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ENGINEERING OF WEAR RESISTANT FABRICS

by

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The improvement of the wear resistance of civilian, industrial and military fabrics is one of the most economical ways of conserving raw materials, production, capacity, and manpower, all of which are critical in times of national emergency.

Illustrative of the savings to be realized are Quartermaster items for which definite data have already been established on the basis of comprehensive field, combat course, and laboratory evaluations. For example, combat course evaluations of fatigue uniforms have shown that a warp sateen of a certain balance in yarn count and texture, worn with the filling side out, may be constructed to have up to 100 per cent more wear resistance than Army herringbone twill. Almost a threefold increase in wear resistance over the herringbone twill can be expected by the admixture of 25 to 50 per cent nylon staple in the filling yarns, which in this wear resistant sateen construction protects the stress-bearing warp yarns.

Data which have been secured in our studies indicate that, conservatively estimated, a 20 per cent increase in wear life may be effected in many commercial cotton fabrics similar to that accomplished in the fatigue uniform fabric without using better raw materials, or special finishes, or requiring additional production capacity. Per billion yards annual consumption of cotton apparel fabrics, in which wear resistance is a definite requirement, a 20 per cent increase of wear resistance is equivalent to a saving in replacement requirements of one hundred and sixty million pounds of cotton, 8 billion spinning spindle hours, and 5 million loom hours.

In the field of wool fabrics, similar improvements in wear resistance should be feasible through modification of constructions and limited utilization of high strength fibers. Major consideration is being given to this phase of our wear resistance program, although actual data are not presently available.

Our studies on wear resistance have now reached a point where it is possible to gain basic information on the service actions and fabric reactions which produce wear, and furthermore to uncover principles which must be observed in developing and manufacturing more durable fabrics. We are presenting data here today on the mechanism of wear and on the effect of yarn and fabric construction characteristics, in terms of parameters which are readily applicable for the engineering of fabrics with improved wear resistance.

What causes wear in textile fabrics?

Much has been said on the complexity of wear and the multitude of obscure factors contributing to the mechanical failure of fabrics. Therefore, it may sound rather paradoxical to state that the mechanism of breakdown in fabrics is substantially the same regardless of fiber type, yarn and fabric construction, finish, and end use. This, however, has been indicated by exhaustive microscopical examination by CLEGG in England of hundreds of worn textile items and also by our own comprehensive correlation studies of a large number of fabrics subjected to normal service wear, accelerated Combat Course wear, and laboratory wear. These investigations showed that primarily bending and flexing stresses cause a transverse cracking of individual fibers which gradually leads to the formation of holes at places of concentrated wear, or to the production of tears and splits in places where partial fiber breakdown has weakened the yarns, making them susceptible to tearing and snagging forces. Chemical and photochemical degradation reduce the resistance of the individual fibers to these bending and flexing forces, thus accelerating the breakdown of the fabrics. Tensile stresses or surface attrition on fabrics do not appear to be major wear factors. Consequently breaking strength and elongation as well as resistance to surface abrasion have been found to be unreliable parameters for the characterization of the wear resistance of fabrics varying in fiber quality, yarn construction, texture or weave.

Are reliable methods available for evaluating wear resistance?

Since 1942 the Quartermaster Corps has conducted field and accelerated field tests for determining the wear life of uniforms. A special proving ground, the "Combat Course" at Fort Lee, Va., was established by the Quartermaster Board, for the evaluation of military textiles. Later it was adapted to provide a basis for the development of adequate laboratory techniques for wear testing (See Figure 1). Experience gained in these tests have indicated that many chances of error are possible in the execution and evaluation of service wear tests. Only if properly designed will service tests supply data which are accurate and representative. For this reason, standard procedures have had to be developed by the Quartermaster Board on a statistical basis for representative selection of test subjects and test conditions, for sampling, and for the recording, scoring, and evaluation of observations.

With the adoption of statistically designed tests it has been possible to obtain reliable service test results. The next step has been to determine the relationship between normal service wear and accelerated combat course wear. Figure 2 shows that the slope characterizing the progress of wear under conditions of actual use is not significantly changed by the acceleration of wear produced by the more severe conditions of the combat course. One cycle on the combat course consisting of two traversals and one laundering produces a wearing effect equal to 1-1/2 times of that obtained in one week wearing under recruit training conditions plus one laundering. Thus, the combat course evaluation not only produces comparative data on the resistance of a fabric or garment to accelerated wear, but makes it also possible to predict wear resistance in terms of duration of useful life under regular service conditions.

After numerous attempts, mostly unsuccessful, an adequate method was found for the laboratory evaluation of the resistance of yarns and fabrics to complex mechanical wear. This method essentially consists of a flex abrasion test in which yarn or fabric specimens are gradually disintegrated by bending and abrading around a thin bar under precisely controlled conditions. Based on the number of cycles required to rupture the specimen and the unit weight of the sample, a flex abrasion index is calculated by the following formula:

$$\text{Flex Abrasion Index} = \frac{\text{Cycles to Rupture X}}{\text{Cycles to Rupture Control}} \times \left[\frac{\text{Weight of X}}{\text{Weight of Control}}\right].$$

Figure 3 illustrates the correlation which has been found to exist between this Flex Abrasion Index and the Combat Course wear score. The test material in this series were fabrics differing in yarn quality, texture, weave, and direction of exposure to wear. No other single fabric characteristic or combination of several physical characteristics determined in the course of this study approached the flex abrasion index in this respect. In other tests carried out under wet conditions, the flex abrasion data proved to be significantly associated with the behavior of fabrics under actual laundering conditions.

As has already been indicated, resistance to surface attrition and tear strength appear to be wear factors of secondary importance. Accordingly, they should also be considered in predicting wear resistance, but with a lower relative importance than the flex abrasion results.

To carry out these laboratory wear tests under precisely controlled conditions, an instrument has been developed which is capable of measuring quantitatively resistance to flex abrasion, surface attrition, and edge abrasion, each under dry and wet conditions.

<u>What contribution does fabric construction make to wear resistance?</u>

The effect on wear resistance of such fabric characteristics as fiber material, fineness, staple length, yarn count, twist, texture, and weave have been most frequently discussed in the past, in qualitative and rather speculative terms. In some studies these factors have been related to such fabric properties as strength or resistance to surface abrasion which, on the basis of our latest knowledge on the mechanism of wear in textiles, cannot be identified with resistance to actual wear.

It has also been found in our studies that such fabric characteristics as texture, yarn count, weight, and weave cannot be correlated as independent variables to wear data. Instead, fabric structure has to be considered in terms of geometric parameters and their basic interrelationship. Those proposed by PIERCE have been found most helpful in our attempt to analyze the effect of fabric construction on wear resistance.

The data which are presented in the following three tables are based on combat course and laboratory data of different experimental series together with consideration of fabric geometry. These results are preliminary in nature and the relations may appear to be somewhat oversimplified. However, these findings have already proved very useful in blueprinting of experimental constructions. Although they may be subject to elaboration and modification, they are presented here as a working basis for the engineering of fabrics with improved wear resistance.

In addition to evaluating the effect of fabric construction, progress is being made in analyzing the contribution to wear resistance of inherent properties of various natural and synthetic fibers, and also of fiber fineness, staple length, and various chemical treatments.

The scope of this report has not permitted the presentation of detailed information and data on the experiments performed and theories and statistics applied. Therefore some of the statements made may appear somewhat provocative. They deserve a wider discussion which, it is planned, will be presented in a subsequent paper. However, it is hoped that this brief summary of some of our work will be helpful in focusing the interest of textile technologists on the wear resistance problem and on the possibilities which exist for the systematic development of fabrics of improved wear resistance.

FIGURE I
QUARTERMASTER BOARD COMBAT COURSE

LENGTH OF COURSE 1700 FEET

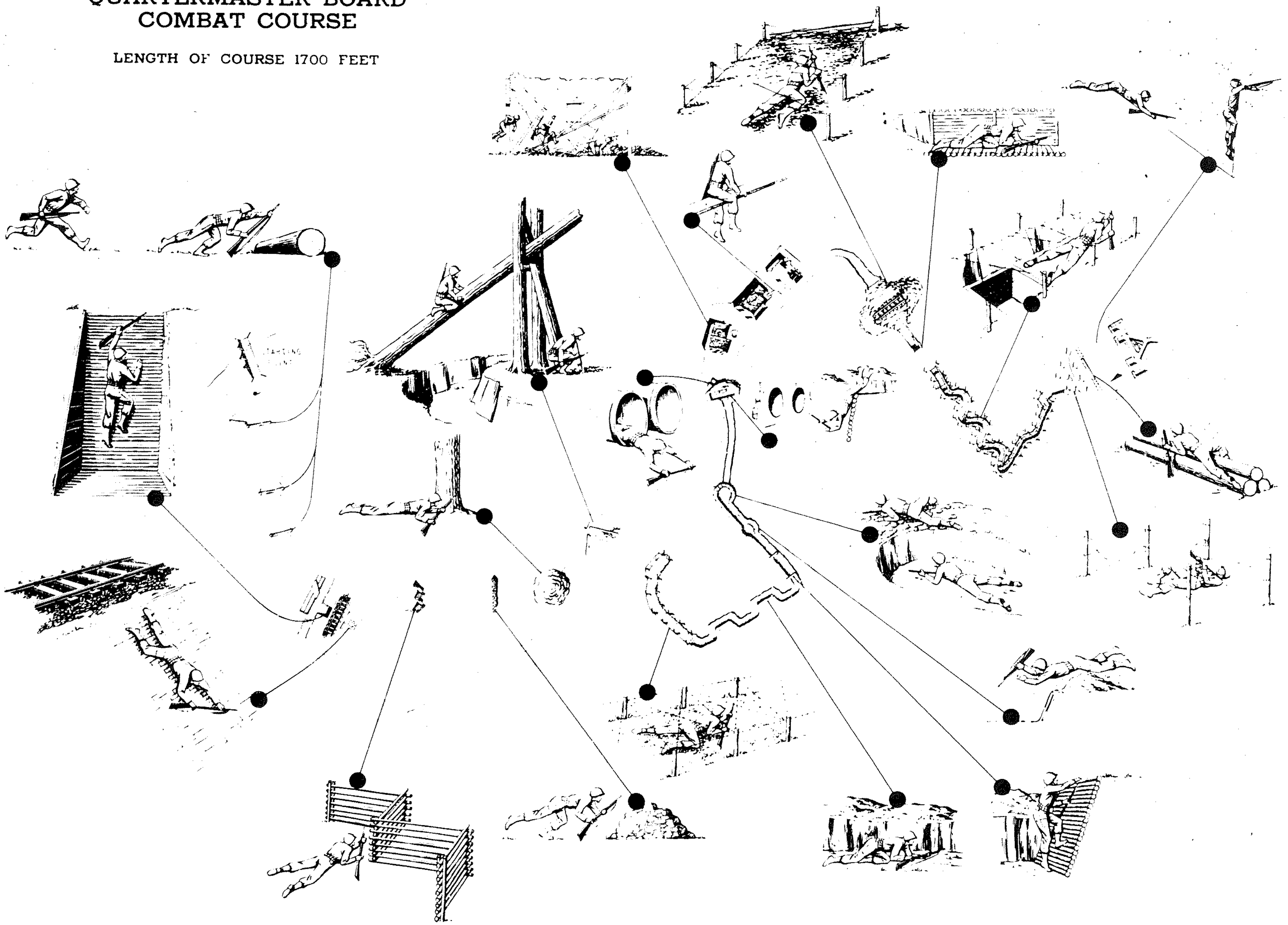

Fig. 2

RELATIONSHIP BETWEEN COMBAT COURSE AND FORT JACKSON WEAR OF HERRINGBONE TWILL TROUSERS

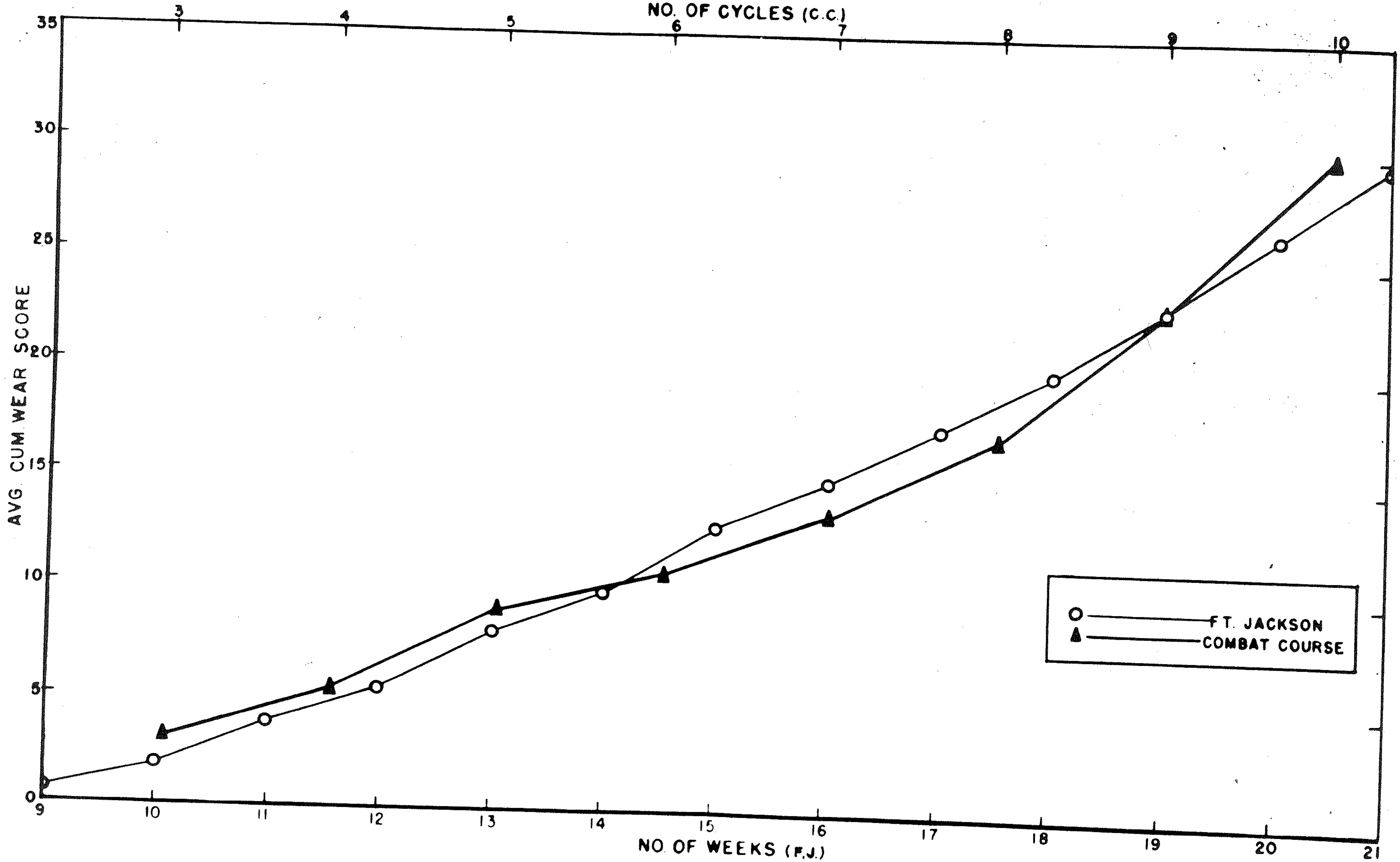

Fig. 2

RELATIONSHIP BETWEEN INDICES OF COMBAT COURSE WEAR AND LABORATORY FLEX ABRASION ON 12 FABRICS.

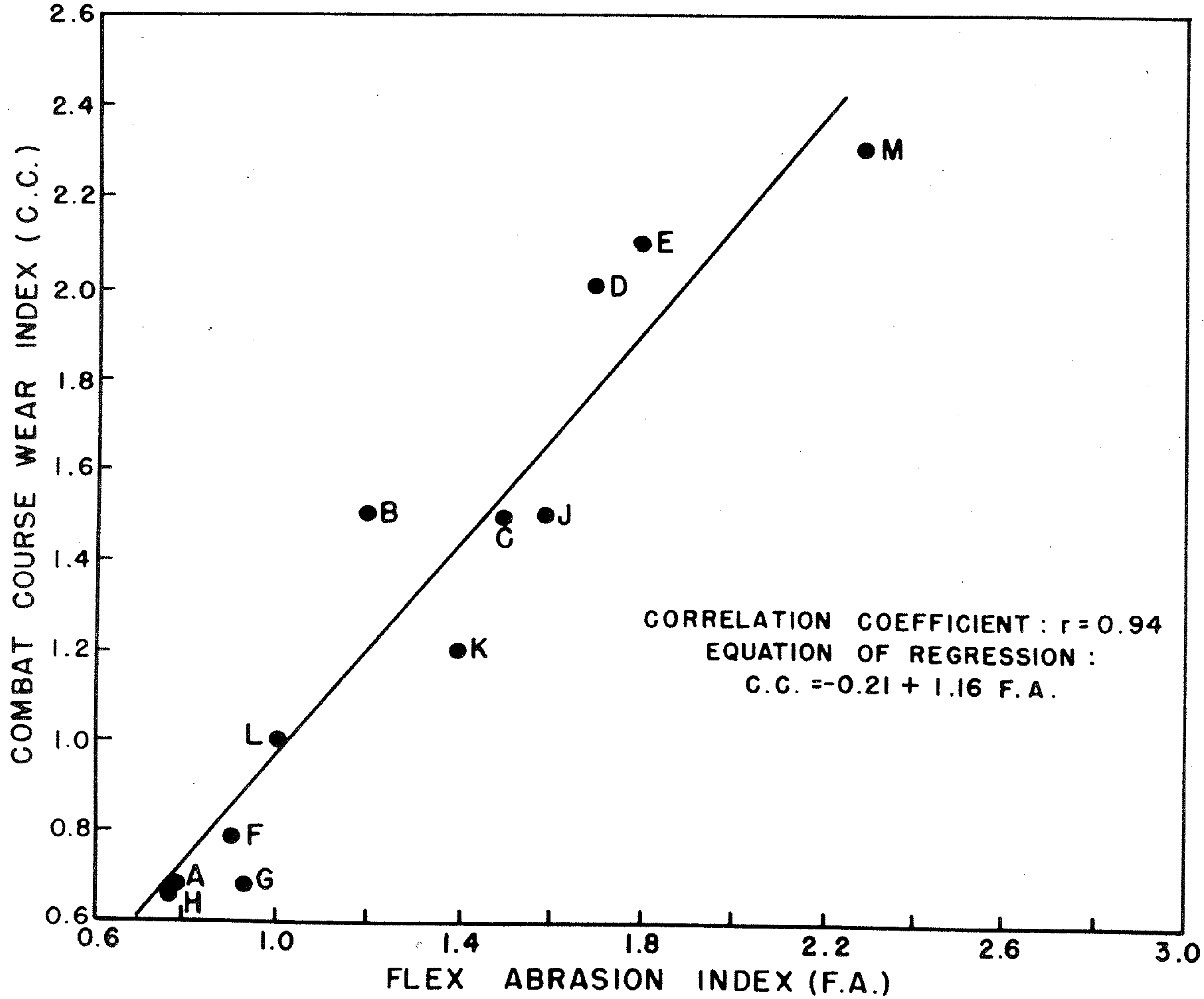

TABLE I

CHARACTERISTIC	EQUATION	EFFECT ON WEAR RESISTANCE
FABRIC WEIGHT W Oz./Sq. Yd.	$W = .6857 \left[\frac{n_1}{N_1} (1+c_1) + \frac{n_2}{N_2} (1+c_2) \right]$ $W = .6857 \frac{1}{\sqrt{N_1}} \left[K_1(1+c_1) + K_2(1+c_2)B \right]$ $W = \frac{.6857}{\sqrt{N_1}} \left[\text{FABRIC SHAPE FACTOR} \right]$	$W.R. = f\ (W^2)$ $W.R. = f \left[\frac{K_1\ (1+c_1) + K_2(1+c_2)\ \beta}{N_1} \right]$ For a given weave and yarn quality W.R. increases approximately with the square of the unit weight when fabric shape factor is at optimum.

Conclusion: Increasing the Fabric Weight is the most efficient way of improving wear resistance.

TABLE II

CHARACTERISTIC	EQUATION	EFFECT ON WEAR RESISTANCE
Cover Factor	Warp Cover Factor $K_1 = \frac{n_1}{\sqrt{N_1}}$ Filling Cover Factor $K_2 = \frac{n_2}{\sqrt{N_2}}$	For single construction of low and medium tightness W·R· increases with increasing K-factors as determined by equation: $\left[K_1(1 + c_1) + K_2(1 + c_2)B \right]^2$ Maximum W·R· is obtained at an optimum tightness which depends on weave and yarn quality.

Weave	Optimum Cover Factor For Cotton Yarns K_1	K_2
Plain Weave	20 to 22	12 to 14
Oxford	22 to 24	13 to 15
Twills, 3 and 4 harness	23 to 25	14 to 16
Crowfoot, 4 harness	24 to 26	15 to 17
Sateen, 5 harness	26 to 28	16 to 20

TABLE III

CHARACTERISTIC	EQUATION	EFFECT ON WEAR RESISTANCE
YARN COUNT	N Warp N Filling	For a given weave, fabric shape factor, and yarn quality, wear resistance is related to the reciprocal of the yarn count: $W.R. = f \left(\frac{1}{N}\right)$
COUNT BALANCE	$\beta = \sqrt{\frac{N_1}{N_2}}$	If major wear stresses run parallel to the warp direction β should be $>$ 1.0
WARP/FILLING WEIGHT RATIO	$\frac{w_1}{w_2} = \frac{n_1}{n_2} \cdot \frac{N_2}{N_1} \frac{(1 + c_1)}{(1 + c_2)}$	In uniform and apparel fabrics: $\frac{w_1}{w_2} = 1.1 \text{ to } 1.4$
YARN TWIST	Twist Multiplier $= \frac{TPI}{\sqrt{N}}$	Variation of twist multiplier from 4.25 to 5.25 in cotton warp and from 3.25 to 4.25 in cotton filling yarns has no significant effect.