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A Comparison of the Abrasion Results Obtained Using Three Different Instruments on Some Woven Fabrics

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A COMPARISON OF THE ABRASION RESULTS OBTAINED USING THREE DIFFERENT INSTRUMENTS ON SOME WOVEN FABRICS

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ABSTRACT

The Stoll (flex), Martindale and Accelerotor abrasion results of 64 plain and twill weave fabrics of differing fibre content and fabric mass were determined and compared. The influence of fabric mass, weave type and component yarn tensile properties on the results of a given abrasion test were examined.

No two tests ranked the fabrics in the same order. The correlation between abrasion tests, even where significant, did not allow for the results of one tester to be predicted from those of another. The degree to which each fabric and yarn property examined affected the result varied between abrasion tests. The weft yarn tensile strength was a significant factor in the three standard abrasion tests applied.

INTRODUCTION

The progressive deterioration of the physical and aesthetic properties of a textile article, which ultimately results in failure or rejection for its intended purpose, is the net result of a complex combination of chemical, biological and mechanical actions encountered in its use[1]. The collective process is loosely termed 'wear'. Abrasion has been cited as the most important single factor in determining wear and, therefore, the laboratory prediction of wear performance, in terms of durability, is based mainly on the results obtained on mechanical abrasion testers. Over a hundred such abrasion machines are reported in the literature, each unique in its combination of abradant (e.g. emery, sand, steel blades, cloth), applied pressure, character of motion (e.g. plane, flex, unidirectional, multidirectional) and end point assessment (objective or subjective). The salient features and operating conditions of some of the more widely used testers have been given in a recent review covering the subject of fabric abrasion and wear[2].

Regrettably, many studies have reported a poor correlation between predicted fabric performance, as determined from the results of any one abrasion tester, and actual fabric performance in consumer use[1-3]. This failing reflects the fact that *no one* abrasion machine thus far developed has simulated all the actions taking place during actual wear.

It is also reported that the correlation between the results of different abrasion testers for a particular set of fabrics is liable to be poor[2-8]. Lord[3], in a study of cotton and cotton blend bed sheets, obtained no agreement in the fabric ranking of seven of the more widely used abrasion testers. Bird and Hunter[4] found no significant correlation between the Stoll flex (steel bar), Accelerotor (grit paper) or Martindale (wool cloth) abrasion results obtained on some woven wool and wool blend fabrics. The Committee of Directors of Textile Research Associations (CDTRA)[5], in a study using woven cotton, viscose rayon and cotton/viscose rayon blend fabrics, reported 'fair' correlation between abrasion testers within the following groups:

(1) Linra, Schiefer (wool abrasive), Martindale (end point);

(2) Boss (loomstate abrasive), Stoll bar, Martindale (mass loss);

(3) Stoll blade, BFT flex, BFT ball, Schiefer (steel abrasive), Boss (mineral khaki-dyed abrasive), Accelerotor (abrasive paper).

The CDTRA concluded that variations arose from fundamental differences in the operating conditions and abrasive actions of each machine, more especially with the abradant used and pressure with which it was applied.

Weiner and Pope[6] reported a high degree of correlation between the Taber and Sand abraders and between the Stoll (flex) and B.F.T. (flex) testers but not between the two groups. They concluded that, of the wear mechanisms considered by Backer[7], the Taber and Sand abraders were primarily abrasive in their action whereas the Stoll (flex) and B.F.T. (flex) were adhesive and that the latter group (adhesive) were sensitive to applied lubricants whereas the former group (abrasive) were not. Elder and Mehta[8] found that the Accelerotor was sensitive both to the amount and type of resin applied to a fabric whereas with the BFT (flex) tester only the amount of resin influenced the result and that, contrary to the findings of the CDTRA, the correlation between testers could be poor, depending on their responses to applied resins.

Abrasion of a fabric results in the gradual mechanical breakdown of fibres accompanied by the loss of short fibre lengths, and abrasion resistance is known to depend on fabric and yarn contructional features[2,13,14]. Hamburger[9] stated that, as abrasion resistance was in essence a measure of the ability of a fabric structure to absorb work, it should then be related to the viscoelastic properties of the constituent fibre. A correlation is reported between the energy of rupture of mechanically conditioned fibres and abrasion resistance as measured on an Accelerotor[10]. Galbraith[11] *et al* reported, however, that the Accelerotor was more sensitive to changes in fibre 'toughness' than was the Stoll (flat) and that the rate and type of fibre damage differed greatly between abrasion machines.

Where yarns spun from staple fibre are used, it is reported that yarn twist, being a significant factor in determining the cohesive forces and hence fibre security within a structure, is more important than fibre type and that resistance to flat (e.g. Martindale) or flex (e.g. Stoll) abrasion is improved with increased twist[2,12–14]. Increased fabric mass is reported to enhance resistance to flat and flex abrasion, though the effect is less pronounced in the latter case where the use of increased fabric sett or heavier yarn counts to increase mass tends to impose a greater strain on fibres during bending[2,13,14]. Plain weave is reported to possess the highest resistance to flat abrasion, but as the degree of flexing experienced during test increases, it can then become advantageous to improve yarn mobility in the fabric structure through the use of yarn floats[2,13,14]. In contrast to flat (e.g. Martindale) and flex (e.g. Stoll) abrasion testers, the results of the Accelerotor are reported to be independent of yarn twist, fabric sett and weave type[10].

The objectives of the present study were twofold. Firstly, to examine the degree of correlation between the results of three standard abrasion machines differing widely in their abrasive action, namely the Martindale, Stoll (flex) and Accelerotor, for a range of woven fabrics. Secondly, to determine the influence of fabric mass, weave type and constituent yarn tensile properties on the fabric abrasion resistance results obtained on each machine; factors which could assist in the future analysis of laboratory abrasion results, more specifically where contradictory rankings are obtained.

EXPERIMENTAL

A total of 64 commercial and development fabrics were chosen so as to include a range of fibre and yarn types and fabric masses. The fabrics were confined to plain and 2/2 twill weave structures.

The yarn breaking strength, extension and work of rupture were determined for each set of warp and weft threads on an Instron tester applying a constant rate of extension. The same rate of extension was used for all yarns. The average of 10 results for each set of threads was taken. The warp and weft linear densities were also recorded.

Abrasion tests were performed on the Martindale, Stoll (flex) and Accelerotor, according to the method prescribed in their respective standard tests with the following operating conditions:

In the Martindale test[15] a fabric sample is subjected to flat abrasion by rubbing, under pressure, against an abradant, the test specimen prescribing a Lissajous figure. The recommended standard crossbred, worsted spun, plain weave, wool cloth abradant and an applied load of 7,78N (12 kPa) were used. The percentage mass loss was obtained after 5 000 and 10 000 cycles, a previous study having recommended this method in preference to thread rupture end point[16]. The mean of 4 results on each fabric was recorded. The test was repeated, the fabric sample itself being substituted for the standard cloth abradant. For some fabrics it was found that one or more of the sample specimens were destroyed during the test. In such cases the mean mass loss of the remaining specimens was calculated and taken to represent the true mean.

In the Stoll flex test[17] a tensioned fabric strip, cut in either warp or weft direction, is subjected to unidirectional flexing and folding round a steel bar. A tension load of 17,8 N (4 lb) was applied to the steel bar for all the test fabrics, a 2,25 N ($^1/_2$ lb) headweight was found sufficient to prevent mounting head vibration. The mean cycles to rupture was obtained for 5 specimen strips in both warp and weft directions. Where a test fabric was constructed from a bicomponent yarn (usually in the weft direction) of core fibres wrapped in a filament sheath, it was noted that the former tended to be removed preferentially long before the rupture of the latter. The breaking cycles recorded in such cases refer to the point of rupture of the filament component.

In the case of the Accelerotor[18] an unfettered specimen square is placed in an abradant lined chamber and driven by a central impeller so that it repeatedly impinges with high impact velocity, against the chamber wall. The specimen is subjected, therefore, to repeated compression and flexing with resultant internal fabric/fibre abrasion as well as to external abrasion against the chamber wall. All the fabrics were tested at an impeller (elongated 'S' shape 114,3 mm) speed of 3 000 rev/min using a 360 grit aluminium oxide abradant ring. The mass loss of the fabric specimen was determined after 3 and 6 minutes, respectively. Mass loss was used in preference to strength loss so as to provide ready comparison with the Martindale results. The mean of 5 results was recorded for each fabric. There was a tendency for fabric samples to 'hang up' or 'wrap around' the impeller blade during test, thus generating a false result. In such cases the result was disregarded. A noticeable rise occurred in fabric temperature during test and it was found necessary to recondition the sample before reweighing for mass loss. Similar observations have been reported in previous studies on the Accelerotor[10, 19]. Where one or more fabric specimens were destroyed during test, the procedure for recording the mean mass loss was as given for the Martindale. Rigid checks were maintained on the uniformity of the abradant rings by use of a control fabric.

Because of the considerable number of results involved, individual fabric test results have been omitted from this report. A complete set of results is available on request.

RESULTS AND DISCUSSION

Correlation Between Different Tests

When comparing the mass loss obtained for each fabric sample, it was found that, for the applied operating conditions, the Accelerotor (6 minutes) exerted a far more severe abrading action than the Martindale (10 000 cycles). For both testers, fabric sample destruction generally occurred where the percentage mass losses exceeded 40%. Directional effects were evident in the abrasion results for Stoll (flex) warp and weft, more especially where the component warp and weft threads differed widely in fibre type and physical properties.

The correlations between the results of the abrasion tests were computed and are shown in Table 1.

The correlations obtained for Martindale (standard cloth) vs both Accelerotor and Stoll (flex) warp, weft and mean were significant at the 95% confidence level. In contrast, the Martindale (self-self) showed no significant correlation with the Martindale (standard cloth), Accelerotor or Stoll (flex) weft. The poor correlation obtained between the Martindale (self-self) and other abrasion tests may be a result of the non-uniformity in applied abradant introduced in this test through using the specimen itself as the abradant.

A significant correlation (95% confidence level) was obtained between the Stoll (flex) warp and mean and the results of all the other abrasion tests. The Stoll (flex) weft, however, showed significant correlation with only the Martindale (standard cloth) after 5000 cycles. The poor correlation of the Stoll (flex) weft may be due, in part, to the results of those fabrics containing a bicomponent weft yarn. Whereas the Stoll (flex) result tended to be insensitive to the premature removal of the core fibre element, this was reflected in the mass loss assessment method employed by both the Martindale and Accelerotor tests.

No two abrasion tests ranked the fabrics in the same order and, even where significant correlations existed between testers, the correlations were not high enough to predict with a fair degree of accuracy the values of one abrasion test from those of another. Nor was there complete agreement between the results for progressive abrasion on the Martindale and Accelerotor, though the correlations were highly significant in both cases.

Effect of Yarn and Fabric Properties on Abrasion

The following expression was derived to obtain some assessment of work potential (W.P.) for each fabric from the work of rupture (W.R.) results of one metre lengths of their respective warp and weft yarns.

$$\text{W.P.} = \text{W.R. warp} \times \underset{\text{in a metre}^2\text{ of fabric}}{\text{length warp yarn (m)}} + \text{W.R. weft} \times \underset{\text{in a metre}^2\text{ of fabric}}{\text{length weft yarn (m)}}$$

Multiple regression analyses were performed to determine the effects of various yarn and fabric variables on the different abrasion test results. The best fit equations obtained, although highly significant (95% confidence level) were complex involving as many as 14 interaction terms. These, therefore, were analysed further to determine the importance of each measured property for a particular abrasion test. From the results, shown in Table 2, it is evident that, under the applied operating conditions, the results of the abrasion testers are dependent on different constructional features of the test fabrics.

For the standard Martindale test (% mass loss) the important factors were firstly fabric mass, then warp and weft tensile strength and to a lesser extent

TABLE I
CORRELATION COEFFICIENTS BETWEEN ABRASION TEST RESULTS

	MARTINDALE Standard Abradant		MARTINDALE Self-Self		ACCELEROTOR		STOLL FLEX		
	5000	10 000	5000	10 000	3 min.	6 min.	Warp	Weft	Mean
Martindale Standard Abradant 5000	1	0,96	0,15	0,12	0,47	0,45	-0,39	-0,27	-0,37
Martindale Standard Abradant 10 000		1	0,17	0,13	0,40	0,39	-0,31	-0,24	-0,32
Martindale Self-Self 5000			1	0,69	0,06	0,07	-0,33	-0,18	-0,28
Martindale Self-Self 10 000				1	0,10	0,15	-0,36	-0,22	-0,32
Accelerotor 3 min.					1	0,90	-0,33	-0,13	-0,25
Accelerotor 6 min.						1	-0,39	-0,19	-0,32
Stoll Flex Warp							1	0,59	0,88
Stoll Flex Weft								1	0,90
Stoll Flex Mean									1

r > 0,25 for significant correlation at 95% confidence level

TABLE 2

APPROXIMATE CONTRIBUTION (%) OF EACH INDEPENDENT VARIABLE TO EXPLAINED VARIATION

INDEPENDENT VARIABLE	MARTINDALE Standard Abradant		MARTINDALE Self-Self		ACCELEROTOR		STOLL FLEX		
	5000	10 000	5000	10 000	3 min.	6 min.	Warp	Weft	Mean
Weave type	7	7	30	12		10	24	5	2
Fabric mass	29	31	4	5			2		
Warp tex	7	3	1	2			3	8	2
Weft tex			5	9			3	6	
Warp yarn ten. str.	13	12	17	17					2
Weft yarn ten. str.	13	12			39	44	12	15	30
Warp yarn work rupt.		1	11	12		7	19	1	7
Weft yarn work rupt.	2	1						1	7
Work Potential			6	2			9	10	14
Warp yarn break. ext.		1	14	3			2	18	8
Weft yarn break. ext.	1						20		
% Fit	72	68	88	62	39	61	94	64	72

weave type. The weave type and the warp tensile properties assumed greater importance in the Martindale self-on-self test. Only three factors appeared to influence the Accelerotor, namely the weft tensile strength which was of considerable importance, and, to a much lesser extent, the weave type and warp work to rupture. With the Stoll (flex) a number of the examined parameters appeared significant and these varied according to the direction of the test. In the warp direction the weave type, warp work to rupture and weft tensile strength and breaking extension, and in the weft direction the weft tensile strength, warp breaking extension and derived work potential were significant factors. For the combined mean result the weft tensile strength was, overall, the single most important factor followed by the derived work potential.

The discrepancies in the examined fabric ranking by the different abrasion testers and tests can, therefore, be attributed to differences in the reactions of the applied abrasion tests to changes in specific fabric properties. It is evident, however, that the weft yarn tensile strength was of significant importance in all the standard abrasion tests. The method of protecting the stress bearing threads (usually warp) from abrasion by exposing the opposite threads (usually weft) at the fabric surface through the use of crimp or weave floats is common practice[2,13,14] and could account for the importance of the weft yarn strength in determining the measured fabric abrasion resistance.

SUMMARY AND CONCLUSIONS

Sixty four commercial and experimental woven fabrics, of various fibre compositions, fabric mass and weave were abraded on an Accelerotor, Stoll (flex) and Martindale according to the respective standard test method, and on a Martindale using the specimen itself as the abradant. The correlation between the test results was examined and the effects of fabric mass, weave and yarn tensile properties on the measured abrasion resistance were also investigated.

A poor, though significant, correlation (95% confidence level) was found between the Accelerotor, Martindale (standard abradant) and Stoll (flex) warp and mean. The Martindale (self-self) and Stoll (flex) weft correlated only with the Stoll (flex) warp and mean and in the latter case with the Martindale (standard abradant) after 5000 cycles. No two testers ranked the fabrics in exactly, or even approximately, the same order, major reversals existing between any two sets of results, nor were correlations high enough to allow the values of one abrasion test to be predicted with any degree of accuracy from those of another.

The multiple linear regression equations obtained for each abrasion test based on the measured yarn and fabric properties were complex. Analyses of the equations revealed that the degree to which each property affected the result of a given tester varied between abrasion tests and that the degree of correlation between any two tests was dictated by these relevant properties in the compared fabrics.

Of the considered properties weft yarn tensile strength was of major importance in all the standard abrasion tests.

Further work is in progress to extend the range and type of fabrics examined with the eventual aim of establishing more precisely the areas in which the different testers and test methods rank the fabrics similarly and the effects of fibre, yarn and fabric parameters on the different abrasion test results.

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THE USE OF PROPRIETARY NAMES

The names of proprietary products where they appear in this report are mentioned for information only. This does not imply that SAWTRI recommends them to the exclusion of other similar products.

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