995:39 and Furry, Bensing & Johnson, 1961: 54). It has no bleaching properties but exposes normally invisible ultraviolet rays to the human eye, making white fabrics look whiter. OBAs in detergents act as dyes and attach themselves to textiles during laundering (Kay, 1995:38). OBA can affect the colours of certain dyed fabrics, especially after a number of laundering treatments. According to Kay (1995:39) OBA resulted in a faded appearance in masking pale yellow, beige, pink, cream and similar coloured fabrics (Kay, 1995:39).

2.1.4 Secondary effects of detergent use on textile fabrics

Although detergency is not the focus of this study, research findings on detergency explain the functions of detergent ingredients, and their effectiveness. Ineffective soil removal may lead to soil re-deposition on fabric surfaces, whereas detergent deposits and the eventual incrustation of fabrics may affect the colourfastness and strength of fabrics.

Re-deposition of suspended soil on fabric surfaces during laundering, is an important secondary effect in detergent use, which may cause gradual greying of fabrics, and therefore change in fabric colour (Krüszmann, 1982:25). Electron microscope techniques have shown that re-deposited oily soil forms a continuous sheath over fibre surfaces, with particular soil embedded in the oily soil layer (Breen, Durham and Obendorf, 1984:198). However, higher wash temperatures, especially for cotton fabrics, increase the rate of detergency and total soil removal. Built detergents (pH 10) remove the fatty acids in oily soils effectively, and the alkaline electrolytes from the detergent builders promote oil removal by emulsification (Breen *et al.,* 1984:200).

Phosphate built anionic detergents seem to be the most effective particular soil removal agents (Webb and Obendorff, 1987:640), whereas the use of detergents with carbonate and zeolite builders lead to increased greying of fabrics (Krüszmann, 1982:25). Cameron and Brown (1995:85) investigated the cleaning effectiveness of 42 laundry detergents. It was found that detergents built with high phosphate concentrations were more effective than detergents built with other compounds.

Besides its main function of effectively cleaning fabrics, one of the secondary effects of detergency is the *incrustation* of fibres over a period of time. This is caused by deposits of insoluble compounds on fabric surfaces due to reactions between hard water components and carbonates, phosphates or silicates in detergents. Incrustation can influence fabric handle, absorbency and mechanical stability negatively. With a 5% incrustation, colour change may occur. Incrustation increases with a decrease in wash temperature and is especially noticeable in cotton fabrics (Krüszmann, 1982:24).

Sainio (1996:83) determined the concentrations of residues in textile fabrics after laundering with three detergent types. Results showed that most residues were anionic tensides. One of the washing powders used, contained a very high amount of silicates, which resulted in a large amount of silica residues (zeolites) on fabrics after washing. The concentrated or micro washing powders tested, left the least residues. It is suspected that detergent deposits on fabrics cause mechanical skin irritations and allergies to some individuals.

In a study by Tinsley, Byrne and Fritz (1991:223) four micro detergents and one conventional detergent were used in washing towels at two different temperatures, after which they were line dried and tumble dried respectively. A consumer panel evaluated fabric handle. The researchers concluded that detergents causing a harsh and unacceptable handle in towels, contained sodium carbonate which leads to a deposition of calcium carbonate on fabrics, causing the harsh feel (Tinsley *et al.*, 1991:227).

2.2 Structure and finishing of cotton

It is recognised that any changes in the structure of the cotton fibre may result in significant changes in its original properties (Ugbolue, 1990:1 and Reinhardt & Graves, 1996:28). In this study, information on fibre structure is needed in order to explain the possible chemical and mechanical damage in cotton fabrics after being subjected to multiple laundering treatments. A brief overview of the main functional finishes applied to cotton fabrics, and resulting changes in fabric behaviour, is given. Since the experimental fabrics used in this study were dyed with reactive dyes, a discussion of this type of dyeing concludes the section.

2.2.1 Structure of the cotton fibre

The cotton fibre is composed of various parts, namely the cuticle or skin, the primary cell wall, the secondary cell wall and a lumen (Hatch, 1993:164). Figure 4 shows a schematic representation of the various layers of which the fibre is composed.

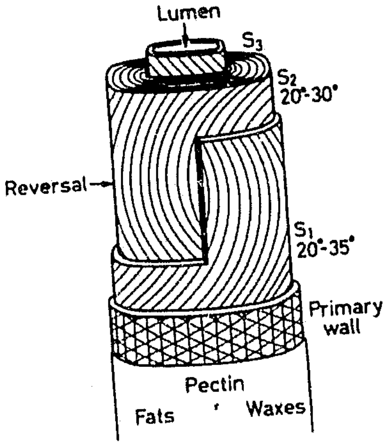

Figure 4: Morphological structure of the cotton fibre (Trotman, 1990:31)

The cuticle consists of a wax like film or layer, which covers the primary wall. This layer is only a few molecules thick and protects the rest of the fibre against chemicals used during processing. Most of the cuticle is removed during laundering (Hatch, 1993:164).

The primary cell wall consists of cellulose layers called fibrils. Beneath the primary cell wall lies the secondary cell wall, which is made up of layers of cellulose. This constitutes the main part of the fibre. In the secondary wall, there is a helical orientation of molecules and fibrils (Hearle & Green, 1970:32). The fibrils are made up of bundles of cellulose chains, arranged spirally (Kadolph, Langford, Hollen & Saddler, 1993:39 and Trotman, 1990:31). These spirals reverse direction and form convolutions or ribbon-like twists along the fibre. The spiral reversals along the cotton fibre, and the places of high distortion in the macrostructure of cotton, are considered the weak points in the fibre (Ugbolue, 1990:2), being 15-30% weaker than the rest (Kadolph, *et al.*, 1993:39).

The mature cotton fibre collapses on drying, to give the typical appearance of a flat, twisted ribbon and a kidney- bean cross-sectional shape (Hearle & Greer 1970:32; Hatch, 1993:164).

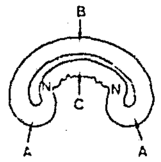

Figure 5: Cross-sectional view of the cotton fibre (Hearle & Greer, 1970:33).

Various zones with different structures can be identified in the mature cotton fibre (Figure 4). In the regions C and N, there is a reversal of curvature, which opens up the structure in these areas. In region A, there is an intensification of curvature, and therefore a tightening in structure. The structure in region B has a almost no change in tightness of the structure. The fibrillar structures in regions C and N are the most susceptible to chemical reaction (Hearle & Greer, 1970:33). This is due to the less compact structure as well as the amorphous molecular arrangement (Lichstein, 1985:272).

Glucose forms the basic unit of the cellulose molecules in cotton with the empirical formula of ($C_6H_{10}O_5$), shown in Figure 6.

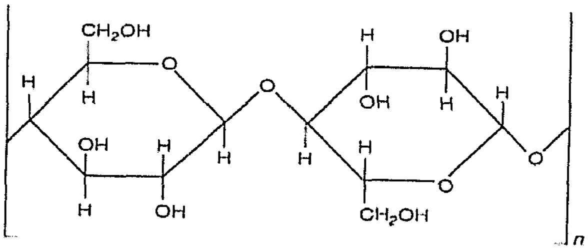

Figure 6: Structural formula for cellulose (Trotman, 1990:37)

The most important chemical group in the cellulose molecule is the hydroxyl group (-OH) which reacts with moisture, dyes and finishes (Kadolph, *et al.*, 1993:42; Hatch, 1993:165). Figure 6 indicates that hydrogen bonds exist between adjacent polymer chains in the crystalline areas, involving the oxygen atom in the chemical structure. These bonds contribute to the strength of the fibre. Studies have shown that the extent of hydrogen bonding in cotton fibrils vary and decrease with decreasing crystallinity of the cellulose within the fibrils (Ugbolue, 1990:3).

When cellulose fibres are immersed in water, the water molecules infiltrate into the fibre and move in between the long-chain molecules. As these molecules are mainly oriented towards the fibre axis, they are pushed apart, and the fibre swells (Moncrieff, 1970:72). During laundering, cotton fibres gain up to 20% tenacity (Hatch, 1993:167). The increased tenacity is caused by the uptake of water, which causes the fibre to swell and untwist. This leads to temporary improvement in the polymer alignment in the amorphous regions of the polymer. However, certain laundry additives such as alkalis and bleaches, may oxidise the cellulose molecules in cotton fabrics, which leads to loss of strength.

2.2.2 Finishing and dyeing of cotton fabrics

2.2.2.1 *Functional finishes*

One of the major treatments cotton fibres undergo during processing, is **mercerisation**. During this process, cotton is impregnated with a concentrated solution of cold sodium hydroxide (Ugbolue, 1990:2; Hatch, 1993: Kadolph *et al.*, 1993:). The main objectives of mercerisation is to improve the luster, tensile strength, dimensional stability and increased uniformity in dyeing of the fibres. Sodium hydroxide causes a pronounced swelling of cotton fibres. This changes the irregular, flattened, ribbon-like structure of the fibre to that of a smooth cylindrical rod. In so doing, the internal strains in the fibres are released (Wyles, 1973:19). The molecular chains within the fibres become less spiral in form and more oriented in length, which leads to an increase in fibre strength. The opening of the molecular structure leads to an increase in available hydroxyl groups which leads to better moisture absorption and an increased dye affinity. Resins used in finishes also reacts easier with fibre molecules (Kadolph, et al., 1993:290).

Liquid ammonia treatments used on cotton fabrics, result in similar changes in fabric properties, as obtained with mercerisation. This finish is cheaper, but not as effective as that of mercerisation. It produces a moderate degree of swelling and an improved resistance to abrasion and shrinkage during washing (Wyles, 1973:20).

As cellulose fibres do not have natural cross-links, the molecular chains are held together by weak hydrogen bonds. In the presence of moisture, these bonds break with the stress of bending and new bonds form to hold the fibre in this bent position, thus forming a wrinkle. Wrinkle recovery is therefore dependent on cross-links that hold adjacent molecular chains together and pull them back into position after the fibre is bent.

Cross-linking with dimethyloldihydroxyethyleneurea (DMDHEU), has been used effectively on cotton fabrics to prevent wrinkles. However, although fabrics treated with these resins are smooth, flat, and wrinkle resistant, they initially exhibited poor abrasion resistance. It has been found that mercerised cotton fabrics show better strength and abrasion resistance after treatment with DMDHEU. The cross-linking of cotton fabrics, decrease their affinity for fluorescent brightening agents used in laundry detergents (Wyles, 1973:18).

Cotton fabrics, cross-linked with (DMDHEU) and 1,2,3,4-butanetetracarboxylic acid (BTCA) respectively, were used in a study to evaluate their resistance to abrasion. Abrasion resistance was evaluated by standard tests and by observing damage to collars and hemmed edges during repeated washing (10,20,30,40,50 cycles) and tumble drying. The results showed that fabrics treated with BTCA, resisted abrasive damage during laundering somewhat better than the DMDHEU-finished fabric, with equivalent resiliency and durable press performance (Morris & Harper, 1994:34-39).

Although conventionally cross-linked cotton fabrics are resistant to dyeing in employing the usual procedures used for untreated cottons, effective processes for producing dyeable durable press cotton have been developed. These dyeable fabrics can be prepared by including suitable additives in the treatment bath together with cellulose crosslinking agents and catalysts in the usual pad-dry-cure finishing procedure.

2.2.2.2 *Dyeing of cotton fabrics with reactive dyes*

Dyes are organic chemicals, which selectively adsorb and reflect wavelengths of light within the electromagnetic spectrum (Hatch, 1993:431). Dye molecules consist of specific groups called chromophores and auxochromes. Chromophores provide colour and molecules without chromophores are colourless. Auxochromes serve to intensify and deepen colour. The auxochromes also aid in the even uptake of the dye. Dyes are usually retained within the fibre by hydrogen bonding, ionic bonding or mechanical entrapment.

Colourfastness of cotton fabrics depend on converting soluble dye substances into insoluble compounds within the fibre. This has been achieved with reactive dyes, which are now widely used on cotton fabrics. These dyes, which consist of chromophores and at least one reactive group, have reactive groups, which form covalent bonds within the cotton fibres. It reacts with the hydroxyl groups and produce the brightest shades with cotton. The covalent bonds are strong and not easily broken by heat, light or during the washing process (Trotman, 1987:447; Kadolph *et al.*, 1993:331).

No dye is totally colourfast. Colourfastness depends mainly on dye penetration into fibres (Kadolph *et al.* 1993:329). The dyes used and the stability of the chromophores to various sorts of chemical attacks, are also of importance (Merkel, 1991:248). In laundering, bleaches and other oxidising agents may destroy chromophores. Its wash fastness therefore depends on the stability of the chemical bonds it forms with the fibre (Trotman, 1990:447). It has been found that the light and wash-fastness of reactive dyes is extremely good, although fastness to hypochlorite bleach is poor (Trotman, 1990:456).

2.3 Laundry degradation and assessment

Two of the important secondary effects of textile laundering are fabric damage, due to mechanical or chemical degradation, as well as change in colour (Higginbotham, 1976:40; Krüszmann, 1982:23; Slater, 1991:49;).

Research on the effect of laundering treatments on fabrics, particularly regarding its effect on colourfastness and strength, is discussed in the section below.

Where applicable, specific reference is made to variables or factors such as detergent type, number of wash cycles and fabric colour, which are included in the empirical part of this study. The research overview is followed by a discussion of methods by which change in colourfastness and strength in fabrics can be assessed.

2.3.1 Effect of laundering on fabric properties

Loss or change of colour by fading, crocking, or running (bleeding) during laundering, can reduce the life of the garment and is frequently the result of degradative processes. Changes in mechanical properties, such as tensile or tearing strength, can also lead to the rejection of an article as unfit to wear.

2.3.1.1 *Effect of laundering on fabric colour*

Research dealing with the effect of laundering treatments on fabric colour indicates that detergent type, number of launderings, water hardness and finishes applied to fabrics (durable press and optical brighteners) are factors to be considered. Colourfastness also depends on the dye treatment employed.

Krüszmann (1982:24) gives an overview of possible causes of colour change in fabrics due to laundering. Reactions between detergent ingredients such as carbonates, phosphates and silicates and Ca^{2+} and Mg^{2+} (water hardness ions), lead to encrustation on textile surfaces. Besides affecting fabric handle, incrustation also cause colour change in fabrics and a gradual loss of colour due to roughening of fibre surfaces.

General work in the area of mechanical and structural changes resulting from degradation includes that of Higginbotham (1976:41-47), who investigated the general phenomenon of deterioration of textiles in use and considered such effects as colour loss or change. According to him, colourfastness of fabrics to washing is largely dependent on dyes used, those having the highest fastness generally being the most expensive. However, the finishes used to confer minimum-care properties on cellulose fabrics, improve the wash fastness of certain of the cheaper cellulose dyes, which would otherwise have insufficient resistance to washing.

Textiles for household use such as bed linen, deteriorate during laundering as a result of mechanical (abrasion) and chemical damage and eventually become discoloured. A comprehensive study on fabric laundering reported by Lord (1971), showed that the conditions of laundering and of use, was more important than the type of fabric from which bed sheets were made. Wear trials were conducted in which 150 sheets were issued to four different institutions or hostels. These were used by institutions and laundered in the normal way. Fifty additional sheets were supplied at the same time, and organisations were asked to wash these by their usual methods, but not use them. As cotton/polyester blends were not used for sheets at the time of study, 100% cotton and blends with viscose rayon and nylon were used.

Results showed that even when sheets were laundered for up to 40 times without use, they eventually became grey (Lord, 1971:321). An increase in yellowness was also recorded after 40 wash cycles, especially in the cotton/nylon blend. As all proprietary washing powders contained a relatively high proportion of powerful bleaching agent (sodium perborate), it might have contributed to the colour change in fabrics.

A study by Ulrich and Mohamed (1982:39) indicates that detergent type and number of launderings may influence whiteness retention in fabrics. Phosphate and carbonate built detergents were used in laundering a white mercerised durable blend cotton/PET fabric in moderately and very hard water. Results showed that fabric laundered with the phosphate detergent, showed an increase in whiteness in both moderately and very hard water. This was probably due to fabric shrinkage, causing an increase in the number of threads per unit area. The optical brightening agent in the detergent also contributed to increased whiteness. Results also indicated that whiteness retention increased with number of launderings. After 50 wash cycles, the highest whiteness values were obtained. Throughout the study it was clear that carbonate built detergents had lower whiteness retention values than phosphate built detergents.

In another study by Mohamed (1982^2:29) the effect of laundering white hospital uniforms with phosphate and carbonate built detergents was compared to dry-cleaning. The retention of whiteness of the polyester/cotton fabrics was measured after being worn by hospital staff and then cleaned for up to 25 times. Results showed that the dry-cleaned fabrics had a high soil content compared to that of the laundered uniforms, already after the 15th wear and cleaning cycles. Dry-cleaning also caused greying, due to the accumulation of re-deposited soils. Soil re-deposition, and therefore loss in whiteness, increased progressively with laundering. Loss of whiteness was 2% for the phosphate built detergent and 2.4% for the carbonate built detergent. The dry-cleaned uniforms showed high losses in whiteness and became grey and dull after the 15th treatment (Mohamed, 1982^2:31).

Reinhardt and Graves (1996.28) conducted a study which proved that cotton fabrics, dyed after being treated with a durable press finish, can be more colourfast than if dyed in the conventional manner. Traditionally, cotton was dyed before finishing, as the finishing processes tended to make cotton resistant to dyeing. Untreated cottons dye well, but has poor wrinkle resistance and dimensional stability qualities. A process was developed whereby cotton was treated with modified cross-linked reactions, before dyeing, adding an appropriate additive such as quaternary ammonium salt. Fabrics were then dyed in various colours, after the durable press treatment. Colourfastness tests were carried out, using a Launder-Ometer at 49°C and a 0.2% detergent solution.

Grey Scales were used to evaluate colour change. Results showed only a small decrease in colour. Between 93.4% and 98.0% of the colour was retained. It was concluded that it is possible to produce dyeable, durable press cotton fabrics with high levels of colourfastness.

The combined effect of optical brightening agents (OBA) and resin finishes on fabrics seem to cause problems with fabric whiteness after laundering. Durable press finishes seem to reduce the fabric's affinity for OBA, and thus the whiter appearance of the fabric. Research by Furry, Bensing and Johnson (1961:50) showed that resin-treated cotton fabrics were less white than untreated cotton fabrics, after laundering with detergents containing OBA. Further to this problem, Carver and Wylie (1980:96) investigated the effect of various laundry treatments on change in whiteness and fluorescence of fabrics. White polyester/cotton fabric with a durable press finish and OBA incorporated into the fibres, was used. Fabric samples were washed for 40 cycles in an automatic household washing machine at temperatures of 40.5°C and 60°C respectively, using a heavy duty detergent containing OBA. Results showed that the lower washing temperature resulted in less decolouration of fabrics. As the number of wash cycles increased, the colour change became more apparent. The increase in laundry treatments, combined with environmental factors such as line drying, caused a greater loss in the effectiveness of the OBAs. It was concluded that fabrics washed at 40.5°C and tumble dried, give the best whiteness retention.

Williams and Horridge (1996:137) conducted research on the effect of selected laundering and dry-cleaning pre-treatments on the colours of naturally coloured cotton. Brown, green and white naturally coloured cottons were subjected to 15 different laundering and dry cleaning pre-treatments. Instrument colour readings were done on a MacBeth Series 1500 Color Measurement System. A panel of four judges evaluated the samples, using Grey Scale measurements. Significant differences were found in all fabric colours due to both the laundry and dry-cleaning pre-treatments. It was found that the colour of the green fabric was more affected than that of the brown and white fabrics. Ammonia and chlorine bleach, two of the pre-treatments included in the study, resulted in the greatest colour changes in all naturally coloured cottons.

2.3.1.2 *Effect of laundering on fabric strength*

Laundering consists of a combined mechanical and chemical treatment of a textile article. Mechanical damage is mainly caused by the relative movement between textile articles in a washing machine, as well as the frictional contact between fabrics and the sides of the washing machine cylinder (Slater, 1991:10). Chemical damage by detergent chemicals such as builders, bleaches and optical brighteners, will deteriorate fibres. However, it is difficult to obtain exact measurements in order to distinguish between chemical and mechanical damage (Krüszmann 1982:26; Slater, 1991:10).

Apart from the degradative effect of laundering on textiles, whether chemical (*detergents*) or mechanical (*wash action*), researchers indicate that the *number of washes* to which textile fabrics are subjected and the *temperatures used*, are factors which influence their durability considerably. Textile degradation, whether mechanical or chemical, only take place after multiple wash treatments (Krüszmann, 1982:23). Research also indicates that *fabric finishes*, especially durable press finishes as well as *water hardness* may have an effect on textile degradation in laundering.

The chemical and mechanical wear of cotton fabric in laundering was investigated in one of the first studies of this kind, reported by Lord (1971:309). An extensive trial was carried out to find out how bed sheets last under different conditions of use (reported in the previous section). Results on the bed sheets of the co-educational boarding school and a men's hostel, two of the institutions involved in the experiment, were compared. Strength losses in fabrics were linearly related to number of laundry cycles used. Also, strength loss was greater

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when sheets were used, than when they were laundered without use (Lord, 1971:312). It was found that with the school's sheets, chemical and mechanical damage contributed about equally to deterioration. In the men's hostel, mechanical damage was the main cause for deterioration. The sheets from the men's hostel were washed at a commercial laundry where little or no bleach was used, whereas the school laundry used bleaching agents. The life expectancy of the sheets used in the men's hostel (equivalent to about 100 launderings) was twice that of the school's sheets where bleaching agents were used. Although the liquid bleach (sodium hypochlorite) would cause degradation of cellulose, it is suspected that sodium perborate, which was present in many washing powders at the time of the study, contributed to fabric degradation.

The tensile and bursting strength properties of woven, dyed fabrics made from air-jet cotton/filament composite yarns as weft, were investigated after repeated laundering in an Atlas Launder-Ometer. The samples were washed and tumble dried up to 50 times at temperatures of 60°C. Results showed that even up to 50 wash cycles, the tensile strength of the tested fabrics was not affected much. It was also observed that the bulky and open textured yarn structures attained a higher relaxation state after laundering, which in turn resulted in improved crease recovery, abrasion resistance and thermal insulation (Sengupta, Kothari & Srinivasan :1990:578).

Jokelainen and Kujala (1984:333) studied the effect of activated sodium perborate on cotton fabric. A plain weave 100% cotton EMPA fabric was used as experimental fabric. It was washed in a top-loading drum-type household washing machine, using two detergents: a basic detergent with 17% sodium perborate and an activated detergent, composed of the basic detergent and a sodium perborate activator (TAGU). The washing temperatures were 60°C and 90°C respectively and up to 25 wash cycles were carried out for each detergent type and temperature. Results showed that the basic detergent did the least damage to cotton at 60°C, because of the slow oxidation reaction of the sodium perborate. However, at 90°C where the oxidation reaction of sodium perborate reaches the maximum level, fabric tenacity decreased. The activated detergent damaged the cotton fabric almost as much at 60°C, as the basic detergent at 90°C. An interesting observation made by the researchers, was that statistically significant differences between washing temperatures and detergents could be obtained with fluidity calculations, but not with the tenacity measurements.

Hördler, Mizner and Hetzer (1976:853) conducted research to establish the effect of multiple washes on the tensile strength, degree of polymerisation (DP) and the general damage of cellulosic based textile fibres. A standard cotton fabric was subjected to 250 washes. Tensile strength and degree of polymerisation were determined in intervals of 25 washes. The damage factor was computed, using a formula based on DP values before and after damage. Results showed that the DP decreased rapidly up to 100 washes. Between 100 and 250 washes this decrease became more gradual. The conclusion was made that both chemical as well as mechanical damage had occurred in experimental fabrics. The mechanical damage was due to washing machine action, resulting in abrasion between fabrics and between fabrics and the washing machine cylinder.

Griffioen (1973:221) conducted research to establish whether mechanical damage in cotton fabrics caused by household washing machines, would automatically lead to an increase in chemical damage. The research was based on the assumption that chemical damage only starts after mechanical damage of textile fabrics occurred during the first few washes. Before washing, the experimental fabrics were abraded mechanically, using a specially designed abrasion machine, which simulated the approximately 150 movements in one wash cycle of a household washing machine. This was followed by chemical degradation of the fabrics by washing them up to eight times in a washing machine, using a detergent containing perborate and phosphate. Results showed a linear correlation between the mechanical damage and decrease in tensile strength of fabrics. However, decrease in tensile strength and chemical damage was not linear. It was concluded that the initial mechanical damage to cotton through abrasion, had no influence on the subsequent chemical degradation through detergent use (Griffioen, 1973:223).

Hurren, Wilcock and Slater (1985:285-288) studied the effects of repeated laundering on chemically pre-treated cotton fabrics. Fabrics used, included a greige fabric, a bleached and de-sized fabric, a bleached, de-sized and mercerised fabric and an unbleached mercerised fabric. Deterioration due to laundering was assessed by studying the effect of abrasion on fabrics, and determining changes in tensile strength after laundering and two minutes abrasion. Measurements were taken after 20, 80, 160, 800 and 1600 wash cycles. Scanning electron microscopy was used to study fibre surfaces after treatment. Results showed that the bleached, de-sized, mercerised fabric and the unbleached, mercerised fabric were least affected by laundering. However, after abrasion in an Accelerotor the bleached, de-sized, mercerised fabric showed the least fibre damage, whereas the unbleached, mercerised cotton was most affected. Scanning electron microscopy showed cracks in fibre walls of the latter fabric. There was a linear relationship between the percentage loss of tensile strength and the number of launderings (followed by abrasion) in the chemically treated fabrics. A similar pattern was observed with samples after laundering alone, although the loss in tensile strength was much less severe.

Mohamed (1982[1]:65) compared the effect of phosphate and carbonate built detergents in laundering white hospital uniforms made from polyester/cotton fabrics. Five treatments were used, including 25 wear and laundry cycles, in collaboration with hospital staff. Apart from colour and durable press evaluations, tearing strength measurements and scanning electron microscope (SEM) photos were examined. Results showed that the carbonate-built detergent caused a higher strength loss than the phosphate-built detergent. The SEM observations showed a deposit of calcium carbonate crystals, which appeared to be firmly bound to the fibre surface. The amount of abrasion, which was severe in the case of the carbonate-built detergent, seemed to be related directly to the amount of deposits on the fabric (Mohamed, 1982[1]:67).

Phosphate- and carbonate-built detergents were also used in moderately hard and very hard water, to investigate the effect of abrasion of mercerised, durable press natural blend cotton/PET (Ulrich & Mohamed, 1982:38). Six laundry treatments were used, with varying combinations of water hardness, detergent type and laundering with and without detergent, to perform 50 laundering cycles for each treatment. Degradation of fabrics was evaluated by tensile strength, weight loss and SEM. Results showed that the carbonate detergent resulted in a significantly lower retention of tensile strength than the phosphate detergent, in moderately and very hard water. However, laundering with water only, showed an even lower retention of tensile strength. Laundry treatments in hard water showed a significant greater strength loss compared to laundering in moderately hard water. As far as the effect of water hardness is concerned, laundering in very hard water caused higher weight loss in fabrics. SEM examinations showed that fabrics laundered in water only, showed severe abrasion due to mechanical action during laundering. Fabrics laundered with detergent, showed peeling of slabs and chunks of fused fibre fibrils.

Raheel (1983[1]:639) conducted scanning electron microscope (SEM) studies of chemically treated fabrics abraded under various conditions, including laundering. A de-sized, scoured and bleached all-cotton broadcloth fabric served as control fabric. This fabric was chemically treated with liquid ammonia, durable press, caustic soda mercerisation as well as combinations of the treatments to give eight different experimental fabrics. The fabrics were subjected to repeated laundering, using a Launder-Ometer. These launderings were the equivalent of home launderings ranging from nought to 400. A low phosphate built detergent was used at a temperature of 40.5 ± 1°C (Raheel and Lien, 1982:556). Results revealed that repeated laundering induced extensive peeling of the fibre surface layers. Long spiral cracks, almost parallel to the length of the fibres, were formed and fibrils were loosened in the form of sheets. The control fabric and the liquid ammonia treated fabric showed extensive fibre surface distortions, whereas the caustic soda treated fabric and caustic soda-liquid ammonia double treated fabric showed less fibre damage and surface distortions. Caustic soda plus durable press treated fabric and caustic soda-liquid ammonia plus durable press treated fabric showed relatively less damage. In general, durable press finished fabrics revealed less damage as compared to non-durable press fabrics.

As part of the above research, Raheel (1983[2]:23) compared the effect of two commonly used household detergents on the variously finished cotton broadcloth fabrics. The detergents included a low phosphate built detergent (6.1% phosphate) and a carbonate-built detergent (35% sodium carbonate) in moderately hard water and hard water, similar to those used in the study by Ulrich and Mohamed (1982:38), reported above. Raheel's study indicated that laundering with or without detergent, produced a loss in tensile strength (abrasive damage) in cotton fabrics. It seemed that the degree of water hardness, rather than detergent type was an important factor in these results. In using water alone (without detergent), the fabric lost significantly more strength in hard water after repeated laundering than in moderately hard water.

The phosphate detergent resulted in a higher strength retention of fabrics than the carbonate detergent. However, the phosphate detergent caused more incrustation of fibres than carbonate detergent in very hard water. With both detergents, laundering in hard water caused greater strength loss than in moderately hard water, except in the case of caustic soda mercerised and durable press finished fabrics. SEM observations showed that in hard water, detergent laundering induced greater degradation in fabrics than laundering without detergent. It was also clear that more fibrillation and fibril separation resulted from laundering with carbonate-built detergent than with phosphate-built detergent. Caustic soda mercerisation, liquid ammonia treatment and caustic soda in conjunction with liquid ammonia treatment, retained the strength of cotton fabrics better than was the case with untreated fabrics. In fact, fabrics with a caustic soda treatment in conjunction with liquid ammonia treatment, showed excellent retention of strength, even after 400 wash cycles (Raheel, 1983[2]:29).

Morris and Harper (1994:43) compared the resistance to laundry abrasion of two types of durable press finishes on cotton fabrics. Cotton print fabric was cross-linked with dimethyloldihydroxyethyleneurea (DMDHEU) and 1,2,3,4-butanetetracarboxylic acid BTCA. Damage to shirt collars and hemmed edges were observed during repeated washing and tumble drying. Results showed that the BTCA treated fabric resisted abrasive damage during laundering better than the DMDHEU treated fabric.

In another study on laundering fabrics with functional finishes, the surface characteristics of fabrics were investigated after laundry treatments (Rhee, Young & Sarmadi, 1993:403). The experimental fabrics used included all-cotton and polyester fabrics treated with various durable press, fluorocarbon stain-repellent and anti-static finishes, with untreated fabrics acting as controls. Samples were laundered for up to ten times in a laboratory, using a modified AATCC test method. One laundering cycle in the Launder-Ometer equalled five cycles of home laundering. Results showed that laundering caused a significant increase in the roughness of fibre surfaces of the untreated fabrics, due to mechanical agitation. A portion of the finishes on finished fabrics were removed after laundering. After one wash cycle (5 household wash cycles) 85% of the durable press finish remained on the cotton fabrics, whereas only 65% remained after ten (50 household) wash cycles. It was concluded that the roughness of fibre surfaces of both cotton and polyester fabrics increased after repeated launderings, mainly due to mechanical agitation (Rhee, Young & Sarmadi, 1993:404).

2.3.2 Assessment of fabric degradation

2.3.2.1 *Assessment of colourfastness*

By definition, colourfastness is the ability of a fabric to maintain its original colour (Hatch, 1991:50). Rheinhart & Graves (1996: 30) quotes the definition of colourfastness by the American Association of Textile Chemists and Colourists (AATCC) as follows: "Colourfastness is defined as the resistance of a material to change in any of its colour characteristics, to transfer of colourant(s) to adjacent materials or both, as a result of exposure of the materials to any environment that might be encountered during the processing, testing, storage, or use of the materials."

Wash fastness is used to assess colour bleeding of fabrics during the first wash as well as colour loss after multiple washes. Internationally standardised *Grey Scales* are generally used by industry and researchers to assess colour change in fabrics (Merkel, 1991:252 & Burdett, 1984:45). This test makes use of a standard set of washing conditions (time, temperature, and soap concentration). Test samples are sewed between two adjacent fabrics and washed in a container, being agitated in a standard manner. After washing and air drying (not in sunlight), the change of shade of the washed sample is assessed against a set of grey standards. These are chips of grey coloured cards paired off to indicate no colour difference (rating 5) to a substantial colour difference (rating 1) (Angliss, 1991:19).

The adjacent fabrics (white), which could include a multi-fibre fabric, are also assessed in terms of staining or the amount of dye transferred to them from the test sample during washing. The rating of these fabrics is carried out by comparison with a scale of paired chips of white and off-white cards, from rating 5 (no colour difference) to rating I (substantial colour difference). The grey scales used for rating change of fabric colour are also used in a range of colourfastness tests such as fastness to perspiration, chlorinated water, dry cleaning, water, salt water etc. Because the care of different fabrics and garments demands varying levels of severity in laundering, the conditions of wash fastness testing may vary according to specified standards (Angliss, 1991:19).

Although the visual evaluation of colour change in fabrics by means of Grey Scales, are widely used by industry, it remains a somewhat subjective assessment. Because of this subjective nature of colour perception and the widespread existence of slight abnormalities of vision, objective methods for classifying and specifying colours are more exact in measuring colourfastness. In the following section an overview is given of the colour systems developed over the years, in order to describe the measurement of colours as well as colour change more effectively.

Ostwald was one of the first researchers who developed a system for objectively assessing colours. He specified a series of shades devoid of hue (colour) in terms of a scale, graded in geometrically progressive steps from white to black, through greys of increasing depth. He divided the pure hues into one hundred colours. For practical testing purposes this number was limited to twenty-four. He constructed triangular diagrams for each hue made of the pure colour, mixed with varying amounts of black or white. These are known as isochromatic triangles (Trotman, 1990:546).

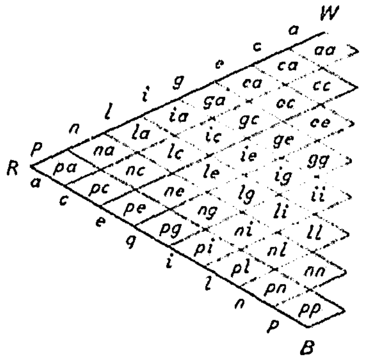

Figure 7: Ostwald's system: isochromatic triangle (Trotman, 1990:546).

The above figure indicates that the parallelogram at the apex marked R, contains the pure hue. The parallelograms at W and B are white and black respectively. The row WB contains no hue and constitutes the white, grey, black scale, divided into eight graduations. The row RW consists of the hue R mixed with different amounts of white, and the row RB is made up of the specific hue, with increasing proportions of black.

The isochromatic triangle represents the range of shades obtainable by mixing varying amounts of black or white with the hue. Two letters, the first of which shows the percentage of white and the second the percentage of black, mixed with sufficient of the hue to bring the total up to one hundred, identify each parallelogram.

The Ostwald classification was replaced by the *Munsell system*, which originated in 1905 but is still used today. This system allows spaces to accommodate pigments of greater brightness than have been made earlier. In this system numerical values are assigned to the three properties of colour, namely hue, value and chroma (Datacolor, 1996:8).

The Munsell system recognises ten principal **hues**. These are yellow, yellow-red, red, red-purple, purple, purple-blue, blue, blue-green, green and green-yellow. Each of these are differentiated into ten subdivisions and numbered in such a manner that the principle hue is always number five (Trotman, 1990:547).

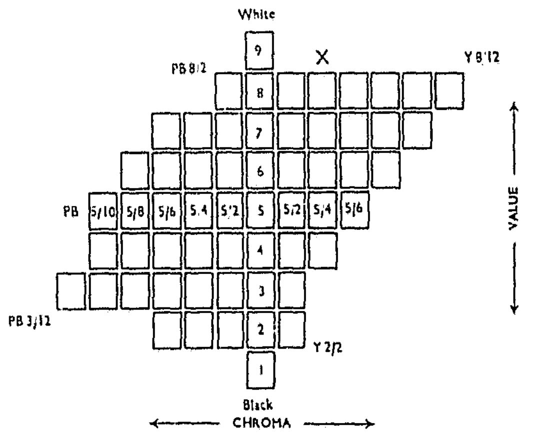

Figure 8: Vertical section through the Y-PB plane of the Munsell solid (Trotman, 1990:549)

In the Munsell model each of the ten hues are represented as a vertical slice or plane (Figure 8), branching from the centre of the three-dimensional model, also known as the Munsell Colour Tree. These slices are subdivided into various values and graduations of chroma (Datacolor, 1990^6:8).

Value is the amount of black mixed with the hue or colour. There are ten numbers on the scale, one being a perfect black and ten an ideal white. As no perfect black or ideal white exists in practice, only numbers two to nine are used. In Figure 8 the vertical axis represents the value (lightness) of colour. The innermost white-black axis represents a descending graduation from white to black, with shades of grey in between (Datacolour, 1996:8).

Chroma indicates the saturation of a colour, measured as the distance from the value axis. In Figure 8 chroma is represented by the horizontal axis, which identifies the colour's horizontal distance from the central grey axis (Datacolour, 1996:8).

The vertical slice in Figure 8 illustrates the hue 5Y (yellow) in various values and graduations of chroma on the right of the central black/white axis. On the left of the same axis, the hue 5PB (purple-blue) is measured in the same manner. Individual colours can be identified according to their positions on the chart. The square marked X in Figure 8 would be designated as 5Y8/4. The hue (5Y) is followed by the value number (8) and separated by a stroke from the chroma number (4) (Trotman, 1990:549).

Although the Munsell chart and Ostwald's system are useful aids in measuring colours, it was found that their construction and use are not free from subjective elements. They also have other limitations such as lack of permanency of the colour standards. In 1931 the Commission Internationale de l'Eclairage (International Commission on Illumination), developed the so-called CIE system for the numerical specification of colour. This was followed by the improved 1976 *CIElab system,* which organises colours in such a way that the numeric differences between colours agree consistently with visual perceptions (Datacolour, 1997:2). This improved system for colour measurement has facilitated and simplified communication on colour differences between laboratories and researchers.

The CIElab system is based on the fact that colour is a sensation resulting from the combination of a light, an object and an observer. It can be explained as follows: a light source illuminates an object; an object modifies light and reflects it to an observer; the observer senses the reflected light. CIE data computes the so-called tri-stimulus values which are co-ordinates of the above colour sensation (Datacolour, 1997:1).

The foundation, on which the CIE method is based, is the colour triangle or chromaticity diagram, illustrated below (Trotman, 1990:545-553; Datacolour, 1996:9).

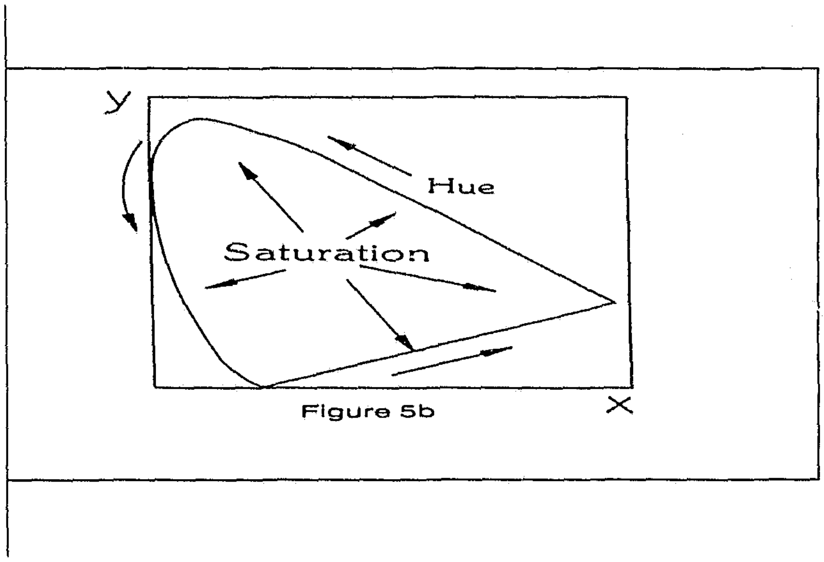

Figure 9: CIE chromaticity diagram (Datacolour, 1996:9)

The above diagram shows that hue is represented at all points around the diagram. A movement represents chroma (saturation) from the central white or neutral area. Towards the diagram's perimeter 100% saturation equals pure hue (Datacolour, 1996:9). The curve in the triangle represents the boundary of colours to which the human eye is sensitive (Trotman, 1990:552).

CIE uses two alternative uniform colour scales to measure colour. These are the CIE 1976 (L*a*b*), also known as CIElab, and the CIE 1976 (L*u*v*) or CIELUV. These colour scales are based on the theory of colour vision that states that a colour cannot be both green and red at the same time, nor blue and yellow. Therefore single values can be used to describe the red/green and the yellow/blue attributes of colour (Datacolour, 1996:10). When the CIElab scale is used, L* defines lightness, a* denotes the red/green value and b* the yellow/blue value. In using the CIELUV scale, L* is lightness, u* is red/green and v* is yellow/blue (Figure 10 below).

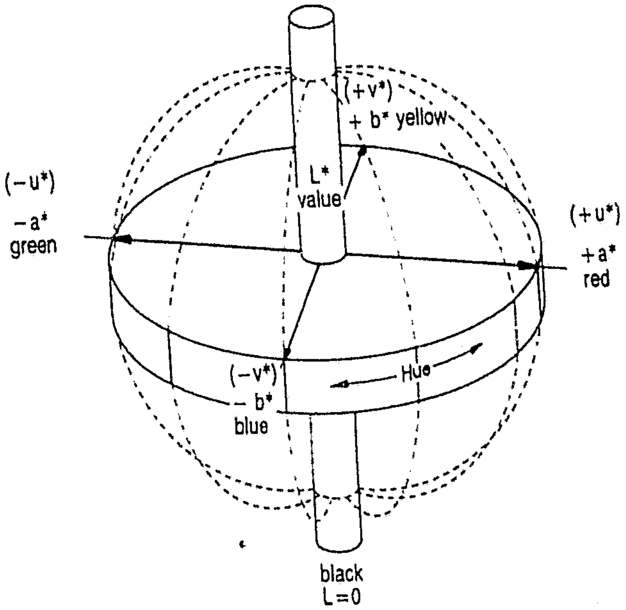

Figure 10: CIElab three dimensional colour space (Datacolor, 1996:11)

The above diagram shows that colour space can be visualised as a three dimensional space, where every colour is uniquely located. The L*, a* and b* colour co-ordinates of a fabric is calculated as follows: a spectrophotometer is used to measure the object (fabric); a light source is selected; an observer is selected; tri-stimulus values are computed from the light-object-observer data; L*, a* and b* are computed, using CIE 1976 equations. When the L*, a* and b* co-ordinates are known, a colour is not only described, but can be located in the three dimensional colour space (Datacolour, 1997:2).

Figure 10 also shows the colour plotting diagrams for L*a*b*. The a* axis runs from left to right. A colour measurement movement in the minus a direction, depicts a shift towards green; a plus a movement, depicts a shift towards red.

Along the b* axis, minus b movement represents a shift towards blue; plus b shows a shift towards yellow. The centre L* axis shows L = 100 (white or total reflection) at the top and L = 0 (black or total absorption) at the bottom. The centre of this plane is neutral, or grey (Datacolour, 1996:12).

CIElab *co-ordinates* describe and locate colours in the three dimensional colour space, whereas CIElab *colour differences* compare colours. The difference between any two colours in the CIE space is the distance between the colour locations. This distance can be expressed as delta E CIE L*a*b*, where $\Delta E^* = (\Delta L^{*2} + 1\Delta C^{*2} + \Delta H^{*2})^{1/2}$. ΔL^* is the lightness difference, ΔC^* is the chroma difference and ΔH^* is the metric hue difference (Datacolour, 1997:3).

The CIElab system is also used to determine *acceptability tolerances* in for instance, dyed fabrics. In industry, the colour differences between a standard sample and a production sample, is computed. This data is compared to the limits of customer acceptability for the coloured product.

2.3.2.2 *Assessment of fabric strength*

The ability of a textile article to function satisfactorily depends to a great extend to its ability to retain its strength (Slater, 1993:36). Degradation in strength of cotton due to laundering is the result of two factors, namely chemical degradation (mainly by oxidising agents) and mechanical abrasion (Vaeck, 1966:374).

The almost universal mechanical way to recognise degradation, appears to be the change in tensile behaviour of fibres (Slater, 1991:74). **Tensile strength** is defined as the ability of a textile to resist a longitudinal pulling force without rupturing (Hatch, 1991:16). Tensile strength is determined by applying a load to a specimen in its axial direction (Booth, 1968:353). The load applied to the fabric will deform or strain the fabric until it breaks. When the fabric breaks, the breaking load is measured. This load can be expressed in kilograms weight or

Newton weight and is used as the expression of fabric strength (Merkel, 1991:165).

As mentioned above, loss of tensile strength can be caused by chemical or mechanical degradation. **Fluididity tests**, which measure degree of polymerisation, are used to evaluate chemical damage in fibres. Fluidity increases with a decrease in chain length of cellulose molecules (Burdett, 1984:46). Many different methods exist for measuring the viscosity or fluidity of cellulose solutions, including the use of a standard cuprammonium hydroxide solution (Vaeck, 1966:374). According to Vaeck (1966:379) a comprehensive study of chemical damage to fabrics entails the relationship between tensile strength loss and fluidity increase. In determining the effect of bleaches on fabrics, 25 wash cycles in total, seem to be sufficient. The calculation of mechanical wear as the difference between total wear and chemical damage is considered to be a valid procedure.

Scanning electron microscopy (SEM) has become valuable in investigating the surface detail of fibres at very high magnification and depth of focus, to evaluate degradation of fibres. It enables the researcher to identify the modified surface morphology of fibres due to incrustation as well as patterns of fibre breakdown (Raheel & Lien, 1985:101). A light microscope is used to examine cotton fibres, swollen in a zinc chloride/potassium iodide solution. Damage on the primary and secondary fibre walls, caused by mechanical stress, bleaching, or alkali treatment, can then be examined (Slater, 1991:93).

2.4 Summary

This chapter constitutes an overview of literature, related to the scope of the experimental part of this study.

Household detergents were described in terms of the main ingredients and their functions. These include surfactants, builders and bleaching agents, which have specific functions in laundering textiles, but could also contribute to fabric degradation.

The secondary effects of detergent use were highlighted. The first is ineffective soil removal, which causes re-deposition of suspended soil on fabrics, and change in colour. Another secondary effect is detergent residues, left on fabrics after laundering, which eventually leads to the incrustation of fibres. This is mainly the case with detergents containing zeolites or carbonate builders.

A brief overview was given of the structure of the cotton fibre as well as a few of the main functional finishes, pertaining to this study. These are mercerising, ammonia treatment and cross-linking.

A detailed review of research reports on the effect of laundering treatments on the colourfastness and strength of fabrics, followed. This included valuable data, of relevance to this study. As far as *colour change* is concerned, the following deductions are made from research reports:

- the use of detergents containing carbonates and silicates, leads to fibre incrustation and colour loss in fabrics;
- detergents containing sodium perborate, cause greyness and yellowness in white fabrics;
- phosphate built detergents increase the whiteness retention of fabrics, whereas carbonate built detergents had lower whiteness retention values;

- cotton fabrics, dyed after cross-linking, is more colourfast;
- cross-linking reduces white fabrics' affinity for OBA;
- lower wash temperatures result in less discolouration of fabrics, but colour change increase with number of wash cycles;

Research showed that the degradation of fabric strength due to laundering, results from the combined effect of mechanical and chemical damage. The following is a summary of the main research findings regarding the effect of laundering on fabric strength:

- strength loss increase with number of wash cycles;
- detergents containing activated perborate decrease fabric strength at 90°C;
- bleached, mercerised cottons showed less strength loss after multiple wash cycles than unbleached mercerised cottons;
- carbonate built detergents cause a higher strength loss in fabrics than phosphate built detergents in moderately and very hard water;
- in hard water, detergent laundering causes fabric degradation;
- cotton treated with liquid ammonia, shows extensive fibre damage after multiple wash treatments, whereas fabrics with caustic soda and ammonia treatments, fabrics with caustic soda plus durable press treatment show less fibre damage;

The chapter concludes with a discussion of the methods used to assess degradation of fabric colour and strength after multiple wash cycles.

The information obtained in Chapter 2, serves as theoretical background for the planning and execution of the empirical part of this study. Chapter 3 describes the research methodology followed, and the results obtained are described in Chapter 4.

CHAPTER 3

RESEARCH PROCEDURE

This section describes the research methodology used in this study and provides a description of the materials and methods used in conducting the research. An experimental study was carried out to compare the effect of household regular and micro washing powders on the colourfastness and tensile strength of dyed and white woven cotton fabrics.

3.1 Choice of detergents

Two different brands of detergents, Skip and Woolworths, were used in this study. The Woolworths washing powder is manufactured and sold by the retail company who commissioned this research. It is also used by this company in wash tests for quality management (Thistleton, 1996). Skip is a well-known detergent, available at most supermarkets and recommended by the South African Bureau Standards for use as standardised detergent in wash tests conducted in the clothing and textile industry (Thistleton, 1996; Hill, 1997). Of each of the two brands, two regular and two micro washing powders from the same batch were purchased from two supermarkets. These detergents were mixed and stored in a dark room in airtight containers, to prevent oxidation. The selected detergents were analysed by the retail company who commissioned this research to determine the active ingredients present (Table 1).

Table 1: Active ingredients in selected household detergents. (Woolwoths analyses, 1996)

Brand	Type	%	Ingredient	Function
Skip	Regular	≤ 5%	Soap	Foam regulator
			Non-ionic surfactants	Wetting agent
			Polycarbonates	Anti-deposition agent
		5-15%	Soda ash	Water softener
			Anionic surfactants	Wetting agent
			LAS	Soil remover
			Silicates	Corrosion inhibitor
		≥ 30%	Phosphates	Water softener
Skip	Micro 2/1	≤ 5%	Silicones	Antifoam
			Phosphonates	Sequestering agent
			Zeolites	Water softener
			TAED	Bleach activator
		5-15%	Anionic surfactant	Wetting agent
			Silicates	Corrosion inhibitor
			Non-ionic surfactant	Soil remover
			Soda ash	Water softener
		≥ 30%	Phosphates	Water softener Soil suspending agent
Woolworths	Regular	≤ 5%	Non-ionic surfactants	Wetting agent Soil remover
			Sodium silicate	Corrosion inhibitor
			Polyacrylate	Builder
			Silicone	Foam regulator
			CB-X	Whitening agent
		5-15%	Anionic surfactants	Wetting agent Soil remover
			Soda ash	Water softener
		≥ 30%	Sodium tripolyphosphate	Builder Anti-deposition agent
Woolworths	Micro	≤ 5%	Non-ionic surfactants	Wetting agent
			Sodium silicate	Corrosion inhibitor
			Polyacrylate	Builder
			Silicone	Builder
			CB-X	Optical brightener
		5-15%	Anionic surfactants	Alkaline wetting agent
			Soda ash	Water softener
		≥ 30%	Sodium tripolyphosphate	Builder, prevent depositions

The above table shows that Skip regular, Skip micro and Woolworths regular contain less than five percent non-ionic surfactants and between five and fifteen percent anionic surfactants. The builders used in Skip regular are sodium carbonate, sodium silicate and polycarbolic acids (ion exchanger) and in Woolworths regular sodium carbonate, sodium silicate and sodium triphosphate (sequestering agent). Skip micro contains insoluble zeolites and Woolworths micro sodium carbonate, sodium silicate, sodium diphosphate and sodium triphosphate. Sodium triphosphate, a sequestering agent, serves to reduce crystal forming. Not indicated in the table is the fact that both Skip detergents contained bleach.

3.2 Choice of fabrics

3.2.1 Experimental fabrics

Three 100% woven cotton fabrics were prepared by SBH Cotton Mills, Cape Town, for use in this study. The fabrics were woven with a fabric mass ranging between 150g and 200g per square meter. Each of the three fabrics were dyed in a different colour, namely forest green (Fabric A), Chelsea non-ionic blue (Fabric B) and white (Fabric C), using reactive dyes. The green and white fabrics were plain woven, whereas the blue fabric was a twill fabric. Although reactive dyes generally show excellent fastness to washing (Hatch, 1993:433; Kadolph et al, 1993:331), problems relating to colour change due to laundering have been experienced with these colours in the past (Thistleton, 1996).

As various finishing processes used on fabrics may have an effect on its colourfastness, tensile strength or shrinkage, the specific finishes used on the experimental fabrics need to be documented. Both white and blue fabrics were mercerized. In addition, the white fabric was sanded and treated for crease resistance whereas the blue fabric received a silk finish and a crease resistant finish. The forest green fabric was unmercerized and had no additional finish.

3.2.2 Make-weight fabrics

White 100% cotton fabric of the same weave type and mass as the experimental fabrics, was used to replace samples of experimental fabrics withdrawn in-between the laundering treatments. This ensured a constant fabric/liquid ratio throughout the multiple wash treatments.

3.2.3 Multi-fibre fabric

In assessing the colourfastness of experimental fabrics to laundering, tests for colour change as well as staining are important (Merkel, 1991:252). Strips of multi-fibre fabric were used during laundering treatments to indicate its possible staining due to colour loss of experimental fabrics. White Multi-fibre Test Fabric number 1, made with bands of acetate, cotton, nylon, silk, viscose and wool (Merkel, 1991:252) was used.

3.3 Fabric sampling

Before sampling, all fabrics were conditioned in a textile laboratory at a standard atmosphere (20°C and 65% RH), in order to prevent the influence of atmospheric conditions on the fibre properties (Booth, 1968:99).

3.3.1 Experimental fabrics

The experimental fabrics (150cm wide) were cut into 1 X 1,5 meter pieces and the raw edges were overlocked. In total, forty one samples were cut from each of the three experimental fabrics. Forty samples (ten for every detergent) of each of fabrics A, B and C were used to compare the effect of regular and micro detergents on the colourfastness and tensile strength of cotton fabrics (objectives 1.3.1 and 1.3.2). One sample of each of the experimental fabrics were used as control.

Three 40cm lines were drawn in the weft direction of each experimental fabric sample, prior to washing, using a laundry marker and shrinkage ruler. These lines were used to measure possible dimensional changes of experimental fabrics after exposure to laundering treatments. These measurements were needed to correct tensile strength data, should there be a change in dimensional stability.

For tensile testing, ten test samples (warp direction), 25 cm long and 5 cm wide, were marked and cut from each experimental fabric sample after drying. These samples were unravelled in the warp direction to an exact width of five centimeters, required for tensile testing. All samples were stored in a standard atmosphere prior to testing.

3.3.2 Make-weight fabrics

In total thirty-six samples of the white makeweight fabric, nine for each experimental fabric, were cut in the same size as experimental fabrics and the raw edges were overlocked.

3.3.3 Multi-fibre fabric

One ten centimetre wide strip of multi-fibre fabric was cut and sewn on to each experimental fabric sample.

3.3.4 Sampling for scanning electron microscopy (SEM)

Samples from all three experimental fabrics, after subjection to fifty wash cycles, were used for SEM examining of fibre surface characteristics. Samples were prepared by cutting an area approximately 1 cm^2 of each of the washed fabrics. These samples were secured on the specimen stub of the electron microscope.

3.4 Equipment

Household equipment was used for washing and drying experimental fabrics to represent realistic conditions. According to Jakobi and Löhr (1987[1]:398), household equipment should be used in comparative tests designed in the interest of both manufacturers and consumers. This is especially needed where product judgements have to be based on all relevant factors affecting the product, and not only on the wash results.

3.4.1 Washing equipment

Laboratory equipment such as the Launder-Ometer, is usually employed in tests for colourfastness to laundering. However, most internationally standardised methods (AATCC and ASTM) for evaluating the effects of refurbishing on textiles (laundering and dry-cleaning), specify home laundering (Merkel, 1991:224).

Further to the above mentioned, as well as recommendations by Jacob & Löhr (1987[1]:398), it was decided to use two Bauknecht WA 9330 household washing machines (Department of Consumer Studies, University of Stellenbosch) to conduct home laundering tests. These were automatic drum-type washers, manufactured in Europe. A perforated, horizontal placed drum, which rotates on its axis in alternating directions, constitutes the wash action. In normal wash programmes for cottons, the lower third of the drum is filled with the wash liquor, which is heated internally by electrical heating coils. The wash temperature can be set manually. Detergent is introduced through a dispenser located in front of the machine.

Wash programme number 3, a short wash programme for coloured cottons, was selected for this study (Table 2).

Table 2: Washing programme for coloureds/cottons

Temperature	60°C
Load	3 kg
Energy consumption	approx. 1,1 kWh
Water consumption approx.	67 l
Total programme duration	approx. 45 min

The wash temperature of 60°C is the upper limit of the temperature range for coloured cottons and can be considered a critical area for appearance retention for this study, as recommended by the AATCC (1996). However, in Western Europe, it is common to wash white and colourfast cottons at 95°C with a low wash liquor ratio. Sodium perborate as detergent bleach additive, exhibits bleaching power at 60°C and higher temperatures, whereas the hydrogen peroxide anion show modest bleaching power below 60°C (Jakobi & Lohr, 1987[3]:358). According to literature, a wash temperature of 60°C is the optimum temperature used to clean fabrics and to test the effect of perborate in washing powders on textiles (Trotman, 1987:519; Ohura, Katayama & Takagishi, 1991:242). A temperature higher than 48°C is needed to inhibit the occurrence of bacterial growth on fabrics (Steyn, 1994:160). This temperature is also recommended by industry for accelerating the effect of detergents in testing for colourfastness to wash (Thistleton, 1996).

According to the Bauknecht washing machine instructions, a load of 3 kg is recommended for the chosen programme. This load was maintained throughout the study to obtain full efficiency during the laundering process and to ensure reliability of the resulting effect on experimental fabrics.

3.4.2 Drying equipment

Fabric samples were line dried indoors on household drying frames at a standard atmosphere (20°C and 65% RH). This is one of the accepted drying procedures mentioned in the set of guidelines developed for the standardisation of laundering and drying test methods (AATCC, 1996:360). The others are tumble, drip, screen and flat-bed press drying. Tumble, line and drip-drying are standardised versions of common household procedures (Merkel, 1991:230). However, tumble-drying may accelerate dimensional change and mechanical abrasion in fabrics. In a single laboratory trial on boys' jeans, using line and tumble drying, it was found that the latter method showed the highest percentage of shrinkage (Powderly, 1978:29). Machine drying is generally considered the most severe method of drying because of the abrasion and agitation to which textile items are subjected (Kadolph *et al*, 1993:358).

3.5 Assessment of degradation

Internationally standardised laboratory equipment was used in taking measurements of experimental fabrics, before and after wash treatments. All samples were conditioned in a standard atmosphere for at least 48 hours before any measurements were taken.

3.5.1 Colourfastness

The most commonly used instruments for measuring the colour and colour change in fabrics are spectrophotometers, colorimeters, and densitometers. While all three types of instruments measure reflected or transmitted light, a spectrophotometer measures light at many points on the visual spectrum which results in a curve.

The Datacolour Spectraflash 500 (Close Tolerance Spectrophotometer) was used for measurement of colour change on experimental fabrics after exposure to treatment processes (Woolworths, Cape Town). The measurements taken include delta values for the chroma, lightness and hue of experimental fabrics. These three elements of colour are widely used in measuring differences or changes in colour and can be used to compute the total colour loss of fabrics.

3.5.2 Tensile strength

Several research reports indicate that tensile strength measurement is widely used in measuring textile deterioration (Slater, 1991:76). In this study the Instron Tensile Tester (Woolworths, Cape Town) was used for measuring the tensile strength of experimental fabrics before and after wash treatments. Woolworths method P 11 was used which corresponds to the BSI method for measuring tensile strength (Greenblau, 1996). The possible shrinkage of experimental fabrics during laundry treatments was determined after taking measurements with a special shrinkage ruler, used in industry.

A scanning electron microscope (Infruitec, Stellenbosch) was used to study the long term effect of repeated laundering on experimental fabrics. The possible deterioration of cotton fabrics and/or the build-up of detergent particles on treated fabrics will be examined in this microscope, as was the case in studies reported by Sainio (1996:87) and Raheel and Lien (1985:24). Sainio (1996:87) successfully used the electron microscope to detect detergent particles such as zeolites on fabrics subjected to standard wash procedures. Raheel and Lien (1985:24) used the electron microscope to assess abrasion phenomena in cotton fabric samples which were subjected to up to 400 launderings, using different conditions of detergency.

Fabric samples were secured with aluminium tape on the specimen stub of the scanning electron microscope. The edges were coated with colloidal graphite in isopropyl alcohol, to ground the fabrics. Samples were then sputter coated with gold and examined in the JSM JEOL-6100 electron microscope, using an accelerating potential of 5 ke V.

3.6 Wash treatments

As stated previously, three differently coloured experimental fabrics were washed with four different detergent types. One wash treatment for a specific experimental fabric consisted of one full wash cycle in the household washing machine, using a specific detergent, and one successive line-drying period.

At least ten samples of each experimental fabric were subjected to each of the four washing powders. According to Raheel and Lien (1985:25) and Vaeck (1966:374), between 20 and 50 wash cycles are needed to study the effect of laundering on textiles. It was decided that for each respective washing powder used with a specific experimental fabric, the treatment process will initially be repeated five and later in the process, ten times. After a certain number of treatments, one sample of the experimental fabric was removed for assessment of colour fastness and tensile strength. Each removed sample was replaced with a make-weight sample as shown in Table 3.

Table 3: Withdrawal of experimental fabrics during multiple laundering treatments

Wash number	Number of exp. fabrics	Make-up replacement
1	10	0
5	9	1
10	8	2
15	7	3
20	6	4
25	5	5
30	4	6
35	3	7
40	2	8
50	1	9

In total, 600 wash cycles were completed, fifty for each of the four detergents and three experimental fabrics. Normally five washing cycles are considered sufficient in the retail and industry to measure fabric characteristics. (Merkel, 1991: 231&236). According to Jakobi and Löhr (1987[1]:397), 25 or 50 washes are necessary in testing detergent performance regarding fibre damage, colour change, fluorescent whitening, soil anti-redeposition properties, degree of whiteness, build-up of undesirable deposits and stiffness. With these numbers of repeats results could be obtained that can be regarded as realistic in determining the long-term effect of repeated laundering on cotton fabrics.

3.7 Pilot study

Prior to the main study, a number of procedures were tested and/or standardised to ensure reliable test results. This included test methods, materials and equipment.

- Samples of experimental fabrics were weighed before each wash cycle to establish the number of samples necessary for a 3 kg load of washing, as specified in the wash program selected for this study. It was found that 120 samples were needed. There was only a slight difference in mass of the samples:

    - ☐ 10 White samples weighed between 2860.6 g and 2992.5g
    - ☐ 10 Blue samples weighed between 2915.3g and 3184.3g
    - ☐ 10 green samples weighed between 3184g and 3552.4g

- The selected washing program was analysed to determine the volume of water used during the main wash cycle, the number of rinses involved as well as the duration of each of these processes.

- The quality of water plays an important role in the success or failure of the washing process. Water contains impurities such as magnesium and calcium, resulting in hard water (Cameron, & Brown, 1995:85). Water hardness can affect the amount of detergent needed for one wash cycle. Poor water quality, containing magnesium and calcium ions can also severely impair the washing process and have detrimental effects on washing machines (Cameron and Brown, 1995:85; Schwuger, 1987:323). It was therefore necessary to get information on the quality of water in the Stellenbocsh area. Information obtained indicated that the water in Stellenbosch is relatively soft and no adjustments concerning the amount of detergent to be used per wash was necessary. The total hardness of the area is 42.2 PP.$CaCO_3$ and the pH is 7.45 in comparison to a city like Pretoria, where the total hardness is 181.6 M.$CaCO_3$ (Woolworths analysis, 1996).

- For each of the four detergents used in this study, the amount needed for a normal wash load of 3 kg fabric was used to determine the total amount needed. The amount (weight in grams) of washing powder used for each wash cycle was adjusted to manufacturers' recommendations. Similar consumer related detergency studies conducted by Cunliffe, Gee and Ainsworth (1988:96), Sainio (1964) and Webb and Obendorf (1987:641) also used detergent concentrations recommended by manufacturers.

□ Skip regular	85g
□ Skip micro	70g
□ Ww regular	80g
□ Ww micro	60g

The required amount of each detergent was purchased and then mixed and kept in sealed containers in a controlled atmosphere, prior to use. As mentioned before, all detergents were bought at two different retail shops in Stellenbosch on the same day and with the same batch number.

□ Skip regular	batch 7031 C
□ Skip micro	batch S 7012
□ Ww regular	batch 15 01 97
□ Ww micro	batch 15 10 97

3.8 Main study

The laundering treatments were carried out in the textile laboratory of the Department of Consumer Studies, University of Stellenbosch. To enhance the validity of test results, the two available washing machines, three experimental fabrics and four detergents were used at random during the experimental study.

After drying, ten test samples (warp direction), 25 cm long and 5 cm wide, were marked and cut from each experimental fabric sample for tensile testing. These samples were unraveled in the warp direction to an exact width of five centimeters, required for tensile testing. All samples were stored in brown marked paper envelopes in a standard atmosphere prior to testing.

On completion of all wash treatments colourfastness and tensile strength tests were carried out in the laboratories of Woolworth's, Cape Town. Multi-fibre fabric strips were examined visually to establish whether there was dye transfer (staining) over the 50 wash cycles. SEM examinations were done at Infruitec, Stellenbosch.

3.9 Statistical analyses of data

A factorial layout was used to determine the affect of the factor types, detergent (regular/micro), fabric colour (white/chelsea blue/forest green) and number of wash cycles (one, five, ten, 15, 20, 25, 30, 35, 40, 50), on the colourfastness and strength of experimental fabrics.

The ANOVA (Analysis of Variance) procedure was used to analyse colour fastness and tensile strength measurements. A regression approach was used to investigate the changes in the measurements due to the frequency of washing.

In the following chapter, tables and figures are used to present data and to illustrate possible significant differences in effect of selected detergents on dyed cotton fabrics. SEM photos are used to indicate possible deterioration of the cotton fabrics and/or build-up of particles on the fabric surface.

CHAPTER 4

RESULTS AND DISCUSSION

The central problem underlying this study was the possible degradation of dyed cotton fabrics after multiple wash treatments with regular and micro washing powders of the same brand. Members of the retail trade suspect that these powders may have a negative effect when used on white, blue and green dyed cotton fabrics.

In this chapter, the major findings obtained by washing dyed cotton fabrics with regular and micro washing powders of two brands are reported. Two different companies manufactured these brands. The results are described in terms of the effect of the wash treatments on the colourfastness and tensile strength of the dyed cotton fabrics.

A short overview is given of the experimental design, indicating the levels used to examine the three factors, *detergent type*, *number of wash* cycles and *colour of fabric*, the fixed levels employed as well as the response measurements used. Research results are then discussed according to the objectives stated in Chapter 1.

4.1 Overview of experimental design

In the literature review, an attempt was made to identify the variables or factors that may influence colour loss in home laundering. The **factors** selected for this study was *type of detergent* (regular and micro), *number of wash cycles* and *colour of experimental fabrics*. These were the *explanatory variables*. The effect of these variables on the *colourfastness* and *tensile strength* of experimental fabrics (*the explained variables*) was measured over relatively wide ranges. The factors used in the experimental design as well as the levels used to examine these factors, are summarised in Table 4.1.

Table 4: Factors and levels used in experimental design

Factor	**Level**
Detergent type	regular (two brands): SR & WR micro (two brands): SM & WM
Number of wash cycles	1, 5, 10, 15, 20, 25, 30, 35, 40, 50
Colour of fabric	white blue green

The **response measurements** used in the experimental design are depicted in Table 5.

Table 5: Response or outcome measurements used in experimental design

Response	**Measurement**
Colourfastness	total difference value chroma lightness hue
Tensile strength	load (kg)

Measurements for chroma, lightness and hue were used to determine colour loss in experimental fabrics. These were expressed as delta values and used to calculate the total *change in colour* (colour loss) in experimental fabrics. *Change in tensile strength* was measured in terms of load in kilograms.

4.2 The effect of laundering with regular and micro detergents on the colourfastness of dyed cotton fabrics

As explained before, the measurement of colour is multi-faceted, as most colours are obtained by mixing the three primary colours. These mixtures can reproduce chroma, lightness and hue. The colour of a fabric can be measured as the colour difference from a known standard. These measurements for colour differences are expressed as delta values.

The three measurements used in this study to determine colour loss are chroma (Delta C), lightness (Delta L) and hue (Delta H). Chroma refers to colour saturation and describes the vividness or dullness of a colour. Lightness or value describes a colour's luminous intensity and colours can therefore be either light or dark. Hue refers to the name of the colour eg. how a colour is perceived (Data Colour, 1996:6). The total difference value or colour loss (Delta C, Delta L and Delta H combined), is expressed as Delta E.

The results concerning the effect of regular and micro detergents on the colourfastness of experimental fabrics will first be presented in terms of the pass/fail method, used by industry. Then follows a description of the total colour loss (Delta E), which is followed by more detailed information on results for Delta C, Delta L and Delta H.

4.2.1 Effect of detergents according to the pass/fail method

Table 6 represents an overview of the total effect of wash treatments on experimental fabrics according to the so-called pass/fail method. This method is widely employed by industry to assess colourfastness in fabrics. As implied, fabrics are either accepted or rejected, depending on results obtained. The pass/fail method is an objective method of decision making, based on measurements of colour differences, using a tolerance factor. Results are automatically computerised by the spectrophotometer to determine whether a fabric sample is accepted (pass) or rejected (fail). Symbols are used to distinguish between fabrics washed with certain detergents, eg. WSR represents the white fabric washed with Skip regular.

Table 6: Pass/fail method: summary of total colourfastness results (All textile test specimens (t.t.s.) were subjected to 50 wash cycles)

Colour of fabric.	**Number of samples.**	**Detergent.**	**Factor Combi-nation Code.**	**Acceptable Response* out of ten.**	**Total Response out of thirty.**
White Blue Green	10	Skip regular Skip regular Skip regular	(WSR) (BSR) (GSR)	10/10 4/10 1/10	SKIPREG 15/30
White Blue Green	10	Skip micro Skip micro Skip micro	(WSM) (BSM) (GSM)	10/10 9/10 2/10	SKIPMICRO 21/30
White Blue Green	10	WW regular WW regular WW regular	(WWR) (BWR) (GWR)	10/10 7/10 4/10	WWREG. 21/30
White Blue Green	10	WW micro WW micro WW micro	(WWM) (BWM) (GWM)	10/10 10/10 3/10	WWMICRO 23/30

*Expressed as the number "passed" out of ten determinations

The following findings are depicted in Table 6:

- The average percentage of samples (tts) accepted on the standard set for colour loss due to Skip regular after 50 wash cycles were fifteen out of thirty (50%).
- The average percentage of samples (tts) accepted on the standard set for colour loss due to Skip micro after 50 wash cycles were twenty one out of thirty (70%).
- The average percentage of samples (tts) accepted on the standard set for colour loss due to Woolworths regular after 50 wash cycles were twenty one out of thirty (70%).
- The average percentage of samples (tts) accepted on the standard set for showing colour loss due to Woolworths micro after 50 wash cycles were twenty three out of thirty (76%).

The above summary of the main findings shows that all the white fabrics passed ten out of ten. The blue fabrics showed an overall high pass rate, with exception of Skip regular which had a pass rate of four out of ten. The green fabrics had a very low pass rate of four out of ten and less for all detergents used.

Table 7: Outcome of total colourfastness results of the experimental fabrics

Response out of 10	Factor combination symbol
Bad - 1	*GSR*
2	*GSM*
3	*GWM*
4	*BSR, GWR*
5	-
Middle of scale	-
6	*BWR*
7	-
8	*BSM*
9	*WSM, WSR, WWR, WWM,*
10 - **Good**	*BWM*

Table 7 shows the range of responses (from bad to good) obtained for the effects individual detergents had on the three colours. From the above summary it is clear that the green fabric showed the highest loss in colour when using Skip regular, whereas Skip micro and Woolworths micro also affected this colour negatively. Skip regular also caused colour loss in the blue fabric.

4.2.2 Total Difference Value (Delta E)

Table 8 shows the results according to analyses of variance (ANOVA's) for the *number of wash cycles, colour of the cotton fabric* and *type of detergent* used. The table indicates which of the factors had a significant effect on total colour loss in experimental fabrics.

Table 8: Analysis of Variance for Delta E in dyed cotton fabrics

Source		**Sum of**	**Mean**		**Prob**
Term	**DF**	**Squares**	**Square**	**F-Ratio**	**Level**
A (Washcycle)	9	4.426	0.492	11.54	0.000**
B (Colour)	2	20.628	10.315	242.09	0.000**
AB	18	2.008	0.112	2.62	0.003**
C (Detergent.)	3	2.350	0.784	18.39	0.000**
AC	27	1.241	0.046	1.08	0.394
BC	6	1.507	0.251	5.90	0.000**

**Term highly significant at alpha ≤ 0.01 (1% level);
* Term significant at alpha ≤ 0,05 (5% level)

From the above table it is clear that the main effects, number of wash cycles, (A), colour of the experimental fabric (B) and type of detergent (C), were highly significant (p ≤1 %). Delta E increased with the number of wash cycles which indicates a gradual loss of colour in fabrics. This increase is shown in Figure 11.

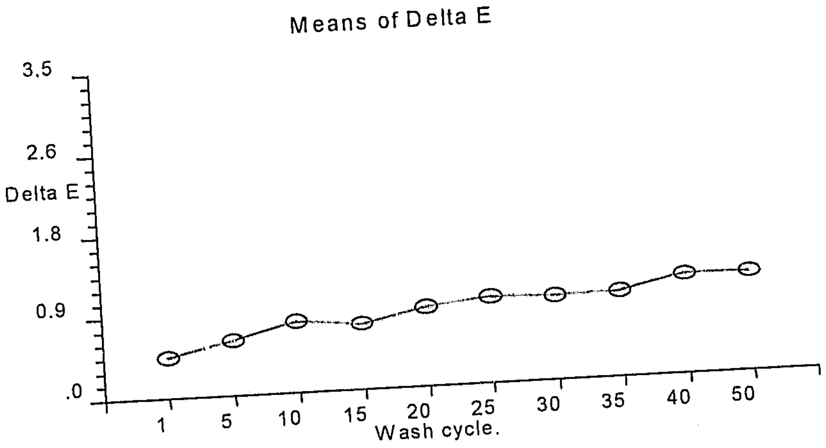

Figure 11: Colour loss (Delta E) according to number of wash cycles

It is clear from the above figure that there was a gradual loss of total colour (Delta E) as the number of wash cycles increased.

Figure 12 (below) shows that Delta E varied for each of the three colours of the experimental fabrics. There was a remarkable colour loss in the green fabric as compared to the blue and white fabrics. The white fabric showed the least colour loss.

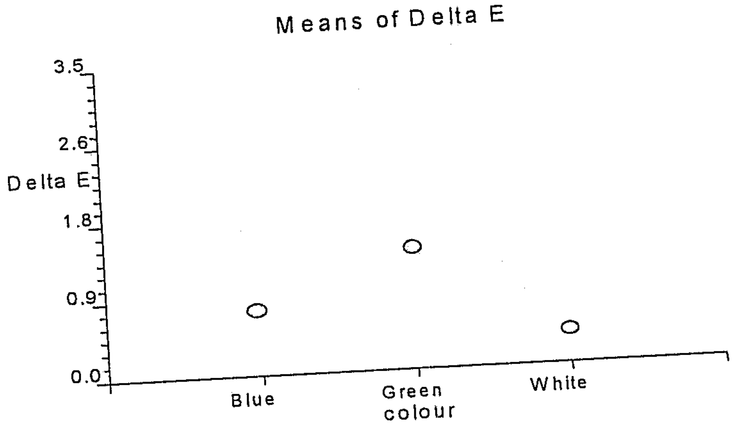

Figure 12: Colour loss (Delta E) according to fabric colour

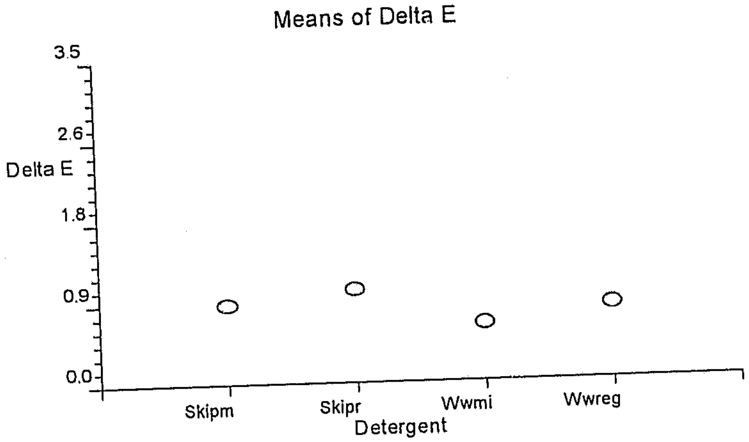

Figure 13: Colour loss (Delta E) according to detergent type

Figure 13 (above) shows that Delta E also varied per detergent after 50 wash cycles. It is interesting to note that in both brands of washing powders (Skip and Woolworths), the regular powders seemed to cause more colour loss than the micro powders. Skip also had higher values for colour loss when compared with the Woolworths product.

The interaction between number of wash cycles and fabric colour was highly significant ($p \leq 1\%$). Therefore the pattern of change for the three fabrics over 50 wash cycles was not the same. This can clearly be seen in Figure 14.(below)

Figure 14 (below) also shows that wash cycle one is the inherent starting point for colour loss and differs for each fabric. However, this is not considered to be significant, neither are the peaks in the trend-lines, but rather the overall trends.

The green and blue fabrics tended to loose colour consistently with each wash cycle, whereas the white fabric showed limited change in colour. The colour loss in the green fabric seemed to accelerate after 10, 25 and 50 wash cycles, which was not the case with the blue and white fabrics

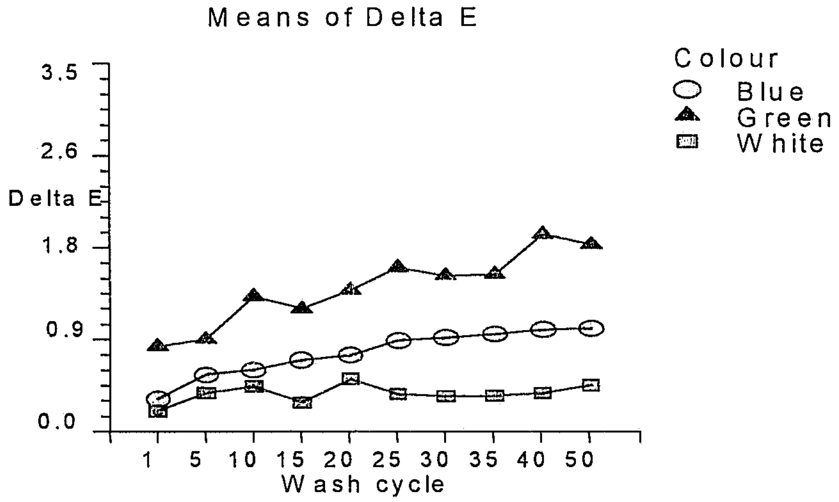

Figure 14: Colour loss (Delta E) according to fabric colour and number of wash cycles

The interaction between the wash cycles and detergent type was not significant ($p \geq 10\%$) Figure 15 (below) shows that there was little change when the three detergents were compared with respect to wash cycles. However, the Woolworths Micro powder seems to have had the least effect on colour loss for each of the three experimental fabrics. All four washing powders hardly affected the white fabric.

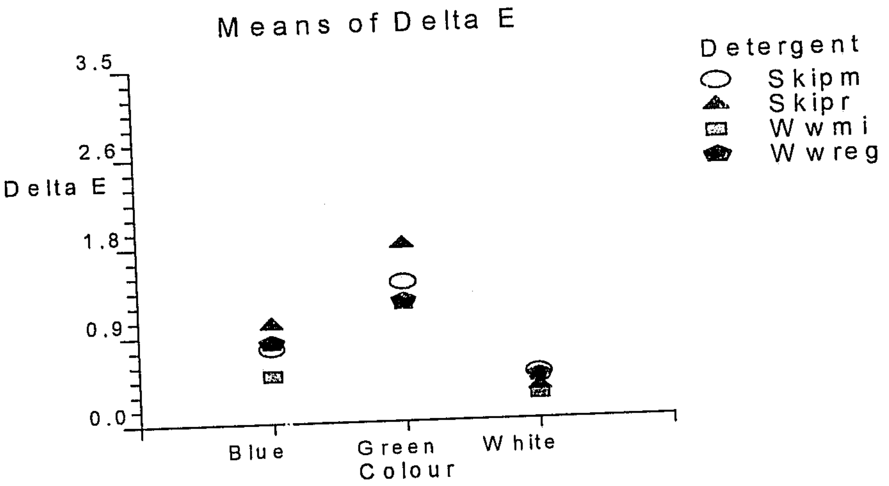

Figure 15: Colour loss (Delta E) according to fabric colour and detergent type

The interaction between the colour of the fabric and detergent type was highly significant ($p \leq 1\%$). Figure 16 (below) shows this variation.

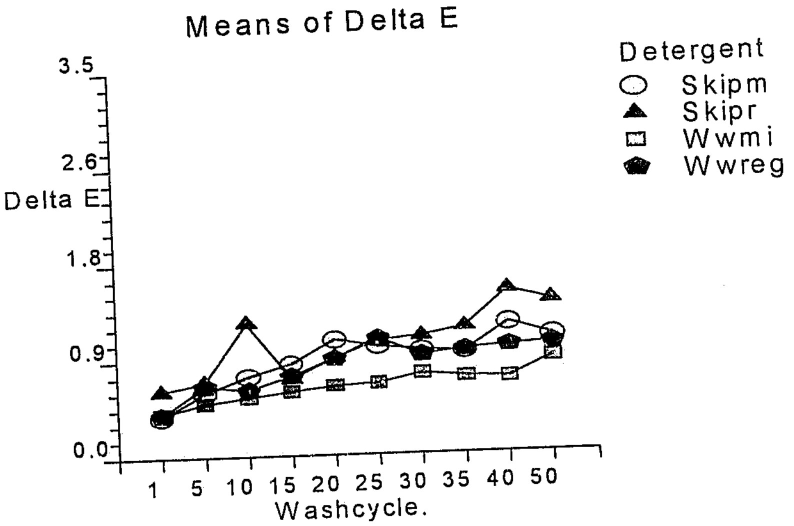

Figure 16: Colour loss (Delta E) according to detergent type and number of wash cycles

The white fabric showed hardly any change but the blue and green fabrics show significant changes in Delta E. The green fabric, which had the highest colour loss, was most affected by the Skip regular powder. In comparison with micro washing powders, colour loss in both the green and blue fabrics was more apparent when using regular washing powders of each brand. Skip regular caused the greatest colour loss in the green fabric. The other three washing powders showed much less overall colour loss.

4.2.3 Chroma (Delta C)

Chroma is a measure of the saturation of a colour. The vividness or dullness of a colour describes its chroma. It indicates how close the colour is to either grey or pure hue (Data Color, 1996:6). Saturation refers to the degree to which the hue is diluted or mixed with white. Saturated colours are 'strong' or 'pure'. When white is added or taken away they become more (very strong colours) or less saturated (pastels) (Lyle, 1976:205). Loss of chroma therefore refers to increased whiteness due to bleaching agents and/or mechanical damage.

Table 9 summarises the results according to analyses of variance (ANOVA) for colour loss in chroma (Delta C) in dyed cotton fabrics.

Table 9: Analysis of Variance for chroma (Delta C) in dyed cotton fabrics

Source		**Sum of**	**Mean**		**Prob**
Term	**DF**	**Squares**	**Square**	**F-Ratio**	**Level**
A (Washcycl.)	9	0.602	0.067	4.06	0.000**
B (color)	2	5.036	2.518	152.76	0.000**
C (Detergent)	3	1.061	0.354	21.45	0.000**
AB	18	0.413	0.023	1.39	0.174
AC	27	0.586	0.022	1.32	0.193
BC	6	0.342	00.062	3.46	0.005**

**Term highly significant at alpha ≤ 0.01 (1% level); * Term significant at alpha ≤ 0,05 (5% level)

The above table shows that the main effects number of wash cycles (A), colour of experimental fabrics (B) and type of detergent (C) had highly significant effects on chroma at a 1% significance level ($p \leq 0.01$). The interaction BC (fabric colour and detergent type) also showed highly significant variations. This means that fabric colours become less saturated because of detergent use and the effect of up to 50 wash cycles.

From Figure 17 (below) it is clear that the greatest loss of saturation of colour occurred between the first to tenth washes. Thereafter the level of colour loss stayed more or less constant.

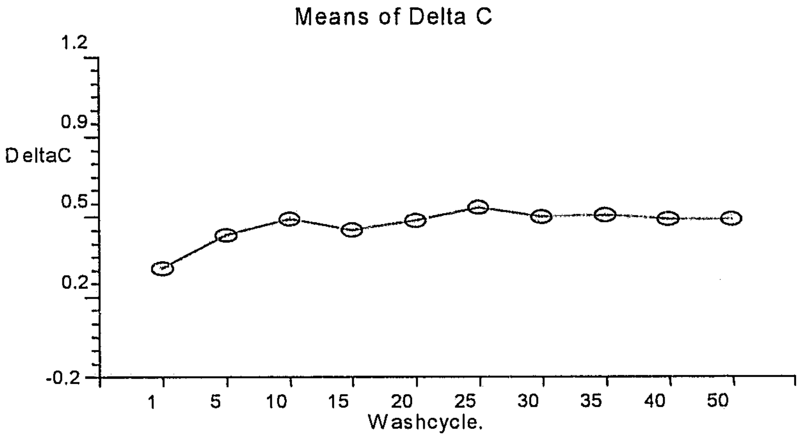

Figure 17: Colour loss (Delta C) according to number of wash cycles

Figure 18 (below) shows that Delta C varies for each of the fabric colours after 50 wash cycles.

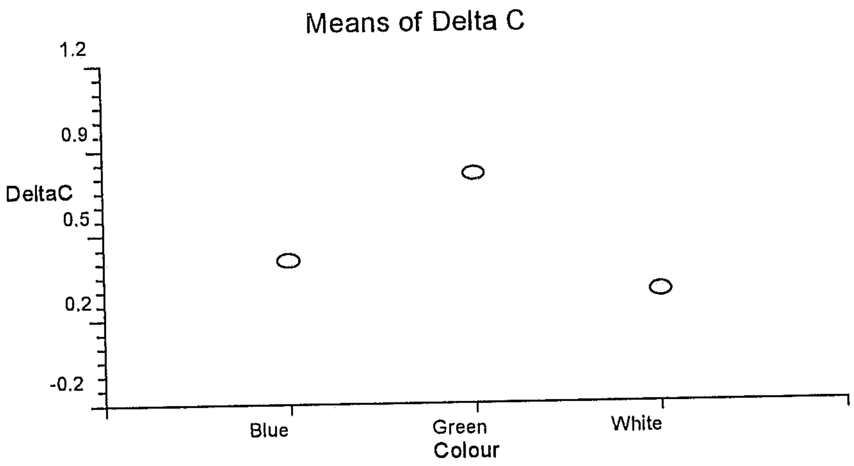

Figure 18: Colour loss (Delta C) according to fabric colour

This figure shows that the green fabric had a greater loss of chroma than the blue or white fabrics.

The figure below shows that there was a difference between the effect of the type of detergent on chroma loss.

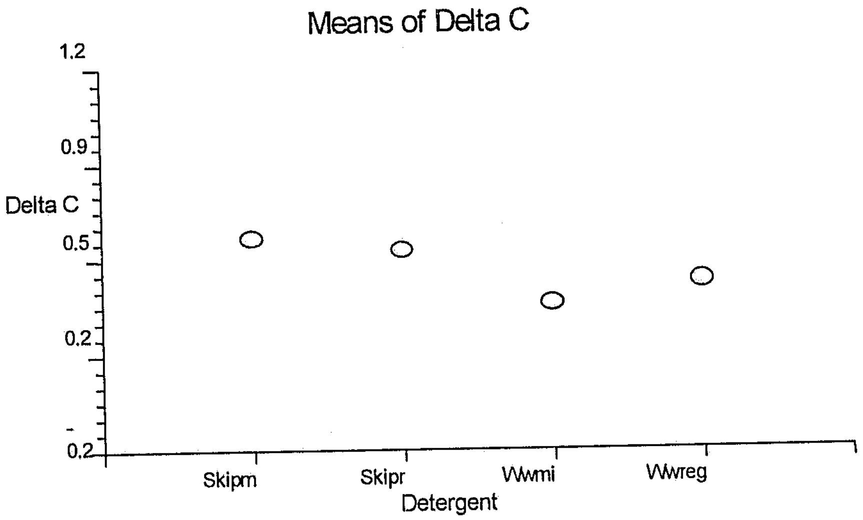

Figure 19: Colour loss (Delta C) according to detergent type

Skip micro and Skip regular had a greater influence on chroma loss than the Woolworth's powders. Micro powders of both brands caused less colour loss (Delta C) than regular powders.

The interaction between number of wash cycles and fabric colour was insignificant ($p \geq 10\%$). However, the colour change in the three fabrics varied considerably, as shown in Figure 20 below.

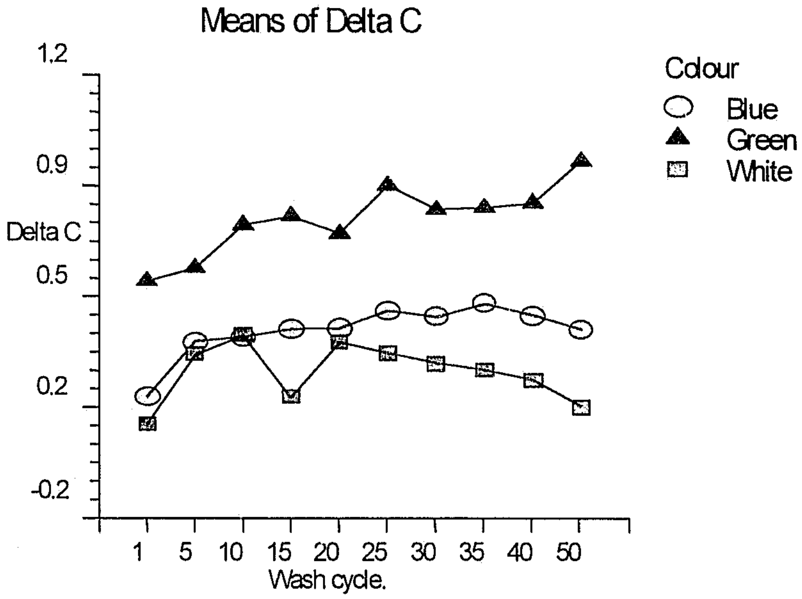

Figure 20: Colour loss (Delta C) according to fabric colour and number of wash cycles

The above figure indicates that in contrast to the blue and white fabrics, the green fabric persistently lost colour (Delta C), from the first wash onwards, and especially between the 25th and 50th washes cycles. Between the twentieth and fiftieth wash cycles, the white fabric gradually became whiter again, probably due to the build-up of optical brightening agents present in the detergents.

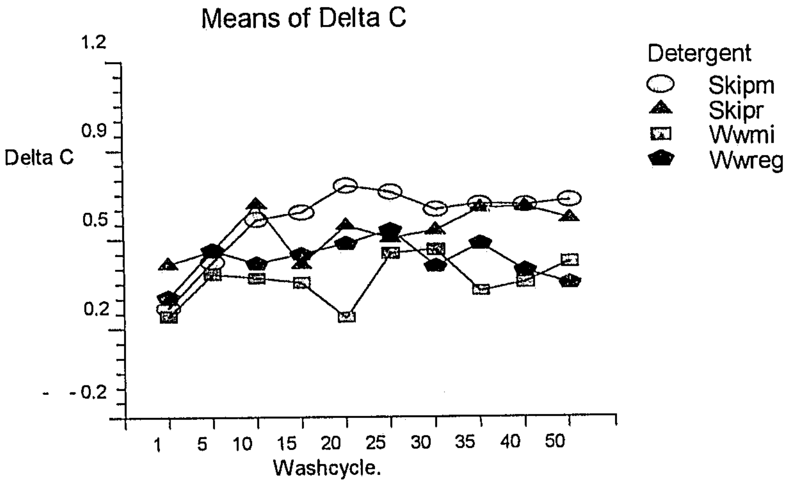

Figure 21: Colour loss (Delta C) according to detergent type and number of wash cycles

As shown in the above figure, the interaction between detergent type and number of wash cycle on colour loss (Delta C) was insignificant ($p \geq 10\%$). The figure however shows that both Skip regular and Skip micro had a somewhat greater influence on colour loss than the Woolworths brand.

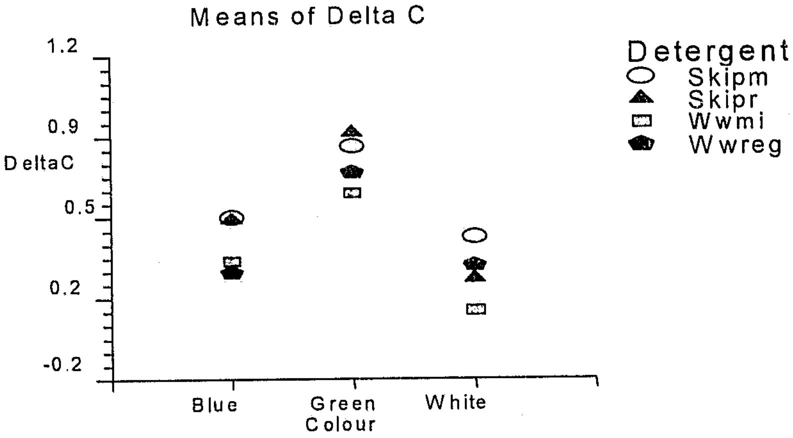

Figure 22: Colour loss (Delta C) according to detergent type and fabric colour

The interaction between fabric colour and detergent was significant ($p \leq 1\%$). Figure 22 (above) shows a difference in chroma loss between the blue, green and white fabrics. The position as well as the order in which the detergents occur has to be noted. Skip micro and regular powders both had a greater effect on chroma loss (Delta C) than the Woolworths products. All four washing powders had a greater influence on the green fabric than the rest. The white fabric was the least influenced, especially by the Woolworths micro powder.

4.2.4 Lightness (Delta L)

Hue is how the human eyes perceive an object's colour. This characteristic of colour describes its luminous intensity or degree of lightness. Colours can be perceived as light or dark when studying lightness values. Lightness is described as the inverse of 'greyness' and shows a range from 'bright' to 'dark' (Lyle, 1976:206). When a colour becomes lighter, it means that the black component of the colour has been reduced .

Table 10 is a summary of the results for lightness measurement (Delta L) according to analyses of variance (ANOVA). It shows that a number of main effects and interactions were highly significant ($p \leq 1\%$). These include the number of wash cycles, fabric colour and detergent type, as well as the interaction between colour of fabric and detergent. The interaction between number of wash cycles and colour of fabric (AB) and number of wash cycles and detergent (AC) was insignificant.

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Table 10: Analysis of Variance for lightness (Delta L) in dyed cotton fabrics

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level
A (Washcycl)	9	2.886	0.321	5.62	0.000**
B (Colour)	2	4.414	2.207	38.67	0.000**
C (Detergent)	3	2.834	0.945	16.55	0.000**
AB	18	1.754	0.945	1.71	0.066
AC	27	1.876	0.948	1.22	0.264
BC	6	1.486	0.248	4.34	0.001**

*Term highly significant at alpha ≤ 0.01 (1% level);

* Term significant at alpha ≤0,05 (5% level)

Figure 23 (below) shows the effect of number of wash cycles on colour loss (Del L). It is clear that there was a steady increase in colour loss in all experimental fabrics from the first, up to the last (50) wash cycles.

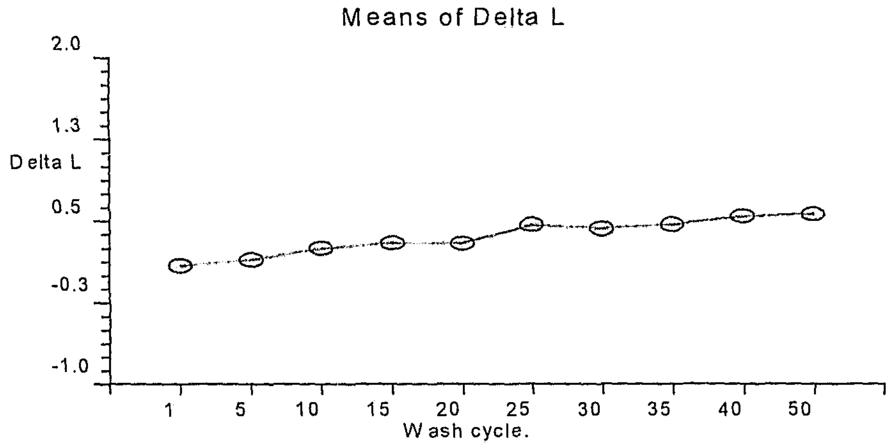


Figure 23: Colour loss (Delta L) according to number of wash cycles

Figure 24 (below) shows that the colour loss in the blue fabric was the greatest, followed by the green and white colours.

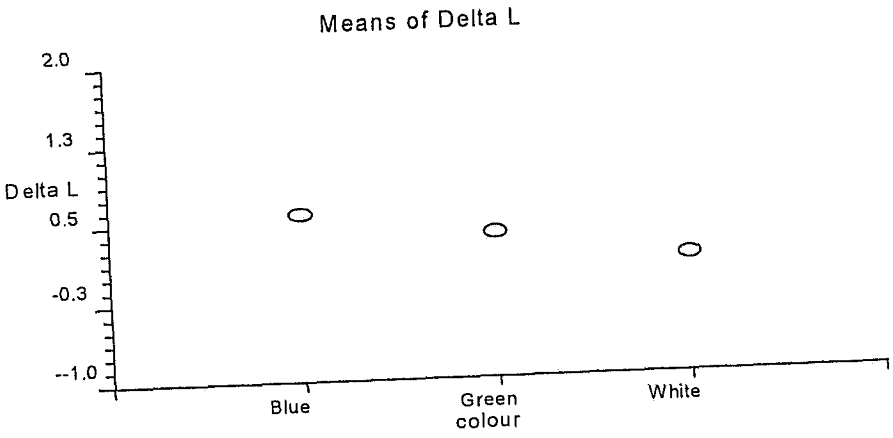


Figure 24: Colour loss (Delta L) according to fabric colour

Figure 25 illustrates that in both brands of washing powders used, the regular powders caused more saturation loss than the micro powders. This could be due to the fact that in micro powders 30% less chemicals are used in comparison with regular powders (Swaine, 1993:4) which reduces the possibility of chemical degradation.

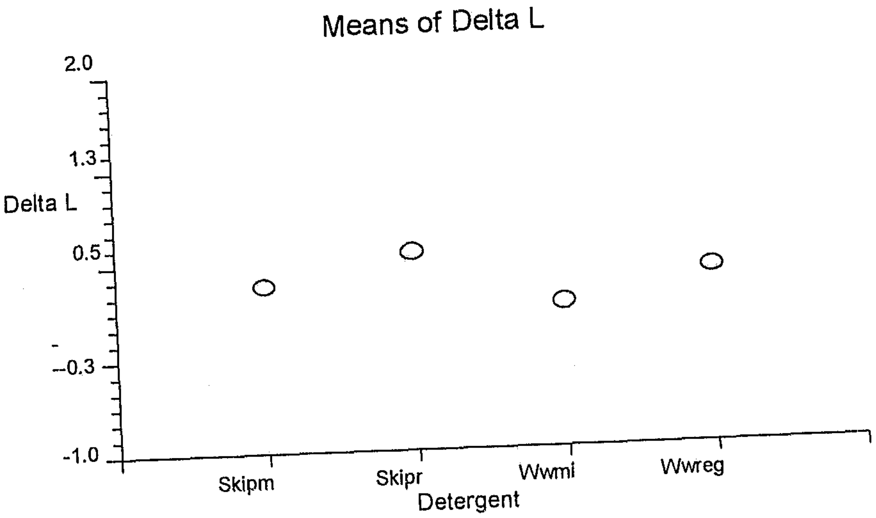


Figure 25: Colour loss (Delta L) according to detergent type

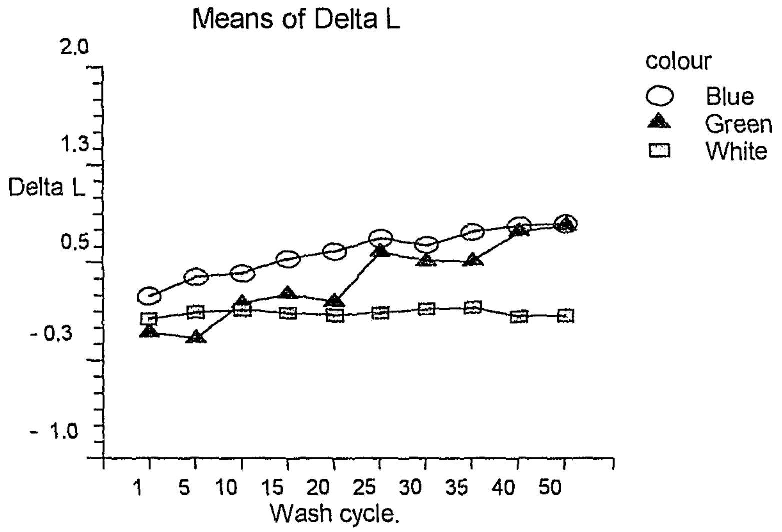


Figure 26: Colour loss (Delta L) according to number of wash cycles and fabric colour

Although this interaction was not significant, the above figure shows a greater value loss in the blue fabric than in the green or white fabrics. All three perceived lines in Figure 26 have different slopes. The lines associated with the green fabric, show exceptional instability. Between 25 to 50 washes the colour loss in the green fabric increased considerably. This may be the result of chemical or mechanical abrasion of the fabrics, which might have a detrimental influence on the more sensitive darker colours (Slater, 1991:55). There seemed to be no difference in the colour of the white fabric over 50 wash cycles.colour loss

Figure 27 (below) shows the colour loss Delta L of experimental fabrics when subjected to the different washing powders. Although no significant difference could be found in this interaction, Skip regular caused the highest colour loss between one and 50 washes in comparison with the other washing powders, especially after ten washes. Woolworth's micro showed the least value loss, from one up to 50 wash cycles. The effect of the different detergents to colour loss could be ascribed to their specific ingredients.

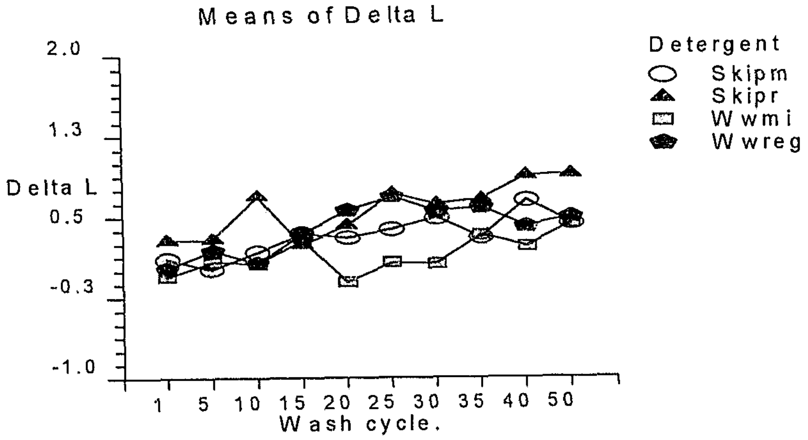


Figure 27: Colour loss (Delta L) according to number of wash cycles and detergent type.

Figure 28 (below) shows that highly significant differences were obtained in the interaction between *fabric colour* and *detergent type*. The value loss in the blue and green fabrics, after 50 wash cycles with Skip regular, is considerably higher than the same number of washes with the Skip and Woolworths micro powders. The blue fabric was also negatively affected by the use of Woolworths regular powder.

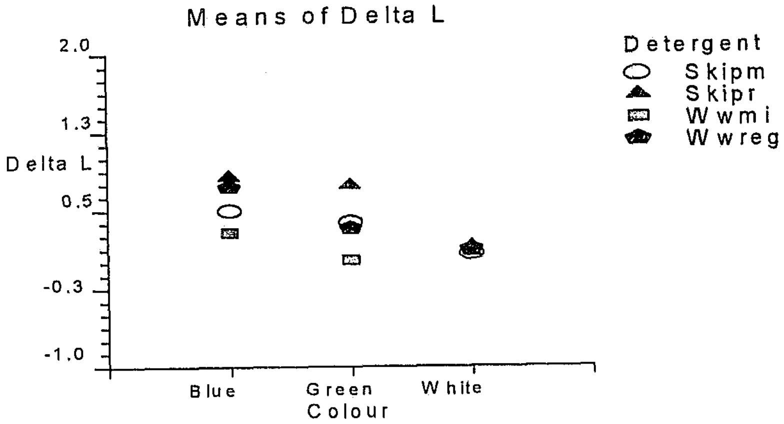


Figure 28: Colour loss (Delta L) according to fabric colour and detergent type

4.2.5 Hue (Delta H)

There are ten principle hues that can be influenced by detergents and the number of wash cycles the fabric may be subjected to. These are yellow, yellow-red, red, red-purple, purple, purple-blue, blue, blue-green, green and green-yellow.

Table 11 shows that all main effects, number of wash cycles, fabric colour and detergent type (A, B & C), as well as their interactions (AB, AC and BC), showed highly significant differences ($p \leq 1\%$).

Table 11: Analysis of Variance for hue (Delta H) in dyed cotton fabrics

Source		**Sum of**	**Mean**		**Prob**
Term	**DF**	**Squares**	**Square**	**F-Ratio**	**Level**
A (Washcy.)	9	0.678	0.076	4.21	0.000**
B (Colour)	2	23.963	11.982	669.80	0.000**
C (Deterg.)	3	1.021	0.340	19.02	0.000**
AB	18	3.073	0.171	9.54	0.000**
AC	27	1.352	0.051	2.80	0.000**
BC	6	0.674	0.113	6.28	0.000**

**Term highly significant at alpha $\leq$ 0.01 (1% level);
* Term significant at alpha $\leq$ 0,05 (5% level)

Delta H increased steadily with the number of wash cycles used on experimental fabrics (Figure 29 below).

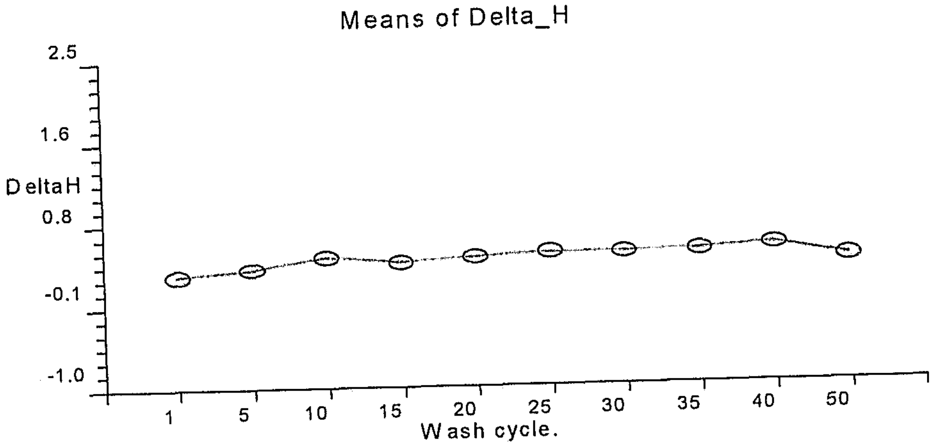


Figure 29: Colour loss (Delta H) according to number of wash cycles

Although this effect was highly significant, there seems to be very little difference in loss between the wash cycles.

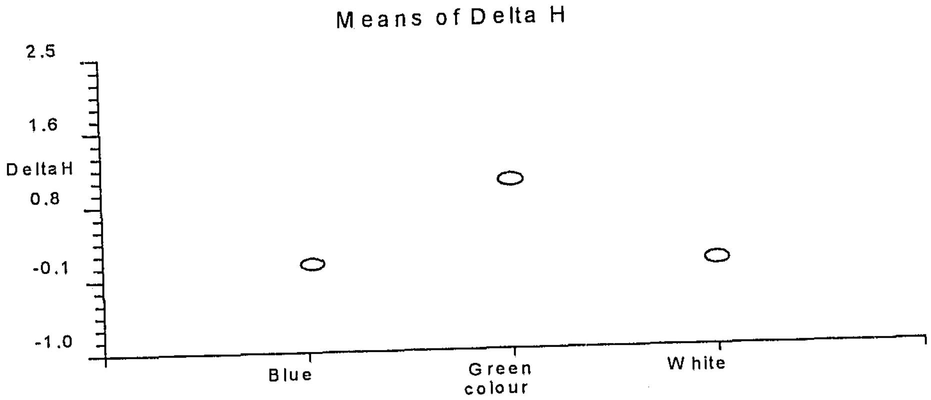


Figure 30: Colour loss (Delta H) according to fabric colour

Delta H varies in a similar pattern as Delta C and Delta L for each of the three colours. From the above figure it is clear that the green fabric showed the greatest loss of hue after 50 wash cycles in comparison to the blue and white fabrics.

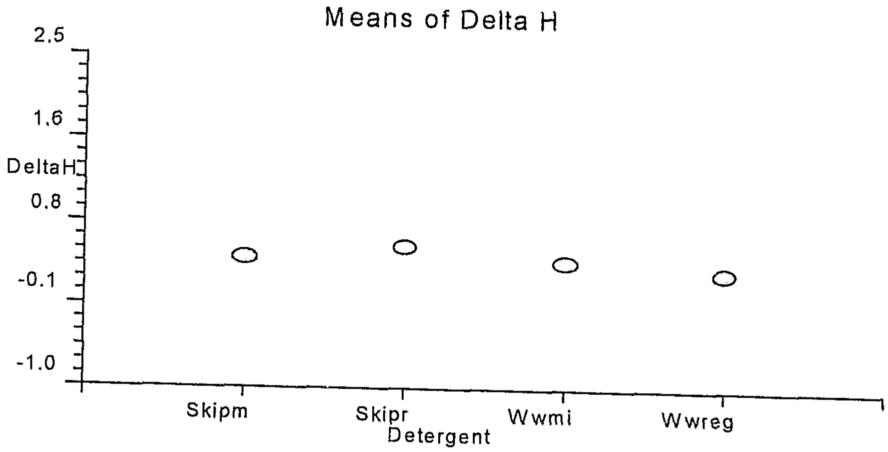


Figure 31: Colour loss (Delta H) according detergent type

The difference in Delta H due to detergent use was highly significant. However, there seems to be little difference between the effect of the various washing powders used. In comparison with the other three washing powders, Skip regular seemed to have had a slightly more degradative affect.

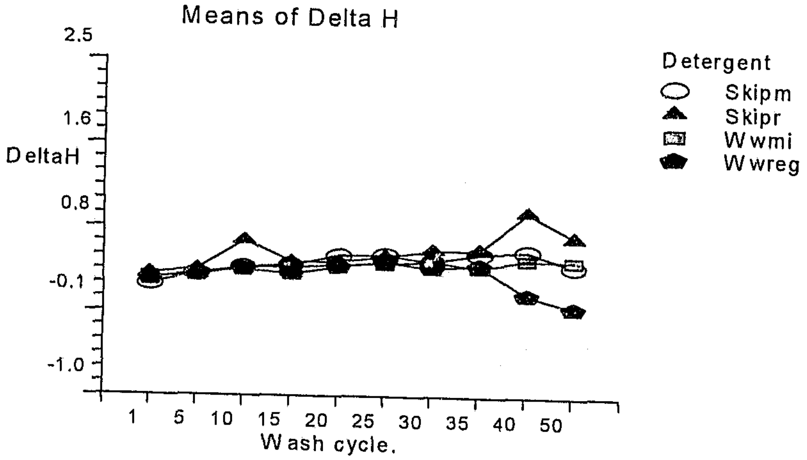


Figure 32: Colour loss (Delta H) according to number of wash cycles and detergent type

The interaction between *number of wash cycles* and *detergent type* was highly significant after 50 wash cycles (Figure 32). Skip regular washing powder again caused the greatest colour loss (Delta H).

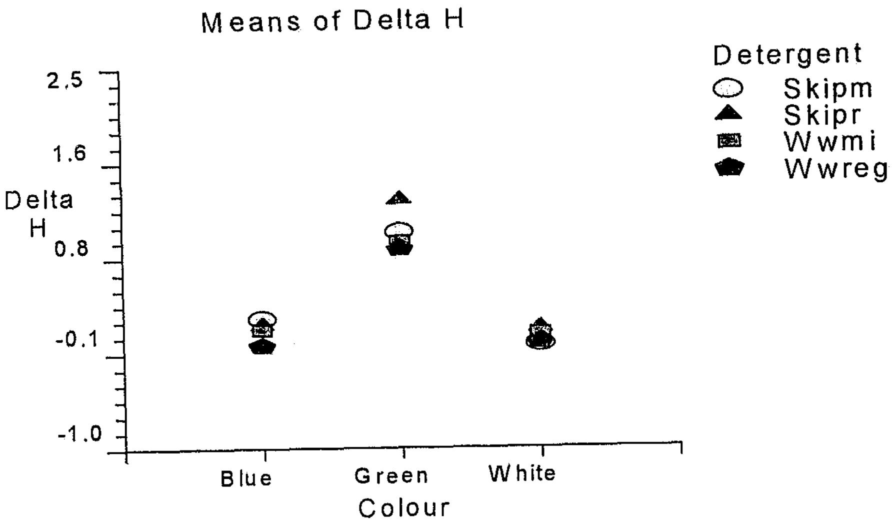


Figure 33: Colour loss (Delta H) according to fabric colour and detergent type

The interaction between *fabric colour* and *detergent type* was highly significant (Figure 33). All four *detergent types* had more or less the same effect on each of the *fabric colours*. It is clear from the figure that the hue of the green colour deteriorated most after 50 washes, especially with Skip regular. The blue and white fabrics seemed to be moderately affected by the detergents.

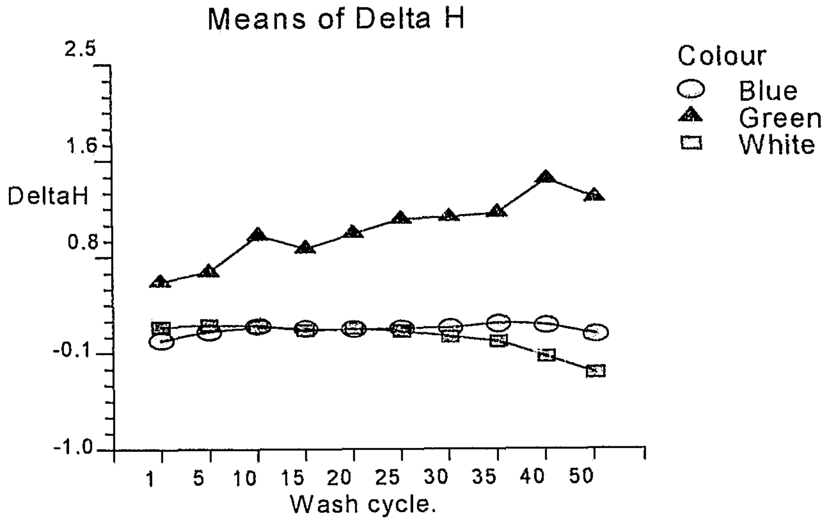


Figure 34: Colour loss (Delta H) according to fabric colour and number of wash cycles

The above interaction was highly significant. The figure clearly shows that over fifty wash cycles, the green fabric (not mercerised) lost more of its hue when compared with the blue and white fabrics. The Delta H measurement associated with the green fabric, shows a positive slope, up to the fiftieth wash. This corresponds with the fact that the multi-fibre fabric attached to the green fabric, showed considerable staining (green colour) after the 50th wash cycle. The blue and white fabrics seemed to loose hue after the first wash due to colour bleeding (blue fabric), as the values thereafter stayed relatively constant, up to the fiftieth wash. However, the lines associated with these fabrics, changed after the 35th wash cycle, probably due to the effect of optical brighteners in the detergent.

4.2.6 Summary and discussion

In this section, results obtained from laundering dyed cotton fabrics with regular and micro detergents were presented in terms of the pass/fail method, used by industry. These findings were based on the measurements chroma (Delta C), lightness (Delta L) and hue (Delta H), which were also used to determine the total colour loss in fabrics (Delta E).

The pass/fail method gave an indication of the average percentage of samples showing colour loss after 50 wash cycles, in using the four different *detergents*. From the results it is clear that in using Skip regular, only half the samples were accepted (50%), compared to Skip micro (70%), Woolworths regular (70%) and Woolworths micro (76%). As far as fabric colour is concerned, the white fabrics showed a 100% pass rate with all the detergents, whereas the blue fabric was negatively affected when using Skip regular and to a lesser extent with Woolworths regular. The green fabric showed extensive colour loss with all four detergents used.

In determining the total difference value (Delta E), the main effects *(number of wash cycles, fabric colour, detergent type)* as well as their interactions, showed highly significant differences ($p \leq 1\%$), excluding the interaction between *number of wash cycle and detergent*. The measurements for chroma, or colour saturation (Delta C), showed highly significant differences in the main effects, but not in the interactions between them. Lightness or degree of greyness (Delta L), showed similar results, with highly significant differences in the interaction between fabric colour and detergent type. Hue (Delta H) showed highly significant differences in all main effects and interactions. The variations in some of the colour measurements, especially those shown in Figures 20 and 21, are possibly due to a combination of varying colour spots on experimental fabrics.

According to Trotman (1987: 456-457) colour loss due to laundering is more apparent in deeper shades. The extensive colour loss in the green fabric corresponds with results obtained by Williams and Horridge (1996:151), who reported significant colour differences in laundering naturally dyed green cotton fabrics, and no colour change in white cotton. It is generally accepted that most reactive dyes, also used on experimental fabrics in this study, are colourfast (Trotman, 1990:457). However, yellow dyes seem to fade more rapidly than normal. Green contains yellow dye. This may explain the colour loss of the green fabric used in this study. Although sodium perborate bleaches more effectively at higher temperatures, it may be possible that the presence of sodium perborate in Skip regular at the wash temperature of 60°C, was responsible for the cumulative deterioration of the chroma.

In studying the three-dimensional colour space with represented colours plotted (Figure 10), it is clear that the highly saturated reds, yellows and oranges, situated near the spectrum loci boundary in the chromaticity chart, can have luminosity factors up to 0.72 or more. However, the corresponding values for saturated blues and greens lie between 0 and 0.3. In the yellow region, both high saturation and luminosity can be obtained. In this case any de-saturating stimuli will be green and red which together give yellow, thus promoting the dominant hue. If on the other hand, the stimulus is blue or blue-green, the adulterants will be red and yellow-green, which in combination yield white light, which has a de-saturating effect (Trotman, 1991:556). The above description explains the greater loss of saturation or lightness in the experimental fabrics.

It has to be noted that detergents for household use are very complex formulations, containing several types of substances. The effects of chemical degradation causing colour loss will therefore differ. Studies have shown that the more alkaline a detergent because of a high sodium perborate content, the more it will enhance whiteness in fabrics, even after 50 washing cycles. Repeated washing therefore improve whiteness but has an adverse effect on other variables (Slater, 1991:11 & 12). It is suspected that the optical brightening agents present in detergents, also contributed to the improved whiteness of the white fabric used in this study.

Figure 33 shows that Skip regular caused significant colour loss in the green fabric. This may be due to the carbonate and silicate content of the detergent, which according to researchers such as Krüszmann (1982:24) and Ulrich and Mohamed (1982[1]:39), cause incrustation on fabric surfaces. This eventually leads to colour loss in coloured and white fabrics. Another explanation for the extensive colour loss in the green fabric, when using all four detergent types, may be the fact that this fabric was not mercerised and did not have a durable press finish, as was the case with the white and blue fabrics. Reinhardt and Graves (1996:28) proved that cotton fabrics with a durable press finish are more colourfast, than untreated fabrics.

4.3 The effect of laundering with regular and micro detergents on the tensile strength of dyed cotton fabrics

The measurement of the tensile strength of experimental fabrics was included in this research to establish whether there would be a decline in fabric performance after exposure to laundry treatments with regular and micro detergents. This measurement is a universal mechanical way to assess degradation of textile fabrics (Slater, 1991:74). Tensile strength is the ability of a fabric to withstand a pulling force. When the fabric breaks, the breaking load is measured in Newton or kilogram (Merkel, 1991:165).

The repeatedly laundered experimental fabrics (50 wash cycles) were also viewed in a scanning electron microscope, to establish whether the surface properties of the fibres had changed, due to possible mechanical and/or chemical damage. As explained in Chapter 2, scanning electron microscopy is a useful technique for describing fabric damage (Raheel, 1983:647; Raheel & Lien, 1982:555; Hurren, Wilcock and Slater, 1985:286).

4.3.1 The effect of laundering on tensile strength

As mentioned in Chapter 3, dimensional stability measurements were taken after successive wash cycles (1, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 wash cycles), to establish whether the experimental fabrics showed any dimensional changes. Possible shrinkage of the fabrics would necessitate adjustments in tensile strength data. However, no change in dimensional stability occurred in any of the experimental fabrics, in using the shrinkage ruler, after the above number of wash cycles. Therefore, no adjustments to tensile strength measurements were necessary.

A factorial analysis of variance was used to determine the effects of individual factors (detergent type, number of wash cycles and fabric colour) and their simultaneous interaction upon tensile strength. Table 12 represents a summary of the effects of *number of wash cycles* (A), *colour of cotton fabric* (B) and *type of detergent* used (C). The interactions AB, AC, BC and ABC also had highly significant effects on tensile strength at a 1% significance level (p ≤ 1%).

Table 12: Analysis of Variance for tensile strength of dyed cotton fabrics

Source		**Sum of**	**Mean**		**Prob**
Term	**DF**	**Squares**	**Square**	**F-Ratio**	**Level**
A (Wash cycle)	9	1456.319	161.8133	6.48	0.000000**
B (Colour)	2	1560.81	780.405	31.26	0.000000**
C (Detergent)	3	2773.189	924.3964	37.03	0.000000**
AB	18	2773.137	154.0632	6.17	0.000000**
AC	27	7176.628	265.8011	10.65	0.000000**
BC	6	794.7916	132.4653	5.31	0.000021**
ABC	54	5809.538	107.584	4.31	0.000000**

**Term highly significant at alpha ≤ 0.01 (1% level);
* Term significant at alpha ≤ 0,05 (5% level)

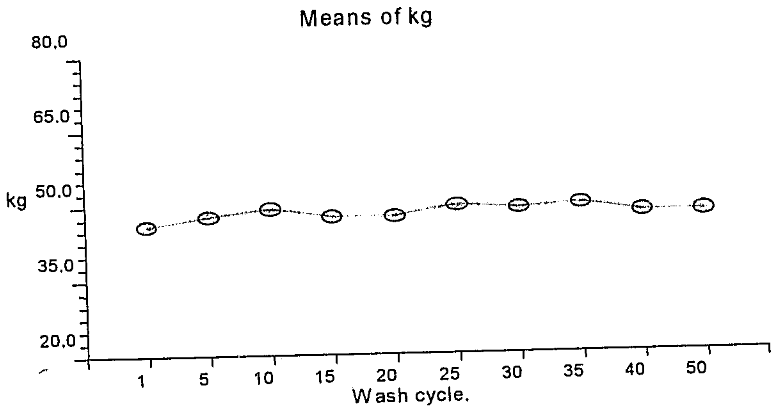


Figure 35: Tensile strength according to number of wash cycles

Figure 35 (above) shows that there was some variation in the tensile strength of all experimental fabrics over the 50 wash cycles.

The tensile strength values of the *three coloured fabrics* and the *four washing powders*, as shown in the figures below, are nominal classes, and therefore not connected by means of lines.

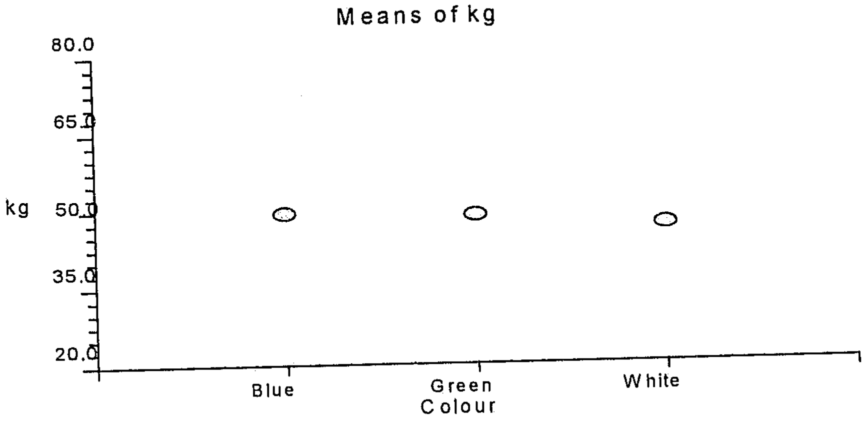


Figure 36: Tensile strength according to fabric colour

In the above figure, tensile strength measurements were related to the *number of wash cycles* and the estimates of means by lines, to facilitate easier summary of general trends. The above figure shows that the tensile strength of the three fabrics varied slightly after exposure to multiple wash cycles.

Figure 37 (below) indicates how these results varied over 50 wash cycles.

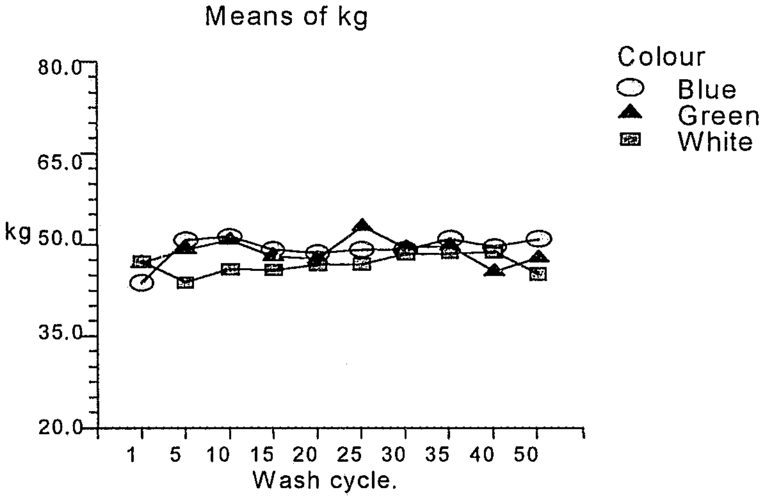


Figure 37: Tensile strength according to number of wash cycles and fabric colour

The above figure shows that the strength of the green fabric gradually increased, up to the 25th wash and then lost some of its strength at the 40th wash cycle. Both blue and white fabrics showed a gradual increase in strength up to the 40th and 50th wash cycles.

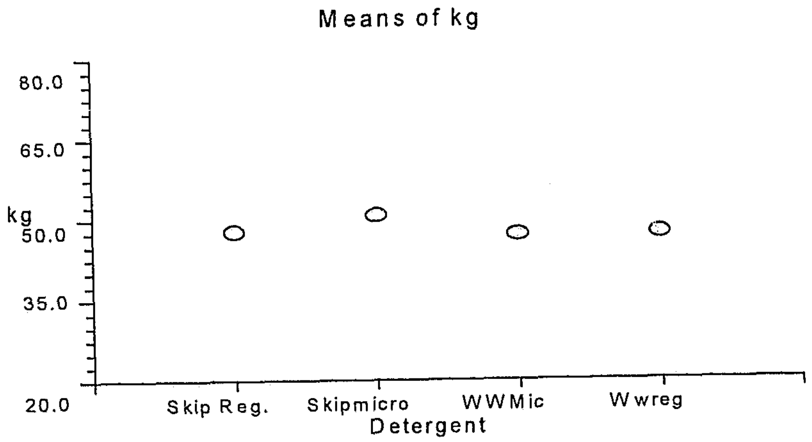


Figure 38: Tensile strength according to detergent type

The above figure shows that the tensile strength of the three experimental fabrics varied per detergent after 50 wash cycles. The lines connecting values for the three detergents are insignificant for the interpretation of the data. The tensile strength of all fabrics washed with Skip micro for 50 wash cycles was somewhat higher than with the other three detergents.

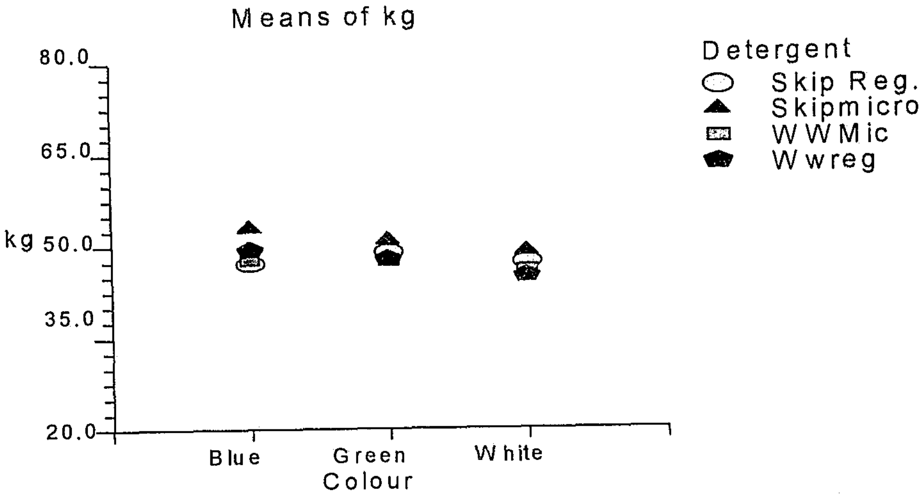


Figure 39: Tensile strength according to fabric colour and detergent type

The different coloured fabrics showed variations in strength with the four detergent types used in this study. The white and green fabrics seemed to have been affected in the same way by the four detergent types, whereas the blue fabric seemed to have been less affected by the Skip micro powder.

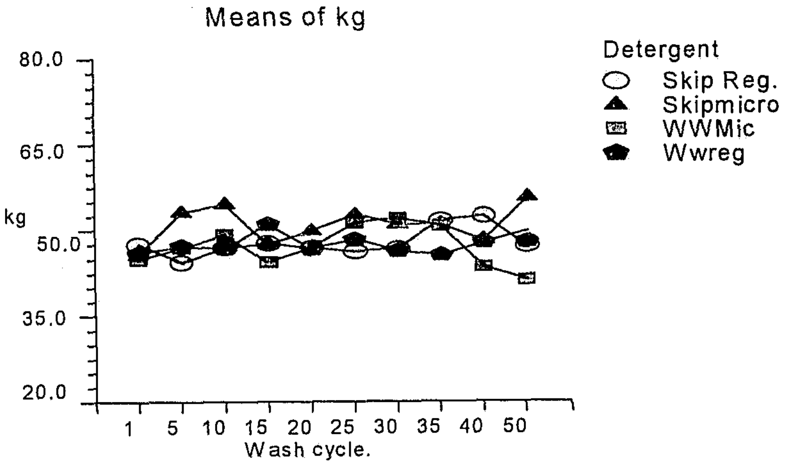


Figure 40: Tensile strength according to number of wash cycles and detergent type

Figure 40 (above) shows the variation in tensile strength caused in all fabrics by the different washing powders as well as the *number of wash cycles* used. It seems that Skip micro had the least effect on fabric strength over 50 washes. With Woolworths micro the strength decreased after the 35th wash. Both Skip regular and Woolworths regular did not affect fabric strength much over the 50 washes.

Addendum B provides detailed information on the effect of the four detergents on the tensile strength of the respective experimental fabrics after multiple laundry treatments. This data is illustrated in Figures 41, 42, 43 and 44.

According to Figure 41 (below), the blue twill fabric showed a sudden increase in tensile strength up to the tenth wash cycle, followed by a decrease. The tensile strength of the plain woven green and white fabrics, remained relatively constant after multiple wash cycles with Skip micro.

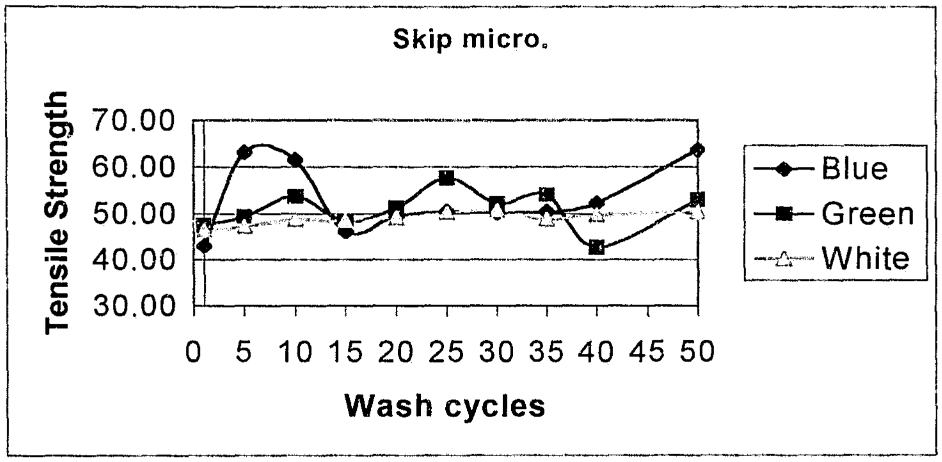


Figure 41: Tensile strength according to fabric colour and number of wash cycles with Skip micro detergent

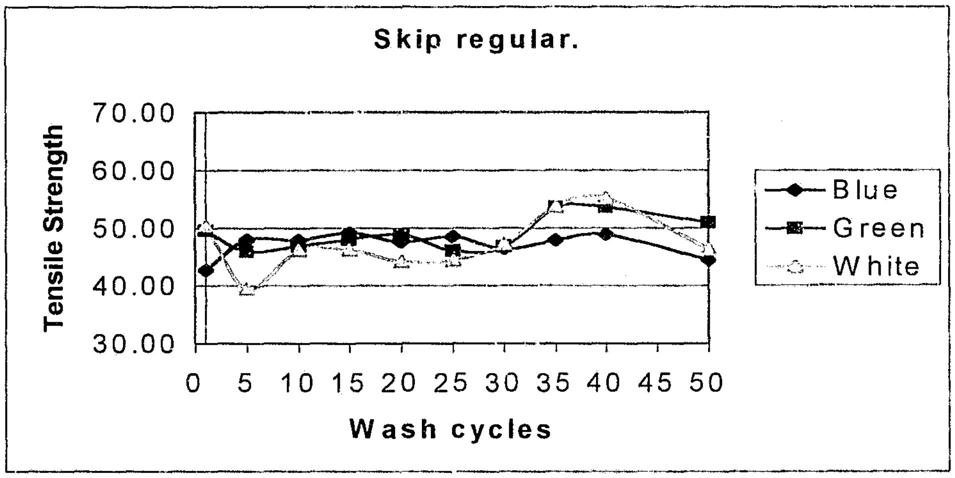


Figure 42: Tensile strength according to fabric colour and number of wash cycles with Skip regular detergent

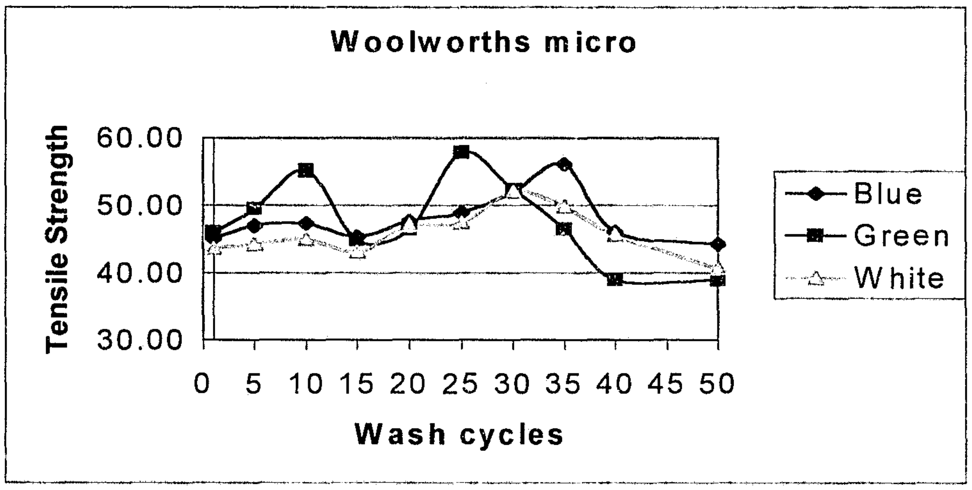
Figure 42 (above) indicates that when using Skip regular, all three experimental fabrics hardly showed a change in tensile strength.

Figure 43 (below) shows very little loss in tensile strength of all three fabrics when washed with Woolworths micro. This washing powder seemed to be less degradatative on experimental fabrics after 50 wash cycles when compared with Skip micro.

50 wash cycles (Figure 44 below).

Figure 43: Tensile strength according to fabric colour and number of wash cycles and with Woolworths micro detergent

As was the case with the Woolworths micro powder, the Woolworths regular powder also showed no significant tensile loss in experimental fabrics over the 50 wash cycles (Figure 44 below).



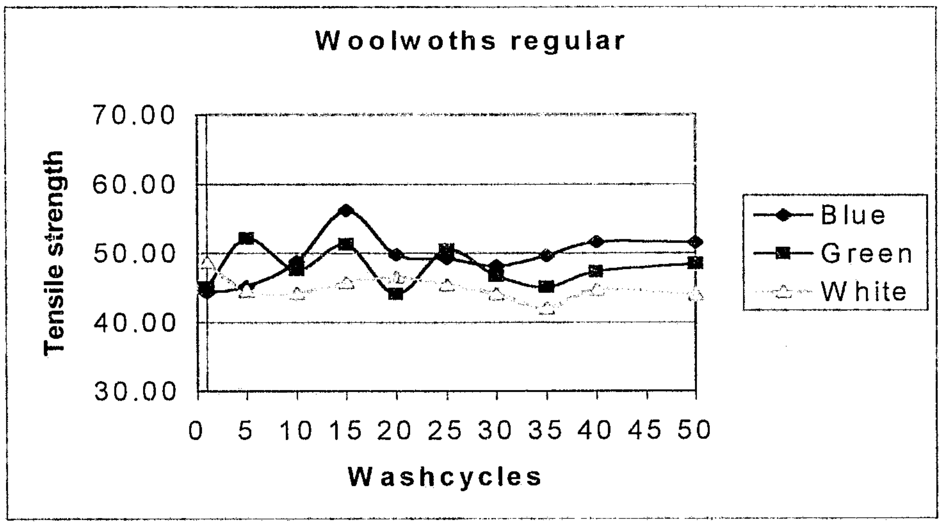


Figure 44: Tensile strength according to fabric colour and number of wash cycles with Woolworths regular detergent

4.3.2 The effect of laundering on fabrics as viewed in a scanning electron microscope

Scanning electron microscopy was used in this study as an aid in interpreting the tensile strength data. This was done by investigating the surface detail of fibres at 900X magnification before and after 50 wash cycles, in laundering the white, blue and green fabrics (Figures 45 to 59).

In comparing the three fabrics, the reduced number of twist, visible in the fibres of the white and blue control samples, is characteristic of mercerisation (Figures 45 and 50). In comparison with the green and blue fabrics, the white fabric showed some foreign matter among the fibres (Figures 45, 50 and 56).

All three fabrics show some extent of degradation after 50 wash cycles. However, the fibrillation of most fibre surfaces, does not correlate with the tensile strength data shown in Addendum B. The fibrillation of the fibre surfaces of the green fabrics (Figures 56 to 58), also shows less resistance to degradation, when compared with the mercerised, durable press white (Figures 46 to 49) and blue fabrics (Figures 52 to 54).

The effect of *detergent type* on the deterioration of fabrics used in this research showed variations. The use of Skip regular seemed to have a more damaging effect on the green fabric (Figure 56), whereas the blue fabrics hardly showed any sign of fibrillation after 50 wash cycles (Figure 51). The use of Woolworths regular seemed to have influenced all three fabrics negatively (Figures 48, 53 and 58), especially the green fabric, which was fibrillated to some extent. As far as the micro washing powders are concerned, Skip micro seemed to have a negative effect on the green fabric only (Figure 57), whereas Woolworths micro affected all three fabrics in a moderate way (Figures 49, 54 and 59). In observing The green fabric, which was fibrillated by all four detergent types after 50 wash cycles, Skip regular and Woolworths regular seemed to have caused more fibre damage, than the micro washing powders of the same brand.

White fabric as viewed in a scanning electron microscope.

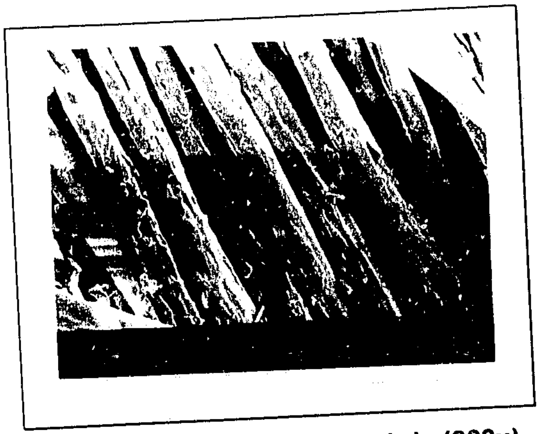


Figure 45: White Control Fabric (900x)

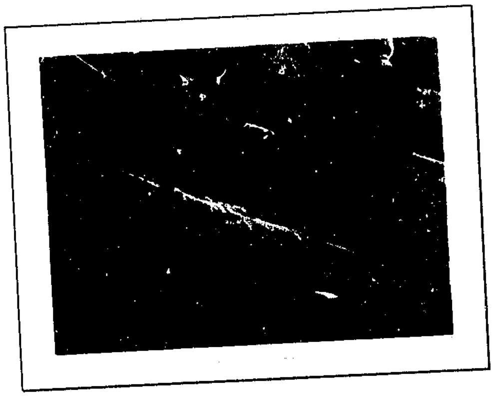


Figure 46: White fabric treated with Skip regular after 50 wash cycles (900x)

Figure 47: White fabric treated with Skip micro after 50 wash cycles (900x)

Figure 48: White fabric treated with Woolworths regular after 50 wash cycles (900x)

Figure 49: White fabric treated with Woolworths micro after 50 wash cycles (900x)

Blue fabric as viewed in a scanning electron microscope

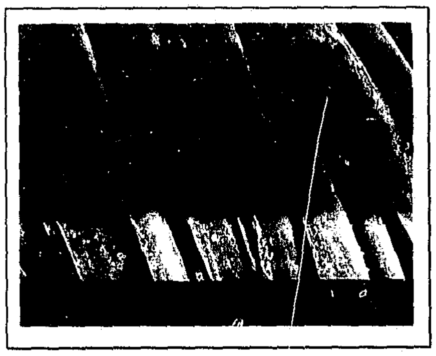


Figure 50: Blue Control Fabric (900x)

Figure 51: Blue fabric treated with Skip regular after 50 wash cycles (900x)

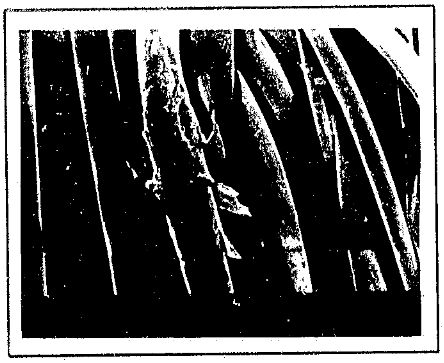


Figure 52: Blue fabric treated with Skip micro after 50 wash cycles (900x)

Figure 53: Blue fabric treated with Woolworths regular after 50 wash cycles (900x)

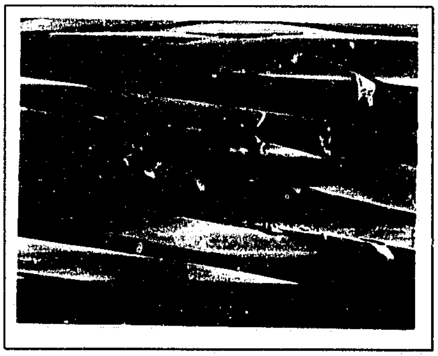


Figure 54: Blue fabric treated with Woolworths micro after 50 wash cycles (900x)

Green fabric viewed in a scanning electron microscope

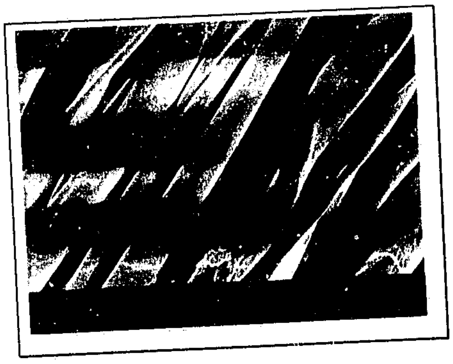


Figure 55: Green Control Fabric (900x)

Figure 56: Green fabric treated with Skip regular after 50 wash cycles (900x)

Figure 57: Green fabric treated with Skip micro after 50 wash cycles (900x)

Figure 58: Green fabric treated with Woolworths regular after 50 wash cycles (900x)

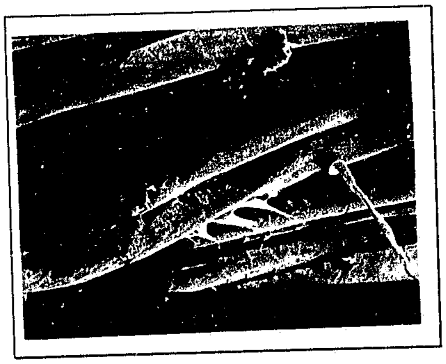


Figure 59: Green fabric treated with Woolworths micro after 50 wash cycles (900x)

4.3.3 Summary and discussion

The effect of regular and micro detergents on the tensile strength of dyed cotton fabrics over 50 wash cycles and at a temperature of 60°C, showed highly significant differences ($p \leq 1\%$). These differences occurred in the main effects (number of wash cycles, fabric colour, detergent type) as well as in the interactions between them (Table 12).

The tensile strength data of experimental fabrics seemed to fluctuate over the 50 wash cycles. It could be expected that shrinkage during laundering contributed to the slight increase in tensile strength of some fabrics. However, no dimensional differences were found in experimental fabrics over 50 wash cycles. It is therefore suspected that variations in yarn twist and possible yarn slippage, especially in the blue twill fabric, could have caused the differences. In a plain weave, which has the maximum number of thread intersections possible, yarn slippage will be restricted. In twill weaves, in which the long floats are a characteristic of the fabrics, the floats will permit easy slippage of the threads.

Similar tensile strength variations were found in research data reported by Jokelainen and Kujala (1984:337) and Raheel and Lien (1982:557).

In general, the experimental fabrics showed very little loss of strength over 50 wash cycles. This corresponds with research findings obtained by Jokelainen and Kujala (1984:333-338) who also found little degradation of cotton during laundering at 60°C, as perborate bleaches are generally activated at higher temperatures. Research by Sengupta *et al* (1990:573-579) also indicated that tensile and bursting strength properties of fabrics are not affected much by laundering treatments.

To summarise, tensile strength measurements showed that none of the detergents used in this study seemed to have had a deteriorating effect on the experimental fabrics. However, on examining the scanning electron microscope photos, considerable damage seemed to have occurred in some fabrics. The fibrillated surfaces indicated that there probably was some swelling of the fibres in the alkaline solutions. In this state, the primary and secondary areas of the cotton cell walls, especially in regions C and N, indicated in Figure 5 (page 23), are easily distorted and fibrils are easily seperated by mechanical and chemical action (Goynes and Rollins, 1971:227). The primary cell wall of the cotton fibre is easily fibrillated, as it almost three times less crystalline than the secondary wall cellulose (Boylston and Hebert, 1995:429).In examining the SEM photos, no traces of detergent deposits could be detected on fibre surfaces.

In comparison with the white and blue fabrics, the fibre surface of the green fabric was fibrillated by most detergents. This can be ascribed to the fact that this fabric was not mercerised or cross-linked. This observation corresponds with findings obtained by Raheel and Lien (1983^1:639). According to Goynes and Rollins (1971:230) cross-linking between adjacent molecules in the cellulose chain increases the lateral bond strength and makes the separation of fibrils more difficult.. Cross-linked fibres also swell less in water. Therefore fabrics with a durable press finish, will retain its strength better after multiple wash cycles, than untreated fabrics.

The final conclusion drawn from the research results discussed in this chapter, will be presented in Chapter 5. The conclusions will be discussed according to the pre-determined objectives and hypotheses, formulated for this study.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This study set out to establish the effect of regular and micro detergents on the colourfastness and strength of dyed cotton fabrics, after multiple wash treatments.

The development of new detergents, including the compact, environmental safe types, necessitated a better understanding of the effect of detergent use over time. The need for research, in order to establish the effect of these new detergents on the *colourfastness* of fabrics, was expressed by members of the clothing retail industry. Rising consumer complaints on laundry related colourfastness problems with dyed cotton fabrics over recent years, made manufacturers and retailers realise that detergents used in laboratory tests for quality management, might have to be adapted. Further to this problem, researchers have shown that mechanical and chemical damage during laundering, lead to loss of *strength* in fabrics.

This chapter constitutes the conclusions drawn after conducting an empirical study on the above subject. The main factors or variables used in the study included *three differently dyed fabrics*, using reactive dyes. *Four detergent types* were used, two regular and two micro of the same brand, The experimental fabrics were subjected to *multiple wash cycle treatments* (up to 50 wash cycles) in household washing machines. These variables were chosen in conjunction with members of the retail company who initiated the research. The conclusions are based on the results obtained in the empirical study, and on information gained in reviewing related research. The chapter is concluded with the researcher's view on conducting similar or follow-up research projects.

5.1 Conclusions

5.1.1 The effect of detergent type on the colourfastness of fabrics

The first objective formulated for this research was, to assess the effect of repeated laundering with regular and micro detergents on the colourfastness of dyed cotton fabrics. The null hypothesis was:

> $H1_0$: There will be no difference in the influence of regular and micro detergents on the colour of dyed cotton fabrics after multiple laundry treatments.

This hypothesis is rejected, as results showed that there were significant differences in colour loss between the detergents used. The pass/fail method, used by industry, indicated that for all three fabric colours, Skip regular caused the most degradation of fabric colours, followed by Skip micro and Woolworths regular, which both had a 70% pass rate. Woolworths micro seemed to have the least influence on all fabric colours, with a pass rate of 76%. Detergent compounds, such as carbonates and perborate bleach, both present in Skip regular, could have contributed to colour loss.

It is however important to bear in mind that colour loss is caused by a number of interrelated factors, and not detergent type alone. This study has shown that an increase in number of wash cycles, the use of fabric finishes, and probably chemical as well as mechanical fibre damage, could have contributed to colour loss.

Finishes such as mercerisation (white and blue fabrics), liquid ammonia treatment and cross-linking with durable press finishes (white and blue fabrics), usually increase fabrics' resistance to chemical and mechanical damage. The green fabric was neither mercerised, nor cross-linked. This led to extreme fibrillation of the primary and secondary fibre walls (especially with Skip regular), and breaking of the covalent bonds between reactive dyes and fibre molecules. The stained nylon fibres in the multi-fibre fabric strips, attached to the green fabric, showed that the use of both Skip washing powders caused fibrillation, and therefore colour loss after 50 wash cycles.

As far as the role of detergent ingredients is concerned, carbonates and optical brightening agents could have contributed to colour change. Both Skip detergents contained perborate bleach, which is activated at 60°C and could have deteriorated fabric colours.

The aim of this research was to establish whether there was a difference in effect on fabric colourfastness between regular and micro detergents of the same brand. Apart from some differences obtained in the Delta C, Delta L and Delta H values, Skip regular caused more colour loss (Delta E) in all experimental fabrics than Skip micro (Figure 15 page 74). The pass/fail method also confirms this (Table 6 page 68). The same conclusion can be drawn from results obtained with the use of the Woolworths detergents. It is therefore clear that the micro washing powders do not cause more colour loss in dyed fabrics, than the regular powders of the same brand.

5.1.2 The effect of detergent type on the strength of fabrics

The second objective for this study was to assess the effect of repeated laundering with regular and micro detergents on the strength of dyed cotton fabrics. The null hypothesis for this objective was:

> $H2_0$: There will be no difference in the influence of regular and micro detergents on the strength of dyed cotton fabrics after multiple laundry treatments.

The second hypothesis is also rejected. As indicated in the previous chapter, there seemed to be no real loss in the tensile strength of experimental fabrics, probably due to shrinkage or problems with shrinkage assessment. This aspect will be referred to again in the next section. However, scanning electron microscope photos indicated that fibre fibrillation had occurred in most of the fabrics, especially the green fabric. The extent of fibre fibrillation also differed with fabric type and detergent use.

It is believed that the combination of number of wash cycles, fabric finishes and detergent composition contributed to fibre fibrillation in fabrics. This will eventually lead to a loss in tensile strength. After 50 wash cycles, the white and blue fabrics showed some fibrillation with the use of different detergent types. The least damage was done to the blue fabric, as this fabric also had received a so-called silk finish, using waxes or resins to obtain a glazed effect. As mentioned before, the green fabric was fibrillated most. This fabric had not received a mercerisation or durable press treatment, as was the case with the blue and white fabrics.

Mechanical damage due to the number of laundering treatments could have contributed to fibrillation. However, the washing machines used in this study are known for their relatively mild wash action. Also, it must be taken into consideration that all fabrics were subjected to the same mechanical abrasion. It is therefore suspected that the differences in fibre fibrillation of each specific fabric (as shown in the SEM photos), were caused by detergent ingredients such as carbonates and perborates. In comparing detergent type, Skip regular caused considerably more fibre damage to the green fabric than the other three washing powders, whereas Woolworths regular damaged both blue and green fabrics to some extent.

In comparing the regular and micro powders of both brands, it seems that Skip regular caused more fibre fibrillation in the white and green fabrics than Skip micro. Woolworths regular also seemed to have degradaded both blue and green fabrics more than the Woolworths micro powder. It seems as if the regular washing powders of both brands caused greater damage to experimental fabrics than the micro powders.

5.2 Recommendations

The recommendations following below are based on experience obtained in conducting this research.

The *combination of measurements* used in this study proved useful in interpreting the results. Colour loss in fabrics could be explained by use of CIElab measurements, combined with examinations of SEM photos and multi-fibre fabric strips. Tensile strength measurements alone would not have been useful if information obtained from SEM photos and multi-fibre fabric strips had not been available. It is therefore recommended that in future research, a combination of assessments for degradation be used in order to explain the effect of detergents on fabrics more effectively. These could include measurements of importance to consumers, such as crease resistance, change of fabric surface appearance and fabric handle. In this study the handle of the green fabric deteriorated in the sense that it developed a harsh, unpleasant touch after 50 wash cycles

Some problems have been experienced during this research in *measuring the tensile strength* of fabrics. According to results obtained, it seemed as if some fabrics had gained strength, which indicated possible fabric shrinkage. It is believed that the use of the shrinkage ruler was not very accurate, as the holes in the ruler, which aids in measuring, were too large. It is therefore recommended that in future research, an ordinary ruler should be used and the percentage shrinkage calculated, to obtain more accurate measurements.

This study has shown that *deterioration of fabrics* due to laundering includes a *combination of factors*. It is difficult to assess chemical damage to fabrics, unless fluidity tests are performed. It is believed that much of the damage during laundering is mechanical. The consumer with a washing machine in which the wash action is less mild than that of the machines used in this study, could face problems with colourfastness and fabric strength in the long run. Also, many consumers have to rely on the so-called coin laundries, which often use the larger, commercial type of washing machine. It would therefore be of use to assess the effect of the different washing machine types on the market in terms of *mechanical damage* to fabrics. On the other hand, the fact that, almost 80% of South African consumers still do hand washing (Hill, 1997), also needs to be considered in future research.

As reported in the literature review, laundering in *hard water* will influence the effect of detergents on the colour and strength of fabrics. The water in Stellenbosch, where this study was carried out, is relatively soft. It is therefore suspected that the effect of some of the detergents used in the study, will be more severe in hard water areas.

As mentioned at the beginning of this chapter, this study was initiated by members of the clothing retail industry who suspected that *detergent type* may cause colour loss in fabrics. Many complaints, relating to colourfastness during fabric care, had been received from customers. It was thought that the newly developed micro detergents, may contribute to these problems. From the results reported in the previous chapter, it seems that this is not the case. In this study Skip regular had a more degradative effect on the colourfastness and strength of cotton fabrics than the other three detergents. This detergent is recommended by the SABS for use as standardised detergent in *wash tests*. As optimum effects are needed in testing for quality management, the results obtained in this study indicate that this recommendation is valid.

As mentioned in Chapter 3, the amounts of detergent recommended by the manufacturers were used in this consumer related study. However, for a more accurate comparison of the effect of the various detergents on fabrics, these amounts have to be standardised. Experimental fabrics of different colours also need to be of the same construction and have the same finishes applied. This will allow researchers to compare the effect of different brands of micro and/or regular detergents more accurately.

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ADDENDUM A

CIElab colour difference results

Skip regular-white (1)

Pass Fail

dataMASTER
21.07.97 14:06

Formula: **CMC 1.0, 2.0:1.0**
Batch: **ISTELL/UNIV 0071**
Standard: **ISTELL/UNIV 0121 WHITE STD**

	delE	delL	delC	delH	Decision	Batch is
msD65-10	0.223	0.118	0.025	0.188	PASS	lighter more red

Formula: **CMC 1.0, 2.0:1.0**
Batch: **ISTELL/UNIV 0072**
Standard: **ISTELL/UNIV 0121 WHITE STD**

	delE	delL	delC	delH	Decision	Batch is
msD65-10	0.281	0.083	0.217	0.158	PASS	lighter stronger more violett

Formula: **CMC 1.0, 2.0:1.0**
Batch: **ISTELL/UNIV 0073**
Standard: **ISTELL/UNIV 0121 WHITE STD**

	delE	delL	delC	delH	Decision	Batch is
msD65-10	0.427	0.138	0.396	0.081	PASS	lighter stronger

Formula: **CMC 1.0, 2.0:1.0**
Batch: **ISTELL/UNIV 0074**
Standard: **ISTELL/UNIV 0121 WHITE STD**

	delE	delL	delC	delH	Decision	Batch is
msD65-10	0.208	0.037	0.074	0.191	PASS	lighter more violett

Formula: **CMC 1.0, 2.0:1.0**
Batch: **ISTELL/UNIV 0075**
Standard: **ISTELL/UNIV 0121 WHITE STD**

	delE	delL	delC	delH	Decision	Batch is
msD65-10	0.439	0.178	0.386	0.107	PASS	lighter stronger

Formula: **CMC 1.0, 2.0:1.0**
Batch: **ISTELL/UNIV 0076**
Standard: **ISTELL/UNIV 0121 WHITE STD**

	delE	delL	delC	delH	Decision	Batch is
msD65-10	0.217	0.117	0.169	0.070	PASS	lighter stronger

Formula: **CMC 1.0, 2.0:1.0**
Batch: **ISTELL/UNIV 0077**
Standard: **ISTELL/UNIV 0121 WHITE STD**

	delE	delL	delC	delH	Decision	Batch is
msD65-10	0.217	0.153	0.153	-0.023	PASS	lighter stronger

DE VILLIERS, M.W.: The effect of regular and micro detergents on the colourfastness and strength of dyed cotton fabric
MHuish University of Stellenbosch December 1998 4/4

Skip regular-white (2)

Pass Fail

dataMASTER
21.07.97 14:06

Formula: ***CMC 1.0, 2.0:1.0***
Batch: *ISTELL/UNIV 0078* *Standard:* *ISTELL/UNIV 0121 WHITE STD*

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.481	0.229	0.420	0.052	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: *ISTELL/UNIV 0079* *Standard:* *ISTELL/UNIV 0121 WHITE STD*

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.319	0.184	0.252	0.067	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: *ISTELL/UNIV 0080* *Standard:* *ISTELL/UNIV 0121 WHITE STD*

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.317	0.208	0.239	-0.013	PASS	lighter stronger

Skip regular-blue (1)

Pass Fail

dataMASTER
21.07.97 14:13

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0091*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.388	0.325	0.197	-0.077	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0092*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.792	0.636	0.454	0.126	PASS	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0093*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.025	0.879	0.507	0.145	FAIL	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0094*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.749	0.616	0.413	0.107	PASS	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0095*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.919	0.786	0.464	0.104	PASS	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0096*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.158	1.030	0.523	0.084	FAIL	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0097*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.092	0.955	0.515	0.122	FAIL	lighter stronger more blue

Skip regular-blue (2)

```
                         Pass Fail                                    dataMASTER
                                                                  21.07.97  14:13
Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0098              Standard:  ISTELL/UNIV 0123 BLUE STD
              delE     delL     delC     delH    Decision          Batch is
msD65-10     1.281    1.097    0.616    0.241     FAIL           lighter stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0099              Standard:  ISTELL/UNIV 0123 BLUE STD
              delE     delL     delC     delH    Decision          Batch is
msD65-10     1.037    0.655    0.704    0.388     FAIL           lighter stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0100              Standard:  ISTELL/UNIV 0123 BLUE STD
              delE     delL     delC     delH    Decision          Batch is
msD65-10     1.345    1.238    0.520    0.082     FAIL           lighter stronger
```

Skip regular-green (1)

```
                           Pass Fail                              dataMASTER
                                                                21.07.97  14:10
Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0081            Standard:  ISTELL/UNIV 0122 GREEN STD
             delE    delL    delC    delH    Decision       Batch is
msD65-10     1.187   0.410   0.891   0.668   FAIL           lighter stronger more green


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0082            Standard:  ISTELL/UNIV 0122 GREEN STD
             delE    delL    delC    delH    Decision       Batch is
msD65-10     0.956   0.155   0.690   0.643   PASS           lighter stronger more green


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0083            Standard:  ISTELL/UNIV 0122 GREEN STD
             delE    delL    delC    delH    Decision       Batch is
msD65-10     2.169   1.050   1.008   1.608   FAIL           lighter stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0084            Standard:  ISTELL/UNIV 0122 GREEN STD
             delE    delL    delC    delH    Decision       Batch is
msD65-10     1.129   0.068   0.712   0.873   FAIL           stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0085            Standard:  ISTELL/UNIV 0122 GREEN STD
             delE    delL    delC    delH    Decision       Batch is
msD65-10     1.283   0.300   0.810   0.949   FAIL           lighter stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0086            Standard:  ISTELL/UNIV 0122 GREEN STD
             delE    delL    delC    delH    Decision       Batch is
msD65-10     1.724   0.995   0.818   1.146   FAIL           lighter stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0087            Standard:  ISTELL/UNIV 0122 GREEN STD
             delE    delL    delC    delH    Decision       Batch is
msD65-10     1.879   0.740   0.934   1.452   FAIL           lighter stronger more blue
```

Skip regular-green (2)

Pass Fail

dataMASTER
21.07.97 14:10

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0088*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.647	0.646	0.828	1.268	FAIL	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0089*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	3.046	1.791	0.918	2.286	FAIL	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0090*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	2.477	1.218	0.980	1.921	FAIL	lighter stronger more blue

Skip micro-white (1)

```
                         Pass Fail                                    dataMASTER
                                                                   21.07.97  14:05
Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0061                Standard:  ISTELL/UNIV 0121 WHITE STD
             delE      delL      delC      delH     Decision        Batch is
msD65-10     0.082     0.059    -0.027     0.051     PASS           lighter


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0062                Standard:  ISTELL/UNIV 0121 WHITE STD
             delE      delL      delC      delH     Decision        Batch is
msD65-10     0.400     0.068     0.384     0.089     PASS           lighter stronger


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0063                Standard:  ISTELL/UNIV 0121 WHITE STD
             delE      delL      delC      delH     Decision        Batch is
msD65-10     0.471     0.142     0.446     0.055     PASS           lighter stronger


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0064                Standard:  ISTELL/UNIV 0121 WHITE STD
             delE      delL      delC      delH     Decision        Batch is
msD65-10     0.411     0.113     0.395    -0.009     PASS           lighter stronger


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0065                Standard:  ISTELL/UNIV 0121 WHITE STD
             delE      delL      delC      delH     Decision        Batch is
msD65-10     0.884    -0.049     0.882    -0.027     PASS           darker stronger


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0066                Standard:  ISTELL/UNIV 0121 WHITE STD
             delE      delL      delC      delH     Decision        Batch is
msD65-10     0.533     0.071     0.528     0.013     PASS           lighter stronger


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0067                Standard:  ISTELL/UNIV 0121 WHITE STD
             delE      delL      delC      delH     Decision        Batch is
msD65-10     0.436     0.098     0.424    -0.025     PASS           lighter stronger
```

Skip micro-white (2)

Pass Fail

dataMASTER
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Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0068***
Standard: ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.366	0.086	0.347	-0.075	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0069***
Standard: ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.473	0.155	0.430	-0.121	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0070***
Standard: ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.566	0.060	0.351	-0.440	PASS	lighter stronger more blue

```
Skip micro-blue (1)
                              Pass Fail                                  dataMASTER
                                                                     21.07.97  14:12
Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0101                  Standard:  ISTELL/UNIV 0123 BLUE STD
            delE     delL     delC     delH     Decision        Batch is
msD65-10    0.331    0.266    0.197   -0.015    PASS            lighter stronger


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0102                  Standard:  ISTELL/UNIV 0123 BLUE STD
            delE     delL     delC     delH     Decision        Batch is
msD65-10    0.465    0.302    0.349    0.060    PASS            lighter stronger


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0103                  Standard:  ISTELL/UNIV 0123 BLUE STD
            delE     delL     delC     delH     Decision        Batch is
msD65-10    0.539    0.282    0.420    0.186    PASS            lighter stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0104                  Standard:  ISTELL/UNIV 0123 BLUE STD
            delE     delL     delC     delH     Decision        Batch is
msD65-10    0.683    0.471    0.474    0.140    PASS            lighter stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0105                  Standard:  ISTELL/UNIV 0123 BLUE STD
            delE     delL     delC     delH     Decision        Batch is
msD65-10    0.776    0.553    0.510    0.190    PASS            lighter stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0106                  Standard:  ISTELL/UNIV 0123 BLUE STD
            delE     delL     delC     delH     Decision        Batch is
msD65-10    0.790    0.521    0.553    0.217    PASS            lighter stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0107                  Standard:  ISTELL/UNIV 0123 BLUE STD
            delE     delL     delC     delH     Decision        Batch is
msD65-10    0.880    0.611    0.578    0.260    PASS            lighter stronger more blue
```

Woolworths micro-green (1)

```
                          Pass Fail                                   dataMASTER
                                                                  21.07.97  13:44
Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0001              Standard:  ISTELL/UNIV 0122 GREEN STD
            delE     delL     delC     delH    Decision          Batch is
msD65-10    0.771   -0.425    0.327    0.554    PASS          darker stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0002              Standard:  ISTELL/UNIV 0122 GREEN STD
            delE     delL     delC     delH    Decision          Batch is
msD65-10    0.793   -0.073    0.556    0.560    PASS          darker stronger more green


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0003              Standard:  ISTELL/UNIV 0122 GREEN STD
            delE     delL     delC     delH    Decision          Batch is
msD65-10    0.915   -0.105    0.530    0.739    PASS          darker stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0004              Standard:  ISTELL/UNIV 0122 GREEN STD
            delE     delL     delC     delH    Decision          Batch is
msD65-10    1.216    0.479    0.730    0.846    FAIL          lighter stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0005              Standard:  ISTELL/UNIV 0122 GREEN STD
            delE     delL     delC     delH    Decision          Batch is
msD65-10    1.153   -0.722    0.437    0.786    FAIL          darker stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0006              Standard:  ISTELL/UNIV 0122 GREEN STD
            delE     delL     delC     delH    Decision          Batch is
msD65-10    1.167   -0.152    0.719    0.906    FAIL          darker stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0007              Standard:  ISTELL/UNIV 0122 GREEN STD
            delE     delL     delC     delH    Decision          Batch is
msD65-10    1.261    0.006    0.800    0.974    FAIL          stronger more blue
```

Woolworths micro-green (2)

Pass Fail

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Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0008*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.175	0.268	0.474	1.041	FAIL	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0009*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.357	0.220	0.561	1.216	FAIL	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0030*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.739	0.727	0.924	1.281	FAIL	lighter stronger more blue

Skip micro-blue (2)

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Pass Fail

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0108***
Standard: ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.893	0.478	0.663	0.361	PASS	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0109***
Standard: ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.130	0.933	0.614	0.173	FAIL	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0110***
Standard: ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.927	0.552	0.666	0.335	PASS	lighter stronger more blue

Skip micro-green (1)

Pass Fail

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Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0111*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.673	0.002	0.521	0.426	PASS	stronger more green

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0112*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.868	-0.328	0.500	0.630	PASS	darker stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0113*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.155	0.089	0.867	0.758	FAIL	lighter stronger more green

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0114*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.404	0.447	0.950	0.931	FAIL	lighter stronger more green

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0115*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.470	0.405	0.739	1.205	FAIL	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0116*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.615	0.552	0.976	1.162	FAIL	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0117*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.493	0.757	0.848	0.968	FAIL	lighter stronger more blue

Skip micro-green (2)

Pass Fail

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Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0118*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.511	0.348	0.903	1.160	FAIL	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0119*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.911	0.858	0.855	1.478	FAIL	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0120*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.663	0.693	0.939	1.185	FAIL	lighter stronger more blue

Woolworths regular-white (1)

Pass Fail

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Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0031*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.329	0.040	0.304	0.121	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0032*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.452	0.179	0.391	0.139	PASS	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0033*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.451	0.183	0.390	0.133	PASS	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0034*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.349	0.171	0.291	0.090	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0035*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.379	0.192	0.313	0.094	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0036*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.384	0.157	0.340	0.085	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0037*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.414	0.190	0.367	0.015	PASS	lighter stronger

Woolworths regular-white (2)

Pass Fail

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Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0038*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.351	0.194	0.287	0.053	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0039*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.498	-0.060	0.151	-0.471	PASS	darker stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0040*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.618	-0.045	0.097	-0.608	PASS	darker stronger more green

Woolworths regular-blue (1)

Pass Fail

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Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0041*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.225	0.165	0.150	0.032	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0042*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.586	0.457	0.364	0.039	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0043*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.458	0.307	0.324	0.104	PASS	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0044*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.899	0.799	0.410	0.022	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0045*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.754	0.680	0.328	0.005	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0046*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.030	0.956	0.378	-0.058	FAIL	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0047*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.966	0.919	0.291	-0.073	PASS	lighter stronger

Woolworths regular-blue (2)

Pass Fail

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Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0048*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.804	0.760	0.241	-0.102	PASS	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0049*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.208	1.185	0.127	-0.193	FAIL	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0050*** *Standard:* ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.074	1.008	0.009	-0.371	FAIL	lighter more green

Woolworths regular-green (1)

```
                              Pass Fail                              dataMASTER
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Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0051               Standard:   ISTELL/UNIV 0122 GREEN STD
             delE      delL     delC     delH    Decision        Batch is
msD65-10     0.595   -0.140    0.361    0.452    PASS          darker stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0052               Standard:   ISTELL/UNIV 0122 GREEN STD
             delE      delL     delC     delH    Decision        Batch is
msD65-10     0.880   -0.074    0.612    0.628    PASS          darker stronger more green


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0053               Standard:   ISTELL/UNIV 0122 GREEN STD
             delE      delL     delC     delH    Decision        Batch is
msD65-10     0.894   -0.285    0.497    0.687    PASS          darker stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0054               Standard:   ISTELL/UNIV 0122 GREEN STD
             delE      delL     delC     delH    Decision        Batch is
msD65-10     0.916    0.046    0.624    0.668    PASS          stronger more green


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0055               Standard:   ISTELL/UNIV 0122 GREEN STD
             delE      delL     delC     delH    Decision        Batch is
msD65-10     1.467    0.811    0.806    0.919    FAIL          lighter stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0056               Standard:   ISTELL/UNIV 0122 GREEN STD
             delE      delL     delC     delH    Decision        Batch is
msD65-10     1.734    0.946    0.888    1.151    FAIL          lighter stronger more blue


Formula:  CMC 1.0, 2.0:1.0
Batch:    ISTELL/UNIV 0057               Standard:   ISTELL/UNIV 0122 GREEN STD
             delE      delL     delC     delH    Decision        Batch is
msD65-10     1.290    0.546    0.519    1.047    FAIL          lighter stronger more blue
```

Woolworths regular-green (2)

Pass Fail

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Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0058*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.650	0.792	0.918	1.120	FAIL	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0059*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.194	0.093	0.851	0.832	FAIL	lighter stronger more green

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0060*** *Standard:* ***ISTELL/UNIV 0122 GREEN STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	1.262	0.515	0.871	0.753	FAIL	lighter stronger more green

Woolworths micro-white (1)

Pass Fail

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Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0011*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.131	0.045	0.078	0.095	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0012*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.334	0.148	0.273	0.123	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0013*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.365	0.080	0.280	0.220	PASS	lighter stronger more violett

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0014*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.133	0.121	-0.034	0.044	PASS	lighter

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0015*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.272	0.066	-0.162	0.209	PASS	lighter weaker more orange

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0016*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.286	0.117	0.249	0.078	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0017*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.276	0.137	0.210	0.116	PASS	lighter stronger

Woolworths micro-white (2)

Pass Fail

dataMASTER
21.07.97 13:59

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0018*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.161	0.116	0.015	-0.110	PASS	lighter

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0019*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.176	0.077	0.115	-0.108	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0020*** *Standard:* ***ISTELL/UNIV 0121 WHITE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.258	0.165	-0.081	-0.181	PASS	lighter weaker more green

Woolworths micro-blue (1)

Pass Fail

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Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0021***
Standard: ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.282	0.211	0.186	0.022	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0022***
Standard: ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.318	0.171	0.262	0.053	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0023***
Standard: ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.316	0.212	0.233	0.024	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0024***
Standard: ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.392	0.235	0.292	0.115	PASS	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0025***
Standard: ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.455	0.336	0.300	0.065	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0026***
Standard: ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.478	0.262	0.368	0.158	PASS	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0027***
Standard: ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.638	0.514	0.365	0.100	PASS	lighter stronger more blue

Woolworths micro-blue (2)

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Pass Fail

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0028***
Standard: ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.731	0.610	0.396	0.079	PASS	lighter stronger

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0029***
Standard: ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.508	0.364	0.323	0.146	PASS	lighter stronger more blue

Formula: ***CMC 1.0, 2.0:1.0***
Batch: ***ISTELL/UNIV 0010***
Standard: ***ISTELL/UNIV 0123 BLUE STD***

	delE	*delL*	*delC*	*delH*	*Decision*	*Batch is*
msD65-10	0.585	0.417	0.387	0.133	PASS	lighter stronger more blue

ADDENDUM A

CIElab colour difference results

The effect of Skip micro on the colour of dyed cotton fabrics over 50 wash cycles

Fabric colour	**Number of Wash cycles**	**Colour loss**
White	1	0.082
	5	0.4
	10	0.471
	15	0.411
	20	0.884
	25	0.533
	30	0.436
	35	0.366
	40	0.473
	50	0.566
Blue	1	0.331
	5	0.465
	10	0.539
	15	0.683
	20	0.776
	25	0.790
	30	0.880
	35	0.893
	40	1.130
	50	0.927
Green	1	0.673
	5	0.868
	10	1.155
	15	1.404
	20	1.470
	25	1.615
	30	1.493
	35	1.511
	40	1.911
	50	1.663

The effect of Skip regular on the colour of dyed cotton fabrics over 50 wash cycles

Fabric colour	Number of Wash cycles	Colour loss
White	1 5 10 15 20 25 30 35 40 50	0.223 0.281 0.427 0.208 0.439 0.217 0.217 0.481 0.319 0.316
Blue	1 5 10 15 20 25 30 35 40 50	0.388 0.792 1.025 0.746 0.919 1.158 1.092 1.281 1.037 1.345
Green	1 5 10 15 20 25 30 35 40 50	1.187 0.956 2.169 1.129 1.283 1.724 1.879 1.647 3.046 2.477

The effect of Woolworths micro on the colour of dyed cotton fabrics over 50 wash cycles

Fabric colour	Number of Wash cycles	Colour loss
White	1	0.131
	5	0.334
	10	0.365
	15	0.133
	20	0.272
	25	0.286
	30	0.276
	35	0.161
	40	0.176
	50	0.258
Blue	1	0.282
	5	0.318
	10	0.316
	15	0.392
	20	0.455
	25	0.478
	30	0.638
	35	0.731
	40	0.508
	50	0.585
Green	1	0.771
	5	0.793
	10	0.915
	15	1.216
	20	1.153
	25	1.167
	30	1.261
	35	1.175
	40	1.357
	50	1.739

The effect of Woolworths regular on the colour of dyed cotton fabrics over 50 wash cycles

Fabric colour	Number of Wash cycles	Colour loss
White	1	0.329
	5	0.452
	10	0.451
	15	0.349
	20	0.379
	25	0.384
	30	0.414
	35	0.351
	40	0.498
	50	0.618
Blue	1	0.225
	5	0.586
	10	0.458
	15	0.899
	20	0.754
	25	1.030
	30	0.966
	35	0.804
	40	1.208
	50	1.074
Green	1	0.595
	5	0.880
	10	0.894
	15	0.916
	20	1.467
	25	1.734
	30	1.290
	35	1.650
	40	1.194
	50	1.262

ADDENDUM B

Results for tensile strength

The effect of Skip micro on the tensile strength of dyed cotton fabrics over 50 wash cycles

Fabric colour	Number of Wash cycles	Tensile strength (kg load)
White	0	45.38
	1	46.25
	5	47.10
	10	48.51
	15	48.27
	20	49.06
	25	50.04
	30	50.60
	35	48.72
	40	49.70
	50	50.26
Blue	0	64.76
	1	42.93
	5	63.07
	10	61.54
	15	46.09
	20	49.43
	25	50.28
	30	50.09
	35	50.32
	40	52.91
	50	63.73
Green	0	46.44
	1	47.44
	5	49.26
	10	53.53
	15	48.37
	20	46.48
	25	57.62
	30	52.14
	35	54.04
	40	42.52
	50	52.86

The effect of Skip regular on the tensile strength of dyed cotton fabrics over 50 wash cycles

Fabric colour	Number of Wash cycles	Tensile strength (kg load)
White	0	45.38
	1	49.72
	5	39.28
	10	46.05
	15	46.18
	20	44.20
	25	44.38
	30	47.15
	35	53.63
	40	55.09
	50	46.24
Blue	0	64.76
	1	42.66
	5	47.94
	10	47.87
	15	49.09
	20	47.61
	25	48.47
	30	46.86
	35	47.86
	40	44.37
	50	44.46
Green	0	46.47
	1	49.48
	5	45.87
	10	46.85
	15	47.95
	20	48.86
	25	45.89
	30	46.71
	35	48.66
	40	53.57
	50	50.88

The effect of Woolworths micro on fabrics over 50 wash cycles the tensile strength of dyed cotton

Fabric colour	Number of Wash cycles	Tensile strength (kg load)
White	0	45.38
	1	41.71
	5	44.13
	10	44.97
	15	43.04
	20	46.94
	25	46.11
	30	49.79
	35	45.53
	40	40.60
	50	39.30
Blue	0	64.76
	1	45.03
	5	47.00
	10	47.33
	15	45.28
	20	43.37
	25	44.43
	30	51.97
	35	56.03
	40	46.11
	50	36.85
Green	0	46.44
	1	46.03
	5	49.39
	10	50.24
	15	44.86
	20	42.29
	25	57.8
	30	52.3
	35	46.43
	40	38.96
	50	50.12

The effect of Woolworths regular on the tensile strength of dyed cotton fabrics over 50 wash cycles

Fabric colour	Number of Wash cycles	Tensile strength (kg load)
White	0 1 5 10 15 20 25 30 35 40 50	45.38 48.6 44.45 44.17 45.69 46.43 45.4 44.03 42.63 44.67 43.95
Blue	0 1 5 10 15 20 25 30 35 40 50	64.76 44.31 45.13 48.75 56.18 49.76 44.75 48.12 45.13 51.59 51.56
Green	0 1 5 10 15 20 25 30 35 40 50	46.44 37.51 52.06 47.5 51.2 44.08 50.48 46.71 45.09 47.29 48.48

The effect of Woolworths regular on the tensile strength of dyed cotton fabrics over 50 wash cycles

Fabric colour	Number of Wash cycles	Tensile strength (kg load)
White	0	45.38
	1	48.6
	5	44.45
	10	44.17
	15	45.69
	20	46.43
	25	45.4
	30	44.03
	35	42.63
	40	44.67
	50	43.95
Blue	0	64.76
	1	44.31
	5	45.13
	10	48.75
	15	56.18
	20	49.76
	25	44.75
	30	48.12
	35	45.13
	40	51.59
	50	51.56
Green	0	46.44
	1	37.51
	5	52.06
	10	47.5
	15	51.2
	20	44.08
	25	50.48
	30	46.71
	35	45.09
	40	47.29
	50	48.48