STUDIES IN WEAR LIFE OF NORMAL AND SPECIALLY FINISHED WOVEN COTTON APPAREL FABRICS

VOLUME - I

BY

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CERTIFICATE

This is to certify that the work reported in this Ph.D. Dissertation has been done by G.V. Sarma under our guidance and supervision. To the best of our knowledge, the work is original and has not been submitted to any other University, Educational Institution or any other body for awarding the Degree of Doctor of Philosophy.

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ABSTRACT OF THE THESIS

Cotton fabrics crosslinked to impart Wrinkle Recovery, Durable Press, Smooth-drying etc. properties or those specially finished to impart functional features, like Soil Resistance or Release, improved lubricity or Flex Abrasion resistance etc. show moderate to substantial losses or gains in mechanical properties related to Wear Life. The direction as well as the extent of such changes are sometimes restricted only to some mechanical properties, depending on the nature of chemical modification or surface finish and the processing conditions etc. and these changes may also be reversed in actual service use of such apparel fabrics, due to many factors, for example, the breakage of crosslinks or lack of wash-fastness of the special finishes and so on. This situation presents complex problems in identifying the dominant physical or mechanical properties and the corresponding laboratory tests actually involved in explaining the wear and tear damage of such apparel fabrics in service use and on the basis of which their Wear Life can be predicted. Volume I of the thesis is chiefly concerned with this problem (Chapters 3 to 7).

The principal approach made to resolve this problem consisted of carrying out controlled service wear trials involving such specially finished cotton apparel fabrics along with their untreated controls and correlating their initial as well as progressively retained mechanical properties with observed

wear and tear damage in service use. A total number of eight such service wear trials were carried out involving about 31 normal and specially finished apparel fabrics in end-uses involving civilian or office-going personnel as well as industrial labour.

Several new approaches were made and refinements introduced in the methods and analysis, such as, separation of tear and abrasion failures, the latter as plane and edge abrasion as well as separate classification by the extent of damage, such as, mild, medium and severe. Edge wear was further followed up zone-wise, such as at the collar folds, collar tips and edges, and cuffs of shirts and bottomfolds of trousers, etc. Several laboratory tests for strength, elongation, toughness and abrasion resistance were performed and many criteria for evaluating the abrasion resistance were adopted and many refinements introduced in characterizing the abrasion cycles, such as, the Weibull's Distribution and the minimum life. A new concept of 'consistency in significance' of the correlations was introduced to identify the dominant mechanical property or the functional laboratory tests in explaining not only the observed differences in wear damage (particularly the edge wear) of different fabrics in service, but also the differences at selected zones within an apparel and at different stages of progression of edge wear damage, i.e., mild, medium and severe and also which yarns systems (warp or weft) were involved at each such stage and zone.

Correlation analysis was also employed to assess the relative contribution of mechanical damage in service in the relatively dry state, i.e. when the apparels were worn or ironed as well as in the wet state, i.e. when they were washed, hydro-extracted (and tumble-dried) and the zone-wise variations or predominance of such damage, i.e. in the dry or wet states in causing the observed differences in edge wear damage of the differently finished fabrics.

Inter-correlations among the physical or mechanical properties computed similarly with progressive use of apparels in service provided useful insight into the changes obtained by the special chemical finishes on the surface properties of yarns and fabrics as well as in the more elementary micro-structure of the fibres and the effect of such changes while the fabrics were used progressively in service in explaining the observed differences in edge wear and tear damage in service use. Similarly the effects of processing conditions, such as, tensions applied to stretch back the fabrics to their normal dimensions when the fabrics were finished under alkali-swollen conditions, on the micro-structure of fibres in the warp and the weft yarn systems and the consequential differences in the mechanical properties as well as in service wear performance could be inferred.

Apart from the effect of several finishing treatments,

the effect of fabric structure has also been examined in Chapter 3 by imparting the same resin formulations to three different varieties of fabrics , i.e. a lawn and a sheeting fabric for shirts and a twill fabric for trousers.

Besides the identification of the dominant physical property and the corresponding laboratory test best correlated with actual in-service wear and tear damage, the physical circumstances and the complex mechanisms governing each major class of failure were identified by a variety of novel approaches. Thus, for example, the mechanisms of edge wear at the collar folds and the collar tips and edges of shirts were found to be different and hence the functional laboratory tests which could predict the failure in service. In most cases, the nature and the predominance of one or more of abrasion actions such as flexing, folding,bending surface rubbing etc., as well as the directions of surface rubbing and abrasive pressures involved, the directions of predominant tensions etc. could be inferred. For this purpose, special weaves, such as cellular weaves and twills were also employed in some end-uses (See Chapters 7 and 11) in which the conventional manner of placing the warp direction of the fabric longitudinally to the wearer while making the garment was altered so that this direction appears crosswise and in the case of twills the side 'exposed out' was also changed from the conventional 'Face' to 'Back'.

Volume II presents work on a number of theoretical aspects relating to some general problems in wear life studies. With a view to understand the physical circumstances and the mechanisms under which some most frequent and representative types of failures occur in Service and get dimensionally extended, 'PROBABILISTIC MODELS' were developed to describe their dimensional parameters such as the tear lengths in woven apparel fabrics (Chapter 8) and the frayed lengths at the folds of collars of shirts (Chapter 9). In particular, a 'GENERALISED WEIBULL'S MODEL' was derived in Section I of Chapter 8 to describe the tear length distributions of apparel fabrics in service by considering the number of sequentially ruptured yarns in a tear as a 'WAITING-TIME' distribution of a Discrete Random Variable and passing on to its continuous form. As a particular case of this generalised model, the 'EXPONENTIAL DISTRIBUTION' was derived when the fabric is subjected to a uniform tearing force around the tearing strength of the fabric, while the Weibull's Distribution with a shape parameter greater than unity was shown to arise when the fabric is subjected instantaneously to a given amount of energy or tearing force. The Weibull's model with a shape parameter less than unity would arise when the tear is a special type of tensile rupture. Extensive data is presented in Section II of Chapter 8 to demonstrate that observed tear lengths in Service conform to

one or other of the Theoretical models developed, of which the 'Exponential Distribution' was the most frequently confronted and it was shown that the parameter μ of this distribution is a fairly good index of the tearing strength of the fabric. An examination of the magnitudes of this parameter of fabrics with nearly the same tear strength in different end-uses is helpful to assess the intensities of stresses or the magnitudes of tearing loads characteristic of such end-uses.

Similarly, the 'GAUSSIAN' or the Normal Distribution, has been proposed in Chapter 9 as a model to describe the frayed lengths at the collar folds of shirts and data was presented to demonstrate the applicability of this model from which it could be inferred that edge wear at the folds of the collars occurred predominantly by the rubbing action of the neck of the wearer when the shirts were worn. Departures from this model indicated that some damage had also occurred in washing.

In order to enable scientifically valid tests of hypotheses on failure parameters, taking into account the 'Rate' of failures, representative parameters of failures, such as the progressive number of shirts torn or frayed and the number of tears and frays etc., were analysed in Chapter 10 by employing 'STOCHASTIC PROCESSES', of which, the STATIONARY

POISSON PROCESS was found to be the usually applicable model.

By combining the counting Stochastic process of cumulative failures over progressive service use of apparels with static probabilistic models developed for their dimensions, it was demonstrated that progressive lengths torn or frayed can be expressed as 'COMPOUND POISSON PROCESS and that 'Wear Life' can be deduced in time durations in terms of Wearing and Laundering Cycles under given conditions with a pre-assigned end-point on the extent of damage. It was also shown that the rates of progression to damage or destruction of apparels can be scientifically compared for differently treated or different fabrics and that their Wear Life can be similarly deduced in time durations and compared employing such rates.

In Chapter 11 is examined the important and interesting problem of variations in the wear resistance of apparel fabrics in service use as measured by the retained levels of selected mechanical properties. Similarly, the variations in visible tear and abrasion damage were examined. Many factors contributed to these variations which include occupations of the wearers, individuals within the same occupation (due possibly to fit and specific bodily motions), zones within the same apparel, and the special Chemical treatments imparted. Apart from main effects, two-factor interactions were found to be

significant suggesting that the said factors did not operate independently but the effect of any one factor depended on the nature or the particular levels of the other factors. It was also observed that the lower portions of shirts were stronger than upper portions and the back portion was stronger than the front and that the sleeves and the collar portions were the weakest zones in a shirt. These observations lent further evidence that a major portion of mechanical damage on shirts occurs when they are worn.

In order to estimate the minimum strength a fabric should possess to prevent sufficient guarantee against premature failure due to tearing and thus ensure satisfactory service life, the concepts of 'Critical Strength' and 'Critical Stress' were introduced in Chapter 11 and the same, as measured by the tensile strength of a 2 cms. wide fabric strip were found to be in the range 15 to 19 lbs. or 19 to 24 lbs. approximately of a one inch strip.

In Chapter 12, a theoretical model was proposed to describe the flex abrasion cycles obtained on the BFT or Stoll testing instruments. By considering the distribution of the flex abrasion cycles required for the rupture of yarns in this test the distribution of flex abrasion cycles is shown to belong to the Weibull's family with a shape parameter greater than unity. Extensive data is presented not only to demonstrate the

validity of the model but also to examine the most frequently confronted bi-modality in flex and flat abrasion test results. Various factors that give rise to bi-modality in flex and flat abrasion cycles to end-point were discussed with illustrative data and the hypotheses of Sippel and Morice in interpreting bi-modality have been critically examined. It was indicated that the data did not consistently manifest either the Sippel effect or the three stages as depicted by Morice. It was further suggested that bi-modality is inherent in the flex abrasion test results as described by the theoretical model when, for example, the minimum stress changes from positive (tension) to negative (compression) and that when surface rubbing involving moderate to high compressive pressures predominates in the fatiguing conditions there will be a sudden increase in the probability of rupture of the yarns which will introduce bi-modality. This tendency is inherent in a sequential yarn rupture model for flex abrasion cycles and arises due to the interactive effects of weave and tensions applied in the test. It is also influenced by the cohesion and compactness of fibres within the yarn structure depending on the extent of swelling and loosening of the fibrillar structure as influenced by moisture content and/or swelling treatments.

Finally in Chapter 13, the total work is integrally reviewed and summarised to arrive at some general conclusions

and make some specific recommendations to predict wear life as well as to improve it.

In Chapter 14 some areas of further research are indicated after critically examining the work done and pointing out the many missing links or the loose ends.

PREFACE TO VOLUME - I

Due to the somewhat huge size of the thesis, it is divided into two volumes, i.e. Volume I and Volume II to facilitate handling.

Volume I covers Chapters 1 to 7 dealing with the Service wear trials of normal and specially finished apparel fabrics (Chapters 3 to 7), besides the Literature Survey (Chapter 1) and outline of specific problems tackled in this work and general methods adopted (Chapter 2).

Chapters 3 to 6 present the laboratory test results and those of actual in-Service wear performance of a number of normal and specially finished apparel fabrics as well as the correlations between the two sets of results with a view to identify those laboratory tests which most nearly predict the observed service wear performance.

Chapter 7 presents the results of some modifications carried out in the manner of placing the fabric in apparels with a view to identify the nature and directions of predominant tensions and abrasion actions in service as well as to examine the effect on wear life consequent on the modifications introduced.

Volume II presents the results of some general theoretical problems relating to wear life details of which are given in the preface to Volume II.

A summary of the total work looked integrally is given in Chapter 13 of Volume II along with general recommendations to predict wear life as well as to improve it.

The last Chapter 14 spells out specific areas for further Research.

References are given after Chapter 14 in Volume II.

A List of papers published (or presented in Conferences) from the work included in the thesis is given in Volume II along with reprints.

List of papers for which manuscripts are nearly ready and arising directly from the work presented in the thesis is also given in Volume II.

Finally, a list of papers published by the candidate from work not included in the thesis but which are frequently referred to or reviewed in the text is presented at the end along with reprints of such papers to facilitate ready reference.

CONTENTS OF VOLUME - I

CHAPTER NO.1 : A CRITICAL REVIEW OF LITERATURE ON WEAR LIFE

CHAPTER NO.2 : OBJECTIVES OF THE PRESENT WORK-OUTLINE OF CONTENTS AND GENERAL METHODS EMPLOYED AND ORGANIZATION OF THE THESIS.

CHAPTER NO.3 : SECTION - III

SERVICE WEAR TRIAL OF SHIRTS MADE FROM U.S. SHEETING FABRIC.

FIGURES (Chapter 3; Section III)

CHAPTER NO.3 : SECTION - IV

SERVICE WEAR TRIAL OF TROUSERS MADE FROM 3/1 KHAKI TWILL FABRIC RECEIVED FROM U.S.A.

CHAPTER NO.4:

CHAPTER NO.5

SERVICE WEAR TRIAL OF PANTS (TROUSERS) MADE FROM PLAIN WEAVE FABRIC SPECIALLY FINISHED FOR WRINKLE RECOVERY AND IMPROVED FLEX LIFE.

CHAPTER NO.6

SERVICE WEAR TRIAL OF SHIRTS SPECIALLY FINISHED FOR WRINKLE RECOVERY, SOIL RESISTANCE, IMPROVED FLEX LIFE IN A CIVILIAN END-USE.

CHAPTER NO.7

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