

The influence of environmental conditions on the testing of textile materials

Committees responsible for this Published Document

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- Association of Consulting Scientists
- Association of Suppliers to the British Clothing Industry
- British Polyolefin Textiles Association
- British Textile Confederation
- British Textile Machinery Association
- British Textile Technology Group
- British Throwsters Association
- Furniture Industry Research Association
- International Wool Secretariat
- Ministry of Defence
- National Wool Textile Export Corporation
- SATRA Footwear Technology Centre
- Society of Dyers and Colourists
- Textile Finishers' Association
- Textile Institute

The following body was also represented in the drafting of the standard, through a subcommittee/working group:

Department of Trade and Industry (Namas Executive)

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Foreword

This Published Document has been prepared by Technical Committee TCI/24, Physical testing.

The purpose of PD 6577 is to give the results of a controlled textile test programme set-up to establish the following:

- (a) whether current practice has resulted in the optimum choice of mean temperature and mean relative humidity, together with the optimum limits of tolerance for variation about these mean values;
- (b) whether a region of temperature and relative humidity can be identified where the physical properties of textile materials do not vary significantly with small changes in conditions.

This Published Document presents results of research work, and gives some recommendations which will be subject to further consideration by the responsible BSI committee. The information in this Published Document has been presented to CEN/TC 248, for consideration in preparing a revision of ISO 139 and EN 20139. Any draft revision of ISO 139 or EN 20139 agreed by CEN/TC 248 will be circulated for Public Comment, when all interested parties will have an opportunity to present their views. However, it has been decided to publish this background information at an early stage to alert users of these standards of the possible future revision. Additional background data would be welcome and should be sent to the Secretary of TCI/24 at BSI Standards, 389 Chiswick High Road, London W4 4AL.

The committee wishes to acknowledge financial support from the Department of Trade and Industry and the contribution of the British Textile Technology Group as the primary author of PD 6577.

The conclusions expressed in this Published Document represent the views of the primary author.

Introduction

Background

Whilst accepting the inadequacies of ISO 139 : 1973 in its present form, it has been acknowledged that this basic Published Document was urgently needed for all on-going standardization work in CEN/TC 248 involving physical test methods; and at the CEN/TC 248 meeting in Gent on 26/27 February 1991, delegates agreed to propose the adoption of ISO 139 : 1973 as a European Standard by submittance to the Unique Acceptance Procedure (UAP).

ISO 139 was published at a time when the range of available textile materials was more limited than is currently in use. Literature searches have revealed a lack of background information about the choice of environmental conditions. The working draft under consideration in ISO/TC 38/-/WG 13 requires laboratories to have six sets of test conditions available for different types of sample and for different conditions of use, which would be very costly to implement.

The accuracy of measurement of relevant humidity is not specified in ISO 139. In the UK, the Scientific Instrument Research Association (SIRA) has been accredited by the National Measurement Accreditation Service (NAMAS) for relative humidity measurement and has published many papers on the subject. Basically this work shows that commonly used techniques for measuring relative humidity give, at best, a result accurate to $\pm 2\%$. If a chilled mirror instrument costing £6000, and calibrated directly at the UK's National Physical Laboratory at a cost of £1500 per point were to be used, with a calibrated platinum resistance thermometer then $\pm 1\%$ can be achieved at a relative humidity of 50 % at one spot in the process. It is considered essential that allowance for the accuracy of measurement of relative humidity be made in ISO 139.

It appears that there are only very limited data relating to the effects of variations in standard conditions on physical properties. Some work has been carried out which suggests that a 1 % reduction in relative humidity results in a 0.3 % reduction in tensile test results on cellulose based materials. Clearly a larger programme of work was required before any changes to the standard atmosphere for conditioning and testing textile materials could be considered.

The need for an extensive programme of experimental work was supported by BSI, and the Department of Trade and Industry agreed to provide up to 50 % funding for the project if BSI selected a suitable contractor and submitted an acceptable proposal.

Objective

The overall objective of the work reported in this document was to recommend atmospheric conditions for testing textiles based on an experimental study of the effects of these conditions on fabric properties.

Review of standards on atmospheric conditions

There are a number of standards which specify the atmospheric conditions under which textiles and other materials need to be conditioned and tested. The required levels and permitted ranges of temperature and humidity of a selection of these standards are summarized in table 1.

The most important points to highlight from table 1 are as follows.

- a) The standard atmosphere for textiles, in temperate conditions (ISO 139) is $(65 \pm 2)\%$ r.h./ $(20 \pm 2)^\circ\text{C}$.
- b) In tropical conditions, a temperature of $(27 \pm 2)^\circ\text{C}$ is allowed (ISO 139).
- c) A wider r.h. tolerance of $\pm 5\%$ is permitted for coated fabrics (BS 3424 : Part 2).
- d) Many other materials, such as rubber, plastics and paper, are tested in warmer, drier conditions, i.e. 50 % r.h. and 23°C .
- e) The general standard, ISO 554, recommends the warm/dry atmosphere with wide permitted ranges $(50 \pm 5)\%$ r.h./ $(23 \pm 2)^\circ\text{C}$ as the everyday working atmosphere for material testing. 65 % r.h./ 20°C , the cold/wet atmosphere, is mentioned as being 'used in certain fields of application'.
- f) Some standards allow the use of either the 'cold/wet' or 'warm/dry' atmosphere, e.g. ISO 2231 (coated fabrics).
- g) The specified permitted ranges for temperature and humidity differ, for no clear reason, from standard to standard.

It is not clear from the standards, or from other sources, why the permitted ranges and levels are different. There are no clear technical reasons; only comments on what is attainable and realizable in certain circumstances, e.g. tropical countries are 'allowed' to test at 27°C , because of the practical difficulties of attaining 20°C , but with no regard to the effect on the test result which this difference in temperature might cause.

Textile standards nearly all call for $(20 \pm 2)^\circ\text{C}/(65 \pm 2)\%$ r.h., whereas standards for plastics specify $(23 \pm 2)^\circ\text{C}/(50 \pm 2)\%$ r.h.

Clearly this situation is unsatisfactory, posing as it does a number of questions as follows.

- 1) What is the effect on textile properties of changes to temperature and humidity for various polymer types?

For example, what would be the effect on test properties of a change from the 65 % r.h./20 °C textile atmosphere to one set at 50 % r.h./23 °C (the plastics and rubber atmosphere)?

- 2) Are the permitted ranges too wide or too narrow? What can be achieved in practice?
- 3) Are the rates of change in properties with temperature or humidity dependent on the set mean levels?
- 4) Does preconditioning matter?

A proposal was made in 1991 to carry out a programme of work to try and answer these questions. This proposal was accepted by BSI Technical Committee TCM/24, and work commenced late in 1992.

It should be strongly emphasized at this stage that the work programme was not intended to be a purely scientific investigation of the influence of humidity and temperature on fabric properties. If that had been the case, a much wider range of conditions, and smaller permitted ranges, would have been employed and the same non-destructive test specimens (e.g. mass per unit area) used for every atmospheric condition.

One objective was to determine the extent to which different laboratories might obtain different results if the atmospheric conditions in those laboratories were not precisely the same.

1 Scope

This Published Document presents information on the results of a controlled test programme to assess the effect of temperature and relative humidity on physical properties of textile materials.

2 References

2.1 Normative references

This Published Document incorporates, by reference, provisions from specific editions of other publications. These normative references are cited at the appropriate points in the text and the publications are listed on page 40. Subsequent amendments to, or revisions of, any of these publications apply to this Published Document only when incorporated in it by updating or revision.

2.2 Informative references

This Published Document refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on page 40, but reference should be made to the latest editions.

3 Definitions

For the purposes of this Published Document, the following definitions apply.

3.1 sensitivity coefficient

Percentage change in the level of a property brought about by a 1 % change in relative humidity or a 1 °C change in temperature.

3.2 significant range (SR)

That change in temperature (°C) or humidity (% r.h.) required to produce a difference in the level of a test property, statistically significant at the 95 % probability level.

4 Work programme

NOTE. Details of the programme of work are given in 4.1 to 4.3.

4.1 Fabric tests

4.1.1 Tensile strength

Tensile strength was determined, using a 500 M Testometric machine with interfaced computer, and testing was carried out in accordance with BS 2576 in both warp and weft directions, i.e. 200 mm × 50 mm strips extended to break. Five specimens were tested in each direction.

4.1.2 Elongation at break

Percentage elongation at break was measured in accordance with BS 2576 under the same conditions as for tensile strength.

4.1.3 Tear strength

Tear strength was measured by the wing-rip method in BS 4303. Specimens were torn across both warp and weft directions, using the interfaced computer of the Testometric machine to evaluate the results by the median peak method.

4.1.4 Crease recovery

The resistance to recovery after creasing was determined in accordance with BS EN 22313 (equivalent to ISO 2313). Five specimens were measured 'face to face' and five 'back to back', in both warp and weft directions. The resulting 10 values were pooled and the mean value calculated.

4.1.5 Mass per unit area

BS 2471 was used to determine mass per unit area of the fabrics. Five specimens (10 cm × 10 cm) were measured for each test.

All five tests (nine responses) were carried out twice at each condition by the same operator on different days.

4.2 Fabrics

Fabrics were selected according to the following criteria:

- a) representative of eight polymer types;
- b) woven, plain weave pattern with no finishes or treatments other than dyeing;
- c) mass per unit area, where possible, in the range $\sim 100 \text{ g/m}^2$ to 200 g/m^2 ;
- d) capable of being tested in accordance with 4.1, e.g. an acceptable tear pattern, and with the minimum of jaw slippage for tensile and tear tests;
- e) having a reasonable level of between-specimen variability along the roll, taking into account the fibre type and polymer class.

Preliminary testing was carried out on a number of fabrics within each polymer class at 65 % r.h./20 °C and many were rejected as unsuitable, according to the above criteria.

The fabrics finally selected, with characteristics as given in table 2 and characteristics of the constituent yarns given in table 3 had along-the-length, within-roll property variabilities as given in table 4.

NOTE. The preliminary testing, through force of circumstances, had to be limited (specimens tested at five equidistant points along the roll) otherwise there would not have been enough fabric remaining for the tests at various atmospheric conditions.

Great difficulty was experienced in finding a suitable polypropylene fabric. Eventually, after rejecting several qualities, a fabric was chosen which was the best, although not ideal, being rather variable and difficult to test for tensile and tear strength in the weft direction.

The coefficient of variation (CoV) for these properties was less than 10 % for all tests; for mass per unit area, the variability was about 1 % or less (see table 4).

The long term variability (specimens selected approximately 2 m apart) compared favourably with short term variability (see table 5) (specimens selected within 1 m) determined later, i.e. there was no evidence that long term within-roll variability was greater than short term variability. The overall mean standard deviations (SD) and CoV from all conditions, together with estimates of variations in SD, are given in table 5.

Scanning electron micrographs (SEMS) were produced at $60 \times$ and $180 \times$ magnification which showed the weave, yarn and filament characteristics. They are not shown in this Published Document.

4.3 Atmospheric conditions

4.3.1 Preconditioning

Prior to testing, all specimens were preconditioned from the dry side by heating in an oven at $(50 \pm 1) ^\circ\text{C}$ and less than 10 % r.h. until no further change in mass occurred. Experiments showed that the time required to reach equilibrium for the most hygroscopic polymers was not less than 4 h.

The value and effect of preconditioning is discussed later in this Published Document.

4.3.2 Conditioning

After preconditioning, specimens were conditioned to equilibrium mass, in the appropriate atmosphere in practice for a minimum of 24 h. The material was considered to be in equilibrium when successive weighings, at intervals of 2 h, showed no progressive change in mass greater than 0.25 %.

After conditioning, testing was carried out in the same atmosphere.

4.3.3 Generation and measurement of conditions

The atmospheric conditions were generated by an 'Airedale' VA4 air conditioning unit modified by a thyristor controlled heater. This system was able to maintain temperature in the conditioning/testing area very accurately, i.e. recorded to within $\pm 0.1 ^\circ\text{C}$ measured over the range (17 to 28) °C. This close temperature control also reduced time and spatial variation in measured recorded humidity to less than ± 2 % r.h. over the range (50 to 70) % r.h.

Humidity and temperature were measured with a General Eastern Digital Thermo-Hygrometer, model 880, calibrated at regular intervals by SIRA Test and Certification Ltd. The instrument showed no signs of drift between calibration checks. Typical calibration values were:

Applied (traceable) % r.h.	Actual (indicated) % r.h.
49.9	49.7
64.2	64.1
33.7	34.3

The overall uncertainty in the measurement of the applied relative humidity was ± 2 % of its value, e.g. at 50 % r.h., therefore, the applied r.h. value is accurate to $(50 \pm 1) \%$.

Occasional checks were made with a calibrated Assman aspirated hygrometer to confirm that the digital instrument was not drifting between calibrations.

Humidity and temperature were continually recorded, to check for time variations, on a Casella recording thermohygrometer.

4.3.4 Test conditions

The tests in 4.1 were performed on each of the eight fabrics (polymer types) under a range of conditions:

relative humidity: (50 to 70) %
temperature: (17 to 28) °C

Relative humidity was varied over a range of fixed temperatures and vice versa.

Table 6 gives the conditions employed.

(50 to 70) % r.h. and (17 to 28) °C represented the range of the air conditioning unit at which steady and reliable conditions could be obtained.

5 Experimental results

5.1 Tabular presentation

The scale of the experiments described in clause 4 is extremely large. For every atmospheric condition there are nine mean values for eight fabrics, carried out twice (sets 1 and 2), i.e. 144 mean values and 800 individual tests.

Individual results are not presented in this document. Mean values were gathered together in a series of tables. Each table provided information on one particular property (e.g. warp tensile strength) at one fixed condition (e.g. 17 °C) for each level of the varied condition (e.g. 50 %, 57 %, 65 % and 70 % r.h.). The tables gave the following details:

- mean values for each of the two repeat sets;
- standard deviation for each set;
- statistical significance of the extreme mean conditions for each set, e.g. between 50 % r.h. and 70 % r.h.;
- combined mean value, i.e. mean of set 1 and set 2.

For each property and condition comparison there were therefore nine tables; one for each test response.

These tables of mean values (72 in all) are not included in this Published Document.

5.2 Graphical presentation

Values from the tables of means were plotted in the following manner:

- A set of graphs representing a test property was plotted against humidity at a fixed temperature (or vice versa) for a particular polymer.
- Separate plots were produced for both fabric directions and for each fixed condition, e.g. the effect of humidity on tensile strength of viscose was shown at 17 °C, 20 °C, 23 °C and 28 °C for warp and weft directions.

c) The mean points for each condition were plotted.

d) The overall mean values of the two sets were joined to show the trend line.

NOTE. It has to be stressed that these plots were trend indications only and not 'best fit' regressions.

These trend graphs (approximately 600) have not been included in this Published Document but are present in the original report.

The purpose of these families of plots was to determine if there was a consistent picture, to answer for example, the following questions concerning trend, interaction and linearity.

- Does increasing, say, temperature consistently reduce the strength of a particular fabric at each fixed humidity and for both fabric directions?
- Is there any indication of interaction, e.g. where the effect of, say, temperature clearly depends on the level of humidity?
- Is there any clear and consistent evidence for non-linearity of effect?

5.3 Analysis

NOTE. The information obtained was analysed as described in 5.3.1 to 5.3.6.

5.3.1 Variation: standard deviation

The standard deviation (SD), coefficient of variation (CoV) and 95 % confidence limits were calculated for each set of test results.

5.3.2 Significance test

A test was performed to determine whether the mean values of the extreme conditions for each experiment were significantly different, e.g. by comparing the mean values for, say 17 °C and 28 °C at 50 % r.h. for tensile strength of polyester. The Student's *t* value was calculated by means of the following equation:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad (1)$$

where

$\bar{x}_1$ is the arithmetic mean value at the first condition;

$\bar{x}_2$ is the arithmetic mean value at the second condition;

S_p is the pooled standard deviation for both conditions;

n_1 and n_2 are the number of specimens respectively for each condition.

The levels of significance were assigned the following symbols:

- a) NS: not significant at the 95 % level;
- b) S: significant at the 95 % level;
- c) HS: significant at the 99 % level.

5.3.3 Regression analysis

It was considered worthwhile to conduct linear regression analysis only for those experiments (variation of condition for property/polymer combination) where the following criteria were met after examination of trend graphs:

- a) similar, approximately linear, trends at each level of temperature or relative humidity;
- b) similar trends for warp and weft;
- c) highly significant differences between extreme condition means for both sets and at each level.

These conditions were satisfied in the case of 12 polymer/property combinations:

- six for variation in humidity at constant temperature;
- six for variation in temperature at constant humidity.

The mean values for both sets at each condition were included in the regression analysis.

The output from the analysis were values from the equation:

$$y = a + bx \quad (2)$$

where

- y is the variable, either temperature °C or relative humidity %;
- x is the mean value of test property;
- a is the intercept y where $x = 0$;
- b is the slope: change in property for 1 °C or 1 % r.h. increase;
- r is the correlation coefficient.

Table 7 lists the selected 12 polymer/property combinations. Coefficients, determined from the regression analysis, are given. However, in this Published Document, the regression parameters (a , b , r) have not been included.

5.3.4 Sensitivity coefficients

The slope values (b) from 5.3.3 were converted into sensitivity coefficients (see 3.1) by means of the equation:

$$\text{sensitivity coefficient} = \frac{b \times 100 \%}{\text{mean}} \quad (3)$$

Approximate sensitivity coefficients were calculated for individual or isolated significant (S) or highly significant (HS) experiments, i.e. where the significance patterns and trend lines were not consistent for all levels and both fabric directions. These approximate sensitivity coefficients were determined from the means of the two sets of the extreme conditions only.

Sensitivity coefficients were not calculated for the non-significant (NS) trends.

The 'regression' coefficients and approximate sensitivity coefficients are given in the 'tables of sensitivity coefficients' (tables 8 to 16). Each table contains the humidity and temperature sensitivity coefficients for one test property (e.g. tensile strength) for all eight polymers, at each humidity and temperature level.

The mean temperature sensitivity coefficients for all humidity levels are listed in table 17. The mean humidity sensitivity coefficients for all temperature levels are listed in table 18.

5.3.5 Significant ranges (SR)

5.3.5.1 General

The SR was calculated from a rearrangement of equation (1) in 5.3.2, and thus depends on the number (n) of test specimens (usually five), specimen test variability (CoV) and the sensitivity coefficient (see 5.3.4).

In calculating SRs, the average test specimen sensitivity coefficient of variation (CoV) was employed, i.e. for any test property/polymer set, the mean value was determined for all humidity : temperature conditions. It was considered legitimate to perform this exercise since examination of individual CoV values showed no evidence of interactions, i.e. a dependence of CoV on atmospheric conditions. These overall mean CoV values are given in table 5.

The SRs, calculated from mean CoV and the sensitivity coefficients, are given in the tables of sensitivity coefficients (tables 8 to 16).

Table 7 gives the SRs for the 12 selected polymer/property combinations referred to in 5.3.3.

The SRs for the non-significant (NS) relationships are, of course, > 20 % for humidity experiments (50 to 70) % r.h. and > 11 °C for temperature experiments (17 to 28) °C. That is to say a 20 % r.h. or 11 °C change in conditions did not, in these cases, produce a difference in the level of the test property statistically significant at the 95% probability level.

An analysis of SRs provides the following information as given in table 19.

5.3.5.2 Effect of temperature

The order by polymer (all tests) of temperature range to produce a significant effect was:

Smallest SR (most sensitive)	wool
	acetate
	viscose
	polyester
	polypropylene
↓	cotton
	nylon
Largest SR (least sensitive)	linen

The order by test property (all polymers) was as follows:

Smallest SR (most sensitive)	tensile strength
	crease recovery
↓	tear strength
	elongation
Largest SR (least sensitive)	mass

That is, in general, wool was the most sensitive to temperature and linen was the least sensitive. Of the properties, tensile strength was the most sensitive and mass per unit area was the least sensitive.

5.3.5.3 Effect of humidity

Analysis of significant ranges provided the information given in table 20.

The order by polymer (all tests) of humidity range to produce a significant effect was as follows:

Smallest SR (most sensitive)	wool
	acetate
	viscose
	cotton
	linen
↓	nylon
	polyester
Largest SR (least sensitive)	polypropylene

That is, wool was the most sensitive to humidity and polypropylene was the least sensitive.

The order by test property (all polymers) was as follows:

Smallest SR (most sensitive)	tensile strength
	crease recovery
↓	tear strength
	mass
Largest SR (least sensitive)	elongation

As for temperature, tensile strength was most affected by humidity.

5.4 Experimental trials: summary

5.4.1 General

Table 21 summarizes all the key information from the experiments, i.e. the significance, size and direction of the effects on fabric properties of varying humidity at constant temperature, and varying temperature at constant humidity, for all eight polymers.

The degree of statistical significance is indicated as follows.

- 0: No statistically significant effects detected between extreme conditions (50 to 70) % r.h., (17 to 28) °C for any of the experiments, e.g. polyester (50 to 70) % r.h. at 17 °C, 20 °C and 28 °C for warp and weft fabric directions, i.e. six experiments.
- 1: Some significant effects.
- 2: Most of effects significant (S; 95 %) or highly significant (HS; 99 %).
- 3: All of the effects highly significant (HS; 99 %).

The size of the sensitivity coefficient is indicated as follows.

- 0: No effect on test property detected when changing from (50 to 70) % r.h. or from (17 to 28) °C, i.e. sensitivity coefficient = 0 %.
- 1: Increasing relative humidity by +1 % r.h., or temperature by +1 °C, produces a change in test property between 0 % and 0.5 %.
- 2: As 1; 0.5 % to 1 %.
- 3: As 1; >1 %.

The direction is indicated as follows.

- + indicates that increasing relative humidity, or temperature, produces an increase in test value.
- indicates that increasing relative humidity, or temperature, produces a decrease in test value.

The main conclusions from table 21, which contains the essence of all the experimental work, are presented in 5.4.2 to 5.4.12.

5.4.2 Effect of humidity on tensile strength

The following conclusions are made.

- Polyester and polypropylene are not affected.
- Increasing humidity increases strength of linen and cotton but the evidence is not good.
- There is very good evidence, however, of the decrease in strength of acetate, viscose, nylon and wool with increasing humidity.
- There are no examples of a sensitivity coefficient consistently greater than 1 %, i.e. where a 1 % increase in relative humidity changes a test property by more than 1 %.
- The effect of humidity on tensile strength has been reported by Meredith [1] the results from which are compared with the present work in table 22.

The agreement with this previously reported work is surprisingly good considering the intrinsic and unavoidable sources of variability.

5.4.3 Effect of temperature on tensile strength

The following conclusions are made.

- All the polymers are either weakened or not significantly affected by an increase in temperature.
- Viscose is weakened the most, with a sensitivity coefficient of about -1.3% .
- Polyester, nylon, acetate and wool are all weakened at the rate of $(0.5 \text{ to } 1)\%$ per $+1^\circ\text{C}$.

5.4.4 Effect of humidity on elongation

The following conclusions are made.

- Elongation at break of the synthetic polymers, polyester, nylon and polypropylene, is not affected by humidity.
- There is some evidence that the elongation at break of cotton, acetate and linen is increased with increasing relative humidity but the picture is not consistent at all temperature levels.
- The elongation of wool is strongly and consistently affected by humidity, with sensitivity coefficients greater than $+1\%$ ($1 \text{ to } 1.7\%$).
- The findings are consistent with Meredith's work [1] which claims the following approximate coefficients.

Wool	$(+1.2 \text{ to } +1.4)\%$
Acetate	$+0.5\%$
Viscose	$(+0.5 \text{ to } 0.7)\%$
Cotton	
Linen	

5.4.5 Effect of temperature on elongation

The following conclusions are made.

- Polyester and polypropylene are not affected.
- There is some evidence, for all the other polymers, that increasing temperature increases elongation at break. The picture is, however, inconsistent in every case except wool where the evidence is good and the sensitivity coefficients relatively high, $(+1 \text{ to } +1.7)\%$.

5.4.6 Effect of humidity on tear strength

The following conclusions are made.

- Polyester, nylon and polypropylene are not affected.
- Cotton and linen show increases in tear strength (like tensile strength) with increasing humidity, with sensitivity coefficients in the range $(+0.5 \text{ to } +1)\%$.
- Acetate and viscose, on the other hand, decrease in strength with humidity. The effects with these polymers are quite large, i.e. $(-1.5 \text{ to } -2.5)\%$.

- The evidence for wool is not good enough to draw any conclusions.

5.4.7 Effect of temperature on tear strength

The following conclusions are made.

- Unlike with tensile strength, there is no firm evidence of the synthetic polymers decreasing in tear strength with increasing temperature.
- Acetate, viscose and wool seem to decrease in tear strength with increasing temperature but the evidence is only fair and not fully consistent at all humidity levels.
- Cotton appears to increase in tear strength with increasing temperature but again the picture is not fully consistent.

5.4.8 Effect of humidity on crease recovery

The following conclusions are made.

- No statistically significant effect was detected for the synthetic polymers and linen.
- The evidence was inconsistent for cotton and viscose.
- The results clearly reveal, however, that wool shows a small $(-0.15 \text{ to } -0.3)\%$ but highly statistically significant reduction in crease recovery angle as humidity is increased.

5.4.9 Effect of temperature on crease recovery

Crease recovery of all polymers, except nylon, was reduced on increasing temperature, with sensitivity coefficients in the range $(-0.5 \text{ to } -1.5)\%$.

It is worth noting that the effect on polypropylene was highly statistically significant and the sensitivity coefficients were greater than -1% . This was the only occasion when a statistically significant effect of atmospheric conditions on the properties of polypropylene was detected.

5.4.10 Effect of humidity on mass per unit area

The following conclusions are made.

- Polyester and polypropylene were unaffected by changes in humidity.
- All the other polymers, as expected, increased in mass/unit area with increasing humidity, although the magnitude of the gains was generally small, i.e. sensitivity coefficients were $(+0.1 \text{ to } +0.25)\%$.

In this case one can compare the sensitivity coefficients found, with those reported in the literature [2] and [3] (see table 23). The agreement is reasonable, given the inherent fabric variability and the small size of the sensitivity coefficients. Note that a sensitivity coefficient of $+0.1\%$ means that increasing relative humidity by $+1\%$ (in the range $(50 \text{ to } 70)\%$ r.h.) increases the fabric mass/unit area by only 0.1% ; i.e. a very small change. Such small sensitivity coefficients could be detected because the specimen coefficients of variation (CoV) were small for mass per unit area compared with the other properties (see table 5).

5.4.11 *Effect of temperature on mass per unit area*

Previous work [3] has shown that increasing temperature at a constant percentage of relative humidity produces a very slight reduction in mass per unit area with some polymers, e.g.:

Wool: -0.03 % per +1°C (in the range
 (14 to 31) °C)

Viscose: -0.05 % per +1°C (in the range
 (14 to 31) °C)

Not surprisingly, therefore, no good evidence was found for consistent effects of temperature on fabric mass per unit area. What evidence there was showed the expected very small reduction in mass per unit area with increasing temperature.

5.4.12 *Summary by polymer*

The following conclusions are made.

a) *Polyester*

The only significant effect for polyester was reduction in tensile strength with temperature. No other properties were influenced by relative humidity or temperature.

b) *Nylon*

The tensile strength of nylon was, like polyester, reduced by increasing temperature. However, unlike polyester, nylon was weakened by increasing humidity.

c) *Cotton*

Increasing humidity strengthens cotton (tensile and tear). Cotton is less affected by temperature than the synthetic polymers, nylon and polyester.

d) *Acetate*

Tensile and tear strength of acetate is reduced but elongation at break increases as both humidity and temperature are increased.

e) *Viscose*

Viscose behaves similarly to acetate with regard to tensile and tear strength. However elongation at break is not affected significantly by humidity changes.

f) *Wool*

Wool showed the strongest, largest and most statistically significant effects of all the polymers. The direction of the effects was similar to viscose and acetate for tensile strength and tear strength.

g) *Polypropylene*

The test properties of polypropylene were not affected by temperature or humidity with the one important exception of crease recovery angle which reduced with increasing temperature.

h) *Linen*

Like cotton, linen increased in tensile and tear strength with increasing humidity. There was little evidence of temperature affecting linen properties.

5.5 Preconditioning

5.5.1 *General*

It has, of course, been long known that textile fibres exhibit hysteresis with respect to moisture and that material approaching standard atmosphere from the 'dry' or 'wet' side does not, at least in the short term, develop the same moisture content or regain when in equilibrium with standard atmosphere.

For that reason it has long been standard practice to precondition to the dry side and approach equilibrium with the standard atmosphere always from the dry side. Equilibrium is defined in a number of standards (e.g. ISO 139) as the state when two successive weighings separated by at least 2 h do not differ more than 0.25 %.

However, common practice is not always to precondition, but to expose samples for some period (e.g. 16 h, 24 h) to the standard atmosphere prior to testing.

The opportunity was taken, therefore, in this work to look at factors such as:

- how quickly samples come to equilibrium;
- what differences in moisture content or regain might exist after fairly short exposure to standard atmosphere;
- based on the findings from the rest of this work, what effect that might have on test results; and
- whether or not the effects were different with the present standard atmosphere of 65 % r.h./20 °C, and the possible alternative of 50 % r.h./23 °C.

5.5.2 *Experimental work*

From each of the eight fabrics in this work, sets of specimens were taken, each set consisting of triplicate mass per unit area specimens. Four such sets of specimens were assembled. Two sets of specimens were then exposed to a low r.h. environment (< 10 %), and the other two sets to a high r.h. environment (> 95 %). All sets were exposed at the same time, and for a period of five days.

The sets were removed from the low and high humidity environments and immediately weighed to give the initial masses. After those weighings the sets were then freely exposed to the 'standard' atmospheres as follows:

- one set from low r.h. exposed to 65 % r.h./20 °C;
- one set from high r.h. exposed to 65 % r.h./20 °C;
- one set from low r.h. exposed to 50 % r.h./23 °C;
- one set from high r.h. exposed to 50 % r.h./23 °C.

Weighings were then made on the specimens after the same progressive lapses of time from the initial weighing. To fit with the working day, the time intervals were as follows.

Day 1:	1.25 h after initial weighing
	2.50 h after initial weighing
	4.0 h after initial weighing
	5.5 h after initial weighing
Day 2:	24.0 h after initial weighing
	26.0 h after initial weighing
Day 3:	48.0 h after initial weighing
Day 4:	72.0 h after initial weighing

Weighings were not continued beyond this stage because it was felt that the main interest was in what might happen in a relatively short time.

After the weighings at 72 h, the specimens were then oven-dried at 105 °C for 48 h, and the oven dry masses determined. From these oven dry masses and the corresponding initial mass to 72 h mass, the moisture regains were calculated for all the specimens at all the various stages of exposure to one or other of the 'standard' atmospheres.

5.5.3 Results

The progressive changes in mass were calculated by taking the difference between the mass at any particular stage and that at the preceding stage, and expressing the change as a percentage of the 'preceding stage' mass; this was to compare with the standard concept of 'equilibrium' being when successive masses do not change by more than 0.25 %. These percentage changes are shown in tables 24 and 25. Table 24 gives the approach from the low r.h. (dry) side to both of the 'standard atmospheres' and similarly table 25 gives the approach from the high r.h. (wet) side.

The regain values calculated for the various stages are given in tables 26 and 27. Table 26 gives regains at all stages approaching the 65 % r.h./20 °C standard atmosphere from both dry and wet sides; similarly table 27 gives the approaches for 50 % r.h./23 °C.

5.5.4 Discussion

Taking the equilibrium basis of ISO 139, i.e. changes in mass not greater than 0.25 %, for successive weighings separated by at least 2 h, then it is evident that most changes occur in the earlier stages of exposure to the two 'standard atmospheres'. However, there are further significant changes with the more hygroscopic fibres up to 24 h exposure, made apparent by the overnight time span between weighings. Although the changes in mass become small as the equilibrium state is approached, nevertheless there

are still, in the main, progressive changes and these will add up, if a long period elapses between weighings, to give apparently large changes.

Bearing in mind that the definition of equilibrium is for changes in mass in a 2 h period, if the longer overnight time span mass differences are normalized to equivalent change per 2 h, then all reduce to small values less than 0.25 %, as will be seen from the figures in brackets in the tables. The same situation will apply to the less hygroscopic fibres, but the changes there are so small that a consideration of this kind is not necessary.

When approaching from the dry side, polyester, nylon, cotton and linen have reached the 'not more than 0.25 % change equilibrium' state after 2.5 h at either atmosphere. Acetate, viscose and wool have also reached 'equilibrium' after 2.5 h at 50 % r.h./23 °C, but at 65 % r.h./20 °C, that state is not reached until 4 h have elapsed.

When approaching 'equilibrium' from the wet side, polyester reaches that state after 1.25 h at either atmosphere, as does polypropylene at 65 % r.h./20 °C. Nylon, cotton and linen reach that state after 2.5 h at 50 % r.h./23 °C, but at 65 % r.h./20 °C not until 4.0 h for nylon and cotton, and 5.5 h for linen. Wool reaches 'equilibrium' with either atmosphere after 5.5 h. In the case of acetate and viscose, these have reached 'equilibrium' at 4.0 h in 50 % r.h./23 °C, but that does not occur at 65 % r.h./20 °C up to 5.5 h, and may not be reached until 24.0 h.

The overall pattern is that coming from either the 'dry' or 'wet' side the 'not more than 0.25 % change equilibrium' state is reached for most fibres within 4 h, only acetate and viscose coming from the 'wet' side needing 24 h or more. However, it is interesting that, coming from either 'dry' or 'wet', the 'equilibrium' state appears to be reached more quickly at 50 % r.h./23 °C than it is at 65 % r.h./20 °C.

With moisture regain, the patterns, of course, follow those of the mass changes, with the greater changes in regain occurring in the earlier stages of exposure to the 'standard' atmospheres. As might be expected from earlier work, the regains tend to be higher when approaching 'standard' atmospheres from the wet side than when approaching from the dry side.

Looking at the differences in regain after 24 h exposure, then at either 'standard' atmosphere the differences with the less hygroscopic fibres (polyester, nylon and polypropylene) are very small, and therefore these fibres will not be considered further in this discussion. With the more hygroscopic fibres (cotton, acetate, viscose, wool and linen) the differences in regain when approaching 'standard' atmospheres from dry and wet sides are greater, but the interesting point is that those differences are less at 50 % r.h./23 °C than at 65 % r.h./20 °C (see tables 26 and 27).

Knowing the rate of change of regain with r.h. [2], then these wet/dry side differences can be converted into an equivalent % r.h. difference, i.e. the change in % r.h. required to produce the regain difference caused by preconditioning from dry and wet sides. Table 28 shows that these equivalent % r.h. differences are quite large (>10 %) for the hygroscopic fibres, especially when conditioned at 65 % r.h./20 °C.

If we now assume that the difference in water content of the fibres, obtained by either wet as opposed to dry side preconditioning, or actual % r.h. changes, has the same effect on fabric physical properties, then we can predict the effect of preconditioning on properties such as tensile strength from the sensitivity coefficients determined in this work.

Using the overall % r.h./tensile strength sensitivity coefficients from table 18 and the equivalent % r.h. differences (table 28), the predicted effects on tensile strength of changing from dry side to wet side preconditioning were calculated (see table 28).

Table 28 shows that:

- a) the effect of preconditioning on tensile strength can be quite large for some polymers like wool and viscose; and
- b) the effects are smaller at 50 % r.h./23 °C than when conditioned, after preconditioning at 65 % r.h./20 °C.

There was not the opportunity in this study actually to measure, as distinct from predict, the effect on fabric properties of preconditioning from the wet and dry sides. Although this confirmation exercise should be carried out in the future, there is nevertheless sufficient evidence to recommend that preconditioning from the dry side should always be performed when testing hygroscopic polymers. However, bearing in mind the status of these findings and the required confirmatory work, it is recommended that the wording in the clause on preconditioning in ISO 139 should be retained, i.e. that 'preconditioning may be required'.

5.6 Two atmospheres comparison

5.6.1 General

In addition to the series of controlled experiments where humidity was varied at fixed temperatures (and vice versa), a separate exercise was carried out in which the two following, widely used, standard atmospheric conditions were compared:

- a) atmosphere A. 50 % r.h./23 °C: the standard conditions for plastics, rubber, etc. also recommended in ISO 554;
- b) atmosphere B. 65 % r.h./20 °C: the current standard temperate conditions for textiles.

The same eight polymers (rolls of fabric) and tests (nine responses) were employed as for the controlled condition experiments.

The objective of this exercise was to determine the implications of changing from atmosphere B to atmosphere A for textiles by determining the following:

- 1) which polymer/property combinations produced statistically significant and consistent differences between atmospheres A and B;
- 2) the size and direction (+ or -) of these differences;
- 3) whether the statistically significant differences obtained were consistent with those expected from the controlled experiments.

5.6.2 Treatment of results

The results from this comparison were treated in a similar manner to the controlled experiments, as follows.

- a) Tests were carried out in duplicate, i.e. two sets of tests performed on separate days (sets 1 and 2).
- b) Means and standard deviations (SD) were calculated for each polymer/property combination.
- c) The statistical significance of the mean differences between atmospheres A and B was estimated, and percentage differences between the pooled means were calculated.

NOTE. Detailed results are not included in this Published Document.

5.6.3 Analysis of results

5.6.3.1 Significant differences between the means

A count was made of the number of statistically significant and non-significant differences between the results at 50 % r.h./23 °C and 65 % r.h./20 °C from all the polymer property combinations. The results of this comparison, analyzed in terms of property, are given in table 29.

This table reveals that only about half of the atmospheric comparisons were statistically significantly different, tear and tensile strength providing the greatest number of significant differences, and crease recovery the least number.

A similar analysis in terms of polymer is given in table 30 which illustrates dramatically the importance of the atmospheric conditions for the wool fabric where all the mean differences were statistically significant and 83 % of them highly significant. At the other end of the scale, perhaps not surprisingly, relatively few statistically significant differences and no highly significant differences were detected for the synthetic polymers, polyester, nylon and polypropylene.