Introduction and theory of finishing

Contemporary wool dyeing and finishing

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AWET
australian wool innovation limited
CSIRO
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Topics

1. Introduction
2. Wet and dry finishing
3. The theory of setting wool
4. Temporary set
5. Permanent set
6. Relaxation shrinkage
7. Hygral expansion
8. Setting in finishing processes

1. Introduction

The aims of finishing

- Finishing is the use of a series of processes to develop the properties of fabrics to meet customer requirements. The desired fabric properties are only achieved if each of the steps in a sequence of processes is carried out in a precise order and in an appropriate manner.
- Unfinished fabrics are referred to as being ‘greige’ (grey) fabrics, or when appropriate, as ‘loomstate’ fabrics. Finishing converts these into ‘finished’ fabrics.

Finishing routines

In finishing fabric, a sequence of operations needs to be followed:

- to **remove unwanted contaminants**, mainly lubricants and anti-static agents introduced during yarn and fabric production
- to **prepare fabrics for dyeing**, if it is to be carried out in piece or garment form
- to **add functional finishes** as required, to produce the required handle, shrink-resistance, flame-retardancy, water-proofing, smooth drying, anti-microbial and antistatic properties
- to **modify the dimensional properties** of the fabric (relaxation shrinkage and hygral expansion) and bring these within desired limits
- to **develop the required fabric handle and appearance**.

Limitations on finishing

- The general character of a fabric is determined by the diameter of the fibres, yarn structure, yarn linear density (count), yarn twist, knit or weave structure and cover factor. These variables are not under the direct control of the finisher. Rather, the finisher develops the latent properties of fabric to meet customer requirements.
- Some of the worst problems in finishing arise from simple design errors (e.g. incorrect numbers of picks and ends) which make it impossible for the finisher to produce fabric with the desired width, mass per unit area.

The effect of finishing

- In most cases, the properties of finished fabric will differ considerably from loom-state fabric. In some cases, the changes are very great
- There is a common saying that “woollens are made in the finishing, whereas worsteds are made on the loom”.
- Actually, large changes in fabric properties can be observed in both the woollen and worsted systems but the changes in say in making woollen blankets are rather more obvious because the finished products bear little resemblance to the greige fabrics.

Finishing can not be done in isolation from the rest of a mill

- For fabric production to be conducted efficiently and economically, it is important that there should be **good communication** between marketers, designers, early-stage processors, spinners, weavers, finishers and dyers throughout the complete production sequence.

- This can enable problems at the sample stage and during manufacturing to be resolved by consultation between all the relevant parties.

2. Wet and dry finishing

Wet and dry finishing

- In finishing, a sequence of operations needs to be followed.
- Generally, wet finishing processes are carried out before dry processes.

Some sequences in the woollen and worsted systems

<table>
<tr><th>PROCESS</th><th>WOOLLEN SYSTEM</th><th>WORSTED SYSTEM</th><th></th></tr>
<tr><td>Inspect (Mend)</td><td>+</td><td>+</td><td></td></tr>
<tr><td>Pre-set</td><td></td><td>+</td><td></td></tr>
<tr><td>Scour</td><td>+</td><td>+</td><td rowspan="5">Wet
Finishing</td></tr>
<tr><td>Carbonise</td><td>+</td><td></td></tr>
<tr><td>Crab</td><td></td><td>+</td></tr>
<tr><td>Mill</td><td>Acid</td><td></td></tr>
<tr><td>Piece dye</td><td>(+)</td><td>(+)</td></tr>
<tr><td>Stenter dry</td><td>+</td><td>+</td><td rowspan="10">Dry
Finishing</td></tr>
<tr><td>Inspect</td><td>+</td><td>+</td></tr>
<tr><td>Condition</td><td>+</td><td>+</td></tr>
<tr><td>Raise</td><td>+</td><td></td></tr>
<tr><td>Crop</td><td>+</td><td>+</td></tr>
<tr><td>Press</td><td></td><td>Rotary</td></tr>
<tr><td>Decatise</td><td>+</td><td>+</td></tr>
<tr><td>Pressure decatise</td><td></td><td>+</td></tr>
<tr><td>Press</td><td>Rotary</td><td>+</td></tr>
<tr><td>Sponge</td><td></td><td>+</td></tr>
<tr><td>Inspect</td><td>+</td><td>+</td><td></td></tr>
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Functional finishes

These are chemical treatments intended to bring about changes in fabric properties such as:

- flat setting
- surface modification
- shrink-proofing
- flame-proofing
- crease setting
- waterproofing
- sanitising
- handle modification
- insect-proofing.

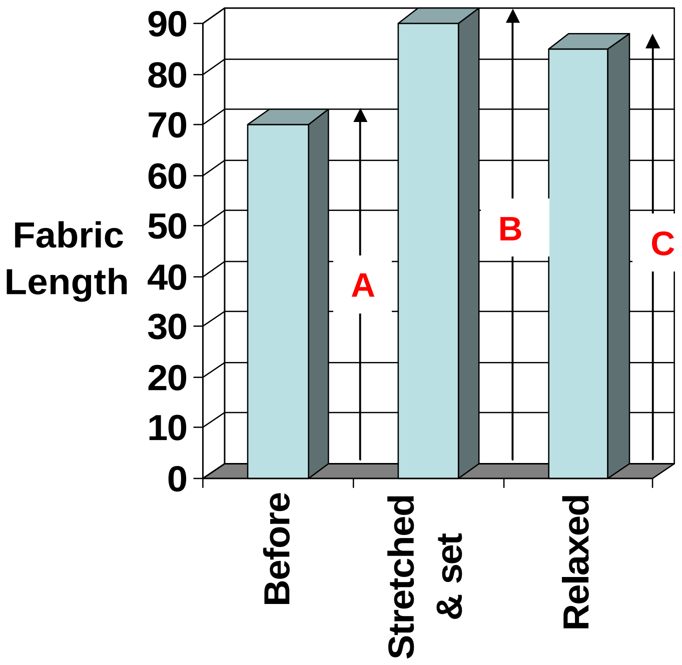
3. The theory of setting wool

The theory of setting

- Many finishing processes involve setting of fabric and an understanding of the mechanisms involved is indispensable to effective processing.
- The aim of setting is to permanently stabilise the dimensions of fabric in length, width and thickness and to give fabric desired surface characteristics (smoothness, fuzziness etc.)
- With wool, setting not only affects fabric dimensions but is intimately involved in determining the dimensional properties of fabric.
- The ability of the wool fibre to absorb appreciable amounts of water greatly complicates setting and its consequences.

Definition of set

- Set is the degree of retention of *strain* that is imposed during a setting process.
- Strain is a change in fibre or fabric shape.
- The amount of set imparted to wool depends on how the setting operation is carried out and particularly on the conditions of regain and temperature to which the fibre is exposed.



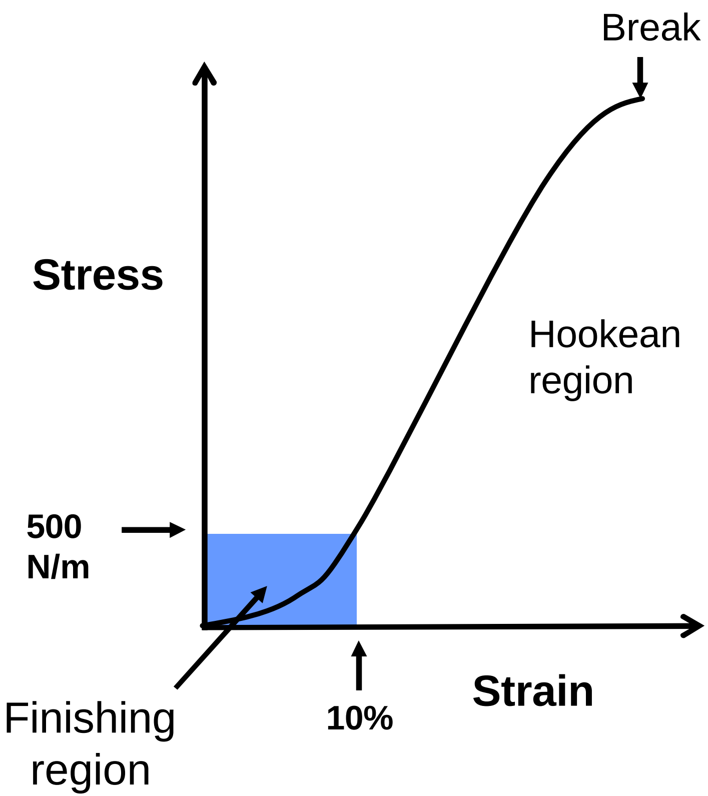
% Set = 100 x (B – C)/(B – A)

(B – A) = Total strain

(B – C) = Retained strain

Stress and strain in fabric finishing

- In finishing of fabric we are only able to impose very low levels of stress and strain.
- Stress applied is only sufficient to straighten or bend the fibres.
- The stress and strain levels are very much less than required to stretch the fibres or break the fabric.



Terminology of set in wool

- Set may be characterised as ‘cohesive’, ‘temporary’ or ‘permanent’, depending on the conditions under which the set may be removed from fabric.
- Cohesive set is removed when fabric is wet at ambient temperatures or even when exposed to very high humidity.
- Temporary set is defined as set which is lost when fabric is wet with water at 70ºC, and allowed to relax free from restraint; while set which remains after relaxation of fabric at 70ºC is defined as permanent.
- For practical purposes, there is not much difference between cohesive and temporary set, so temporary and permanent set are the most useful parameters.

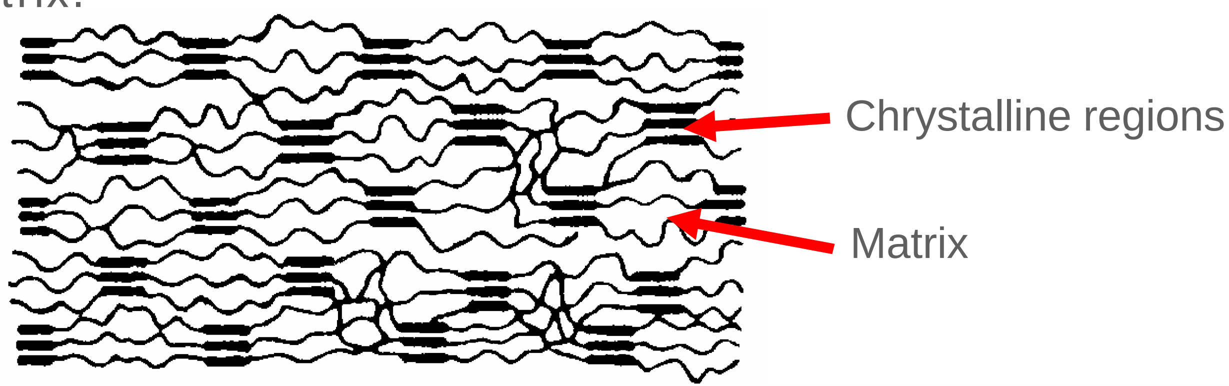
Setting in finishing

- The process of heating followed by cooling produces permanent set in synthetic fibres but in wool and cellulosics the set is only temporary.
- Permanent set in wool and cotton depends on covalent crosslinks.
- In cotton the crosslinks are introduced artificially by treatment with crosslinking chemicals.
- In wool, permanent setting requires the disulphide crosslinks between the polypeptide chains to be rearranged.

Set in textile fibres

Wool setting can be understood in terms of conventional polymer theory

- Textile fibres are composed of long polymer molecules. Most of the polymer molecules are more or less parallel to the fibre axis.
- A proportion of these molecules are in the form of crystals, while the rest of the polymer is much less structured.
- Fibres can be considered to be made up of tiny, elongated crystals embedded in a less structured web-like matrix of polymer chains.
- In wool the crystalline domains are the helical microfibrils and the unstructured keratin surrounding the microfibrils is the matrix.



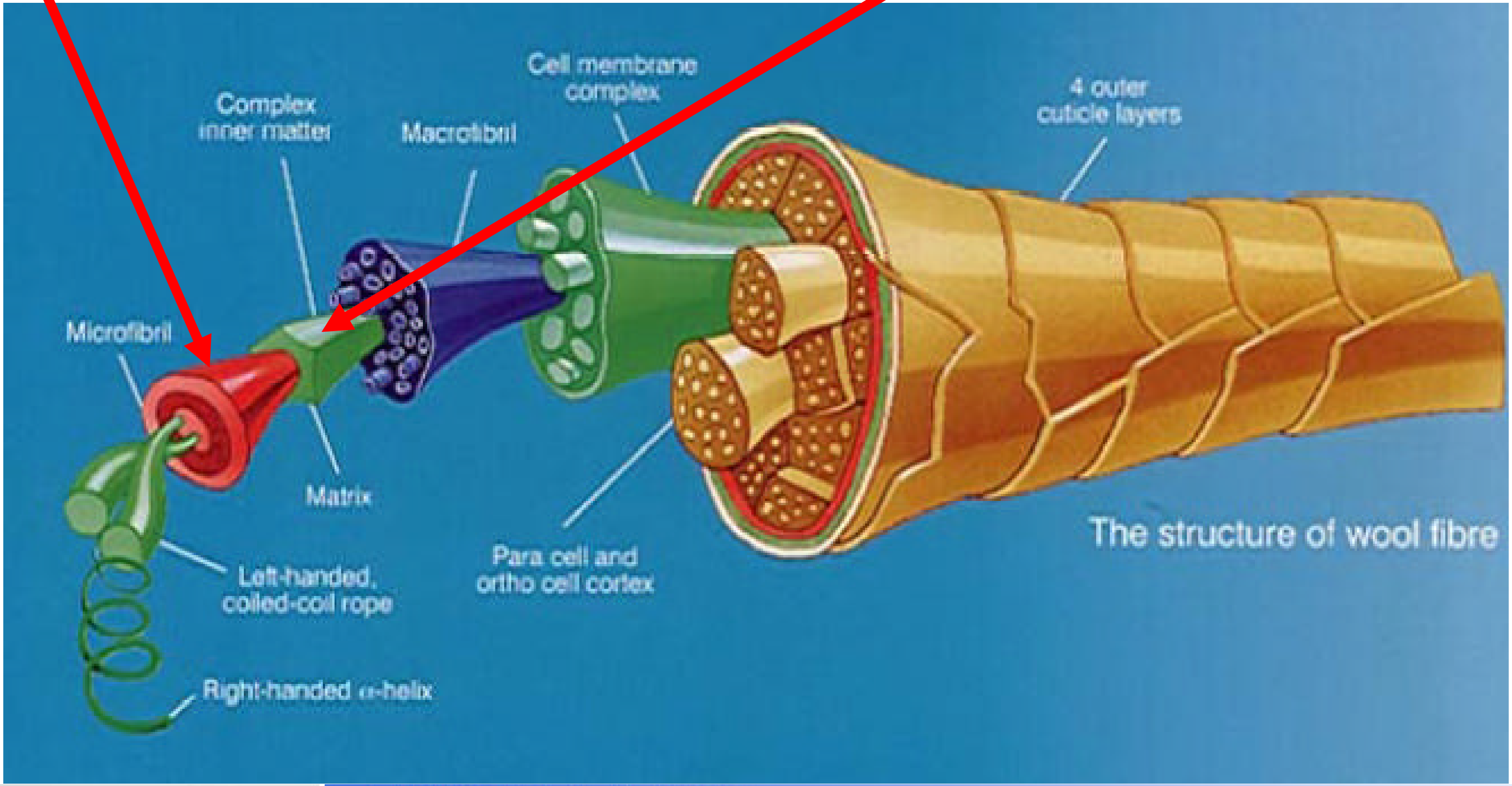
Common structural features of textile fibres

- The long polymer molecules in textile fibres are bonded together mainly via “weak” forces which may include ionic bonds, hydrogen bonds and van der Waals forces.
- Unlike many synthetic polymers, wool also contains strong bonds (crosslinks) between the polymer chains which restrict their mobility.
- The crystalline regions stiffen the fibres and provide strength.
- In the matrix regions, there are relatively fewer weak bonds between the polymer chains and the random distribution of the chains is responsible for the elasticity and flexibility of the fibre.
- The setting behaviour is largely a property of the matrix regions.

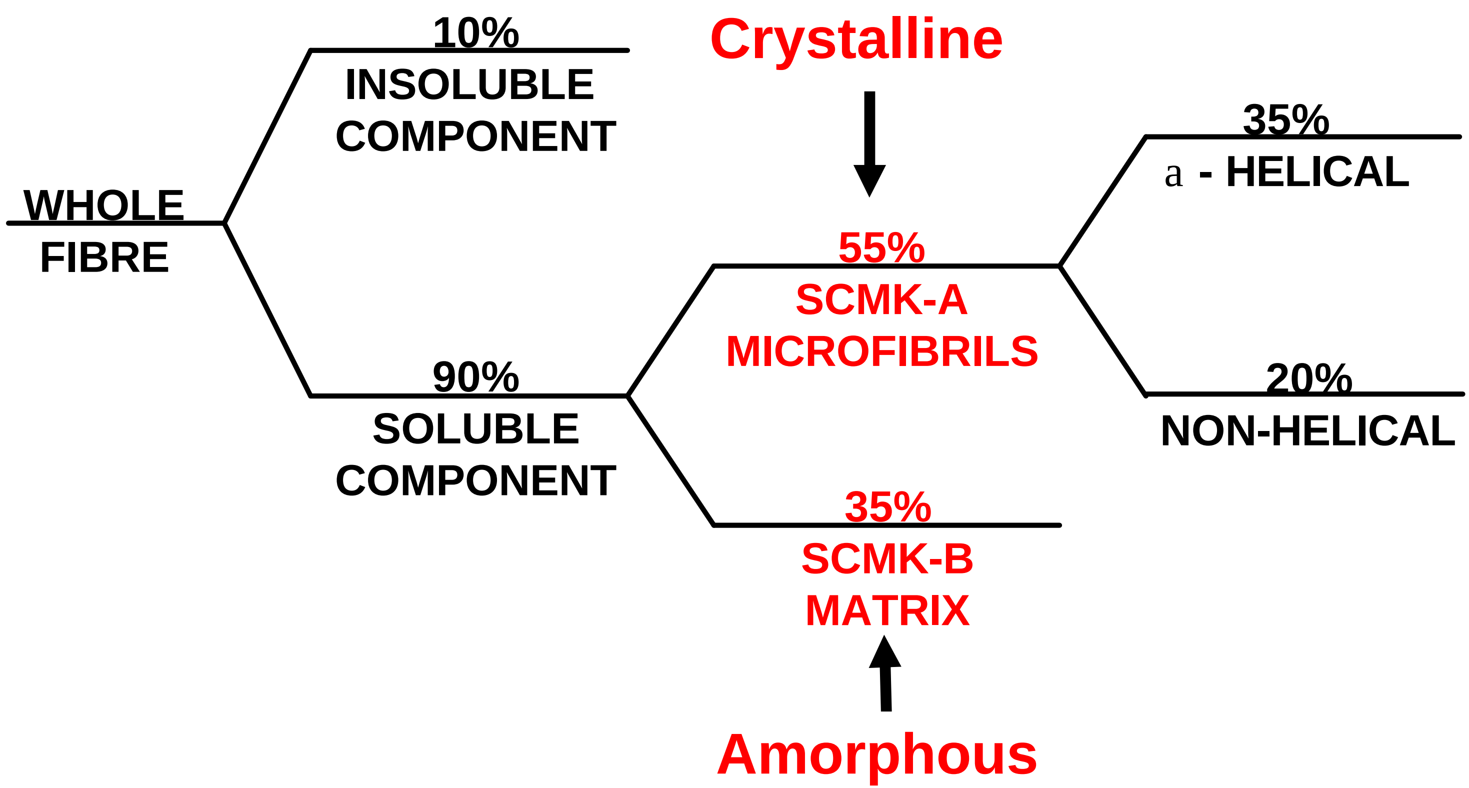
Wool fibre structure

Chrystalline protein

Amorphous matrix protein

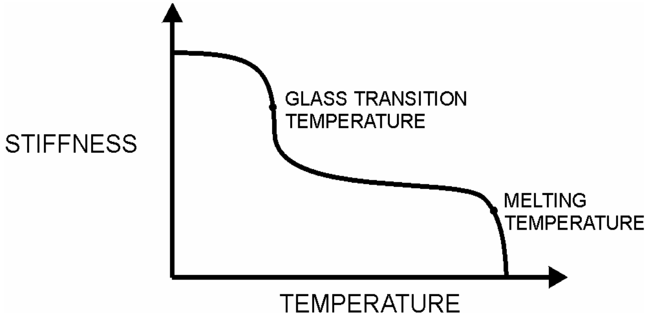


Composition of a wool fibre



The glass transition temperature of a synthetic polymer

- Synthetic polymers do not have a sharp melting point but they have two softening points that can be seen if the stiffness of a fibre is measured as a function of temperature.



- The first softening point, at the lower temperature corresponds to “melting” of the matrix polymer and is called the “glass transition temperature”. It is often given the symbol Tg.

- The second decrease in stiffness at higher temperature corresponds to melting of the crystalline regions in the fibre and can be called the “melting temperature”.

Thermal properties of dry textile fibres

Fibre	Glass Transition Temperature (°C)	Melting Temperature (°C)
Wool	160	decomposes
Acetate	184	260
Triacetate	250	290
Nylon	170	215-265
Polyester	230-255	250-280
Acrylic	150	-
Spandex	175	175

Wool decomposes before it actually melts and decomposition even begins below the glass transition temperature.

Permanent setting of textile fibres

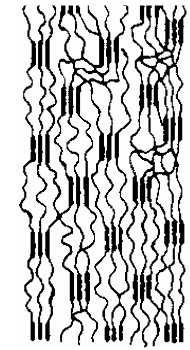
- A thermoplastic synthetic fibre is effectively permanently set (or re-set) any time the temperature is raised to around (or above) the glass transition temperature and then lowered.
- This means that fabric can be permanently flattened or creased by heat setting.
- In setting, strain is imposed on fibres by flattening, stretching or creasing of fabric which causes the build up of local stress in the fibres. The stress in the fibres is released by movement of the molecular chains when the fabric is heated above the glass transition temperature. The new molecular structure is frozen when the fabric is cooled to room temperature.
- By comparison, the permanent setting of wool is much more complicated because it depends on many factors such as regain, temperature, pH, time and the presence of chemicals such as oxidising and reducing agents.

Setting under practical conditions

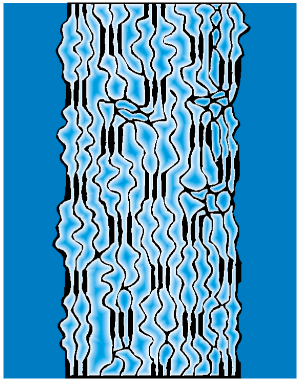
- In practice, stress relaxation during setting is never complete, because even when a polymer is above its glass transition temperature, the molecular chains are not perfectly free to move.
- Movement of the polymer chains is restricted by the bulk of the polymer crystals, which causes friction between the chains, and by the presence of any chemical crosslinks.
- Rearrangement of the chains also takes time because polymers are viscoelastic.
- Therefore, a proportion of any stress imposed while setting is taking place is usually retained. In other words, the degree of setting is almost always less than 100%, but set levels can be higher than 85%.

Special structural features of wool

- In wool (and cotton), the matrix regions are readily swollen (plasticised) by water.
- This results in weakening of the inter-molecular interactions between the polymer chains because of hydration of the ionic and polar groups.
- This causes the molecular chains in the water-swollen matrix to move further apart than in the dry fibre, but the extent of swelling is limited by the (disulphide) crosslinks between the polymer chains.
- Hydrophobic fibres such as polyester are not penetrated by water so their structure is unchanged when they are immersed in water.



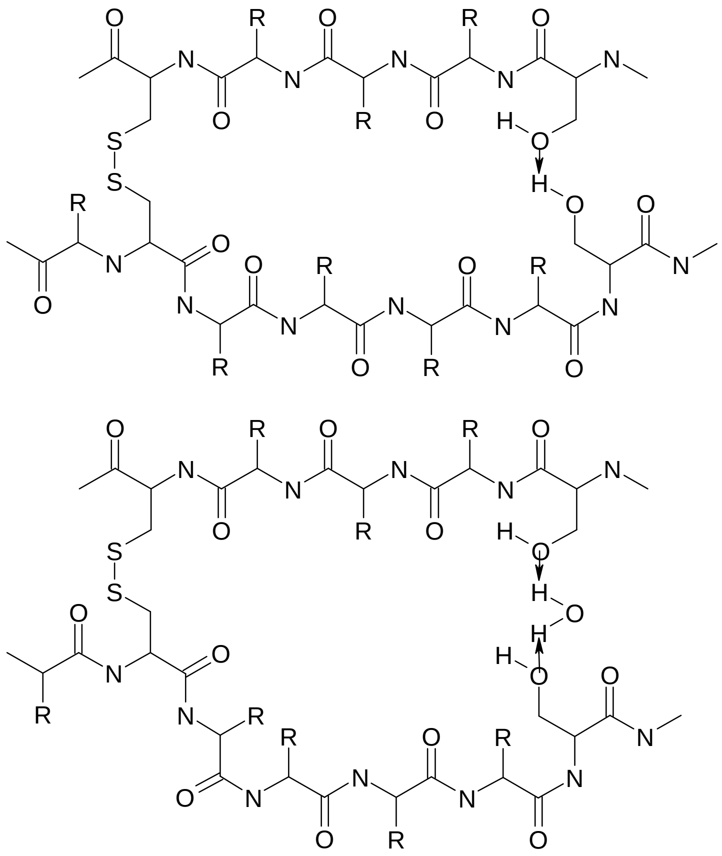
In air



In water

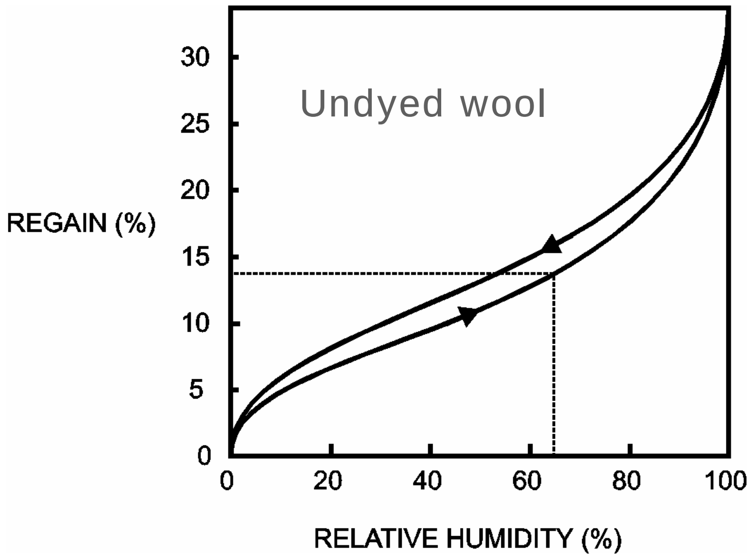
Rearrangement of hydrogen bonds

- Absorption of water causes the polypeptide chains to change shape and the fibres swell.
- Removal of water can leave the polypeptide chains in a different lower energy configuration.
- The disulphide crosslinks limit chain rearrangement.



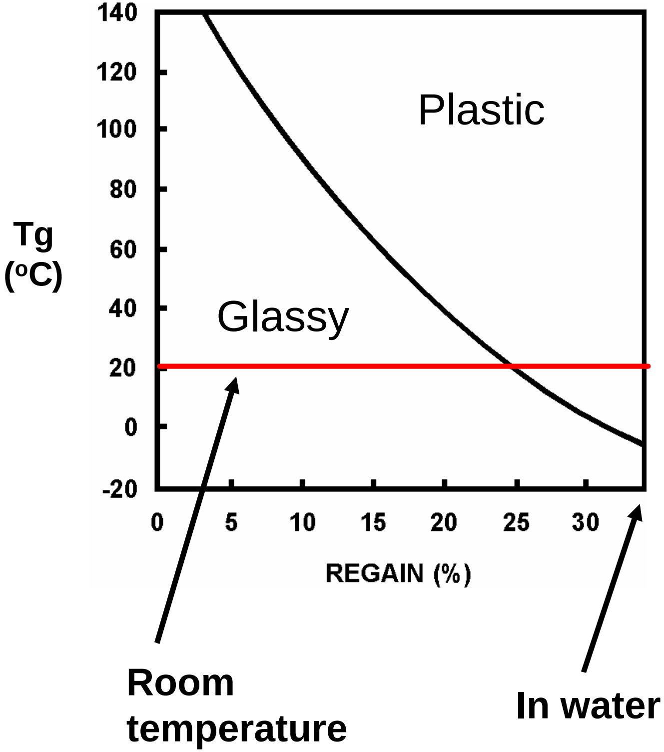
The water content (regain) of wool fibres

- At equilibrium, the regain of wool varies considerably with the relative humidity of its immediate environment.
- At any particular relative humidity, the equilibrium regain depends on the processing history of the wool (depth of dye, type of chemical treatment etc.).
- The regain also is subject to hysteresis, depending on whether the fabric is conditioned from the dry or wet state.
- During processing, wool is usually conditioned after it has been dried, so it will be assumed that the lower curve will be typical of most fabrics.
- At 20°C and 65% relative humidity it will be assumed that the regain is about 14%.



The glass transition in wool

- Because water plasticises the matrix protein in wool, **the glass transition temperature is very dependent upon regain**.
- At room temperature, wool saturated with water is above its glass transition temperature.
- At 14% regain, the glass transition temperature is in the region of 70°C.
- In practice, the glass transition occurs over a temperature range rather than at a single temperature.



Relaxed fabrics

- Wool fabrics that have no residual temporary set are referred to as ‘relaxed’.
- When a fabric is placed in conditions where the fibres can relax completely (as in wet relaxation), it will spontaneously revert to its permanently-set wet-relaxed dimensions.
- Relaxation behaviour is paradoxically the source of some of the greatest advantages of wool and of many of the problems encountered in its use.

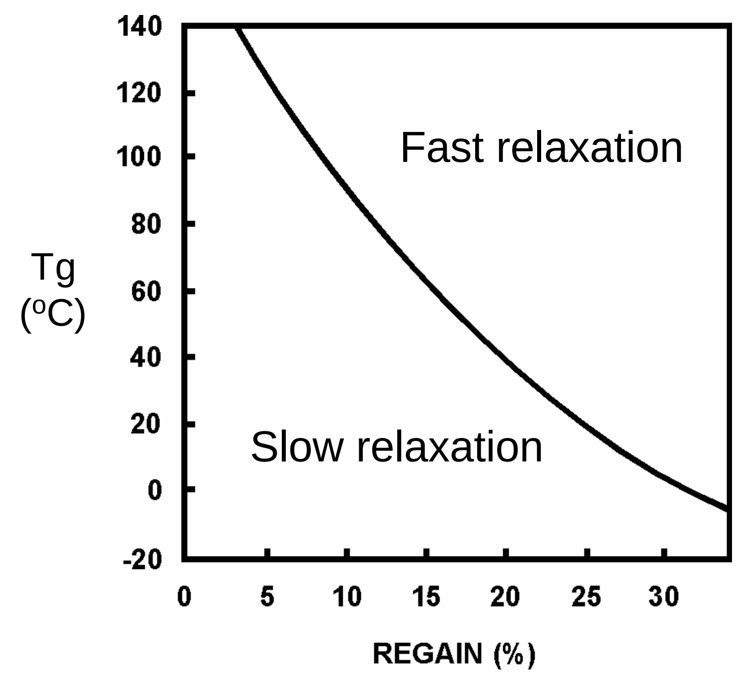
Relaxation of fabric

The loss of set by any means is called **relaxation** of the fabric.

Temporary set can be lost both below and above the glass transition temperature, at any regain.

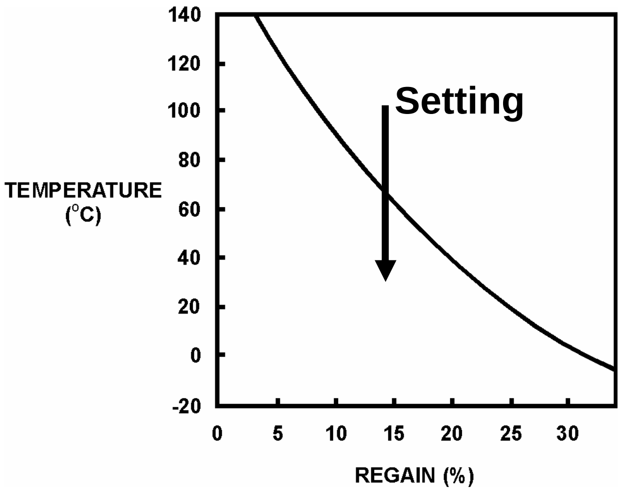
The rate of loss of set is:

- very slow below Tg
- very rapid above Tg.



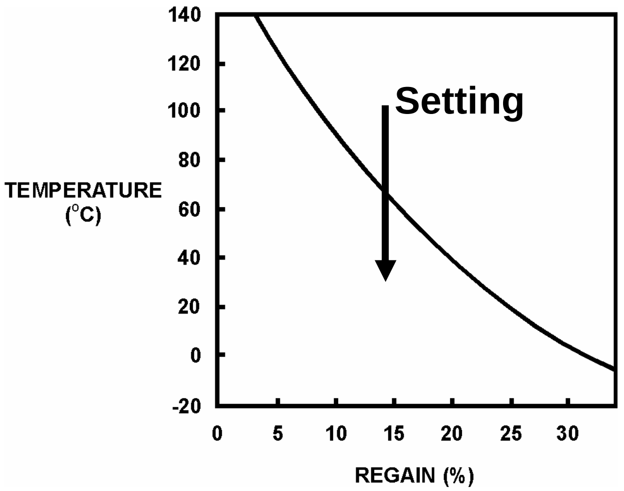
Cold shock setting of wool

- Setting occurs rapidly whenever a polymer is cooled from *above* its glass transition temperature to *below* its glass transition temperature.
- As the polymer is cooled the chains become ‘frozen’ when their mobility is suddenly reduced (within say a few seconds) and the polymer matrix becomes ‘glassy’ as the temperature drops below the glass transition temperature.



Cold shock setting of wool (cont.)

- The shape of a fibre becomes set in the configuration which existed as the fibre went through the glass transition. This is sometimes referred to as ‘cold shock’ setting.
- Set imparted in this way is removed when the fabric becomes wet and it is therefore only **temporary**.
- The low glass transition curve of wool means that it is very easily creased under ordinary conditions encountered in wear.



Setting below the glass transition temperature

- With all polymers, the glassy state is unstable. After fibres have been rapidly set by cooling from above to below the glass transition temperature, further rearrangements of the polymer chains can slowly occur in response to external and internal stresses.
- Below the glass transition temperature at any regain, setting can occur, but the rate is very slow because of the low mobility of the polypeptide chains.
- In practice, if fabric is creased or stretched at room temperature, but depending on the fibre, several, hours, days or weeks may need to pass before appreciable setting is observed.

Anealing effects in wool

- In the absence of external stress on a fabric, so-called ageing or annealing processes can occur below the glass transition temperature at any regain.
- This is due to lowering of internal stress in the fibres by the slow movement of the polypeptide chains into more closely packed (lower energy) arrangements in which they occupy less volume.
- In the case of wool at room temperature, annealing takes place over a time span of several weeks. Annealing can be speeded up in the laboratory by heating fabric at constant regain in a sealed vessel to just below the glass transition temperature, and then cooling slowly to room temperature over 12 hours.
- Typical effects of annealing in wool are the improved wrinkle recovery of fabrics that have been stored for some time and the slower rate of setting of annealed fabric. Raising a fabric above its glass transition temperature rapidly destroys annealing. Annealing is also partly reversed in wool whenever regain increases.

Relaxation shrinkage

- Relaxation shrinkage in fabric occurs when cohesive (or temporary) set is lost.
- Relaxation shrinkage is the percentage length change in the warp or weft direction that occurs when wool fabric is relaxed in water and re-conditioned.
- Shrinkage usually occurs because fabrics become temporarily set during stenter drying at dimensions greater than their relaxed dimensions at room temperature and relative humidity.

RS (%) = 100 x (conditioned dimension - wet relaxed dimension) / (conditioned dimension).

Permanent setting of wool

The chemical basis for disulphide crosslink bond rearrangement is the thiolate-disulphide exchange reaction.

$$W_1 - S_1 - S_2 - W_2 + W_3 - S_3^- \quad \text{Û} \quad W_1 - S_1^- + W_2 - S_2 - S_3 - W_3$$

$$W - SH \quad \text{Û} \quad W - S^- + H^+$$

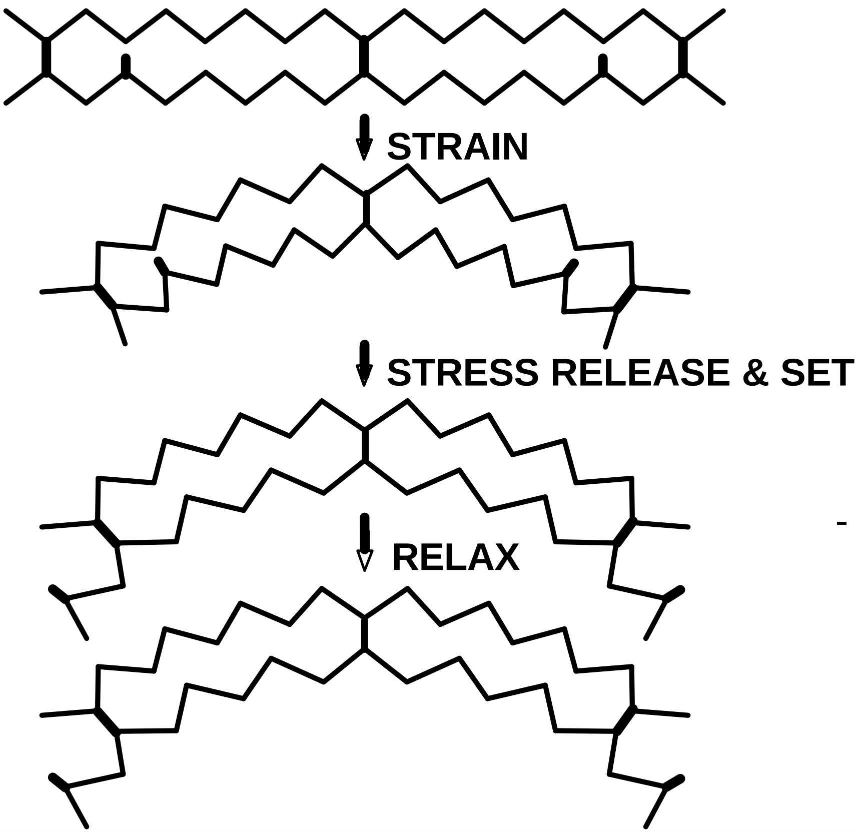
Subscripts (1-3) have been used to distinguish between different sulphur atoms and the wool polypeptide chains to which they are attached.

The thiolate/disulphide exchange reaction depends on the natural presence of small amounts of cysteine residues (W-SH) in wool.

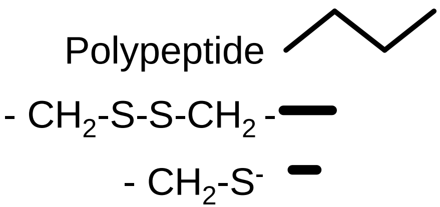
The thiolate ion concentration can vary with the previous history of the wool and the pH of the fabric.

Permanent setting can only occur if the polypeptide chains can rearrange (relax) in response to applied stress; this means that permanent setting requires the fibres to be swollen with water and the temperature must be high enough for the chains to have sufficient mobility.

Permanent setting of wool



This shows how permanent setting of bends in fibres can occur by rearrangement of disulphide bonds.



Chemical permanent setting of wool

$$W_1 - S_1 - S_2 - W_2 + W_3 - S_3^- \;\hat{U}\; W_1 - S_1^- + W_2 - S_2 - S_3 - W_3$$

$$W - S - S - W \;\overset{\text{Reduction}}{\hat{U}}\; W - SH$$

$$W - SH \;\hat{U}\; W - S^- + H^+$$

- The rate at which the disulphide bonds rearrange can be increased by chemical treatment of wool.
- Chemical permanent setting treatments all increase the rate of setting by raising the concentration of thiolate groups:
  - by reaction of the wool with reducing agents
  - by increasing the pH.
- After rearrangement of the disulphide bonds, the excess thiolate ions need to be removed by treating the wool with an oxidising agent (such as hydrogen peroxide). The pH should be lowered with acetic or formic acid.

$$W - SH \;\overset{\text{Oxidation}}{\Rightarrow}\; W - S - S - W + H_2O$$

- If oxidising agents are not used, oxidation can take place very slowly in air, but the results may not be satisfactory if the fabric is not held in its desired permanent shape while oxidation is taking place.

Chemicals for permanent setting of wool

$$W_1 - S_1 - S_2 - W_2 + W_3 - S_3^{-} \quad \hat{U} \quad W_1 - S_1^{-} + W_2 - S_2 - S_3 - W_3$$

$$W - SH \quad \hat{U} \quad W - S^{-} + H^{+}$$

- Sodium bisulphite is a commonly used chemical setting agent for wool.

$$HSO_3^{-} + W - S - S - W \Leftrightarrow W - SH + W - S\text{-}SO_3^{-}$$

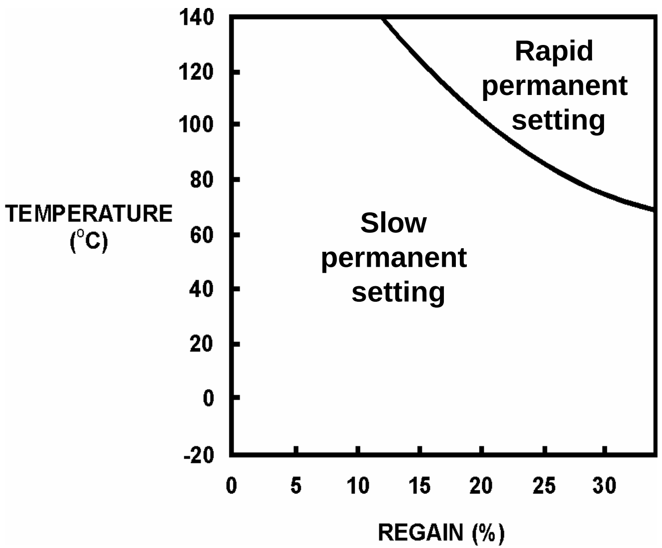
- After permanent setting, sodium bisulphite can be removed by efficient rinsing at low temperature or by treatment with a suitable oxidising agent such as hydrogen peroxide.

$$2\ W - SH + H_2O_2 \Rightarrow W - S - S - W + 2\ H_2O$$

- Siroset chemical setting products (Böhme) contain sodium monoethylamine sulphite which is an alkaline reducing agent.
- A cysteine-containing alkaline product is used for chemical crease setting treatments in Japan.

Permanent setting of wool

Under practical conditions, permanent setting is always less than 100%. This is because stress relaxation is never complete. Complete relaxation is prevented by the rigidity of the protein crystals in the matrix, the inability of some of the crosslinks in wool to rearrange (e.g. lanthionine) and the introduction of more non-labile crosslinks while disulphide bond rearrangement is taking place.

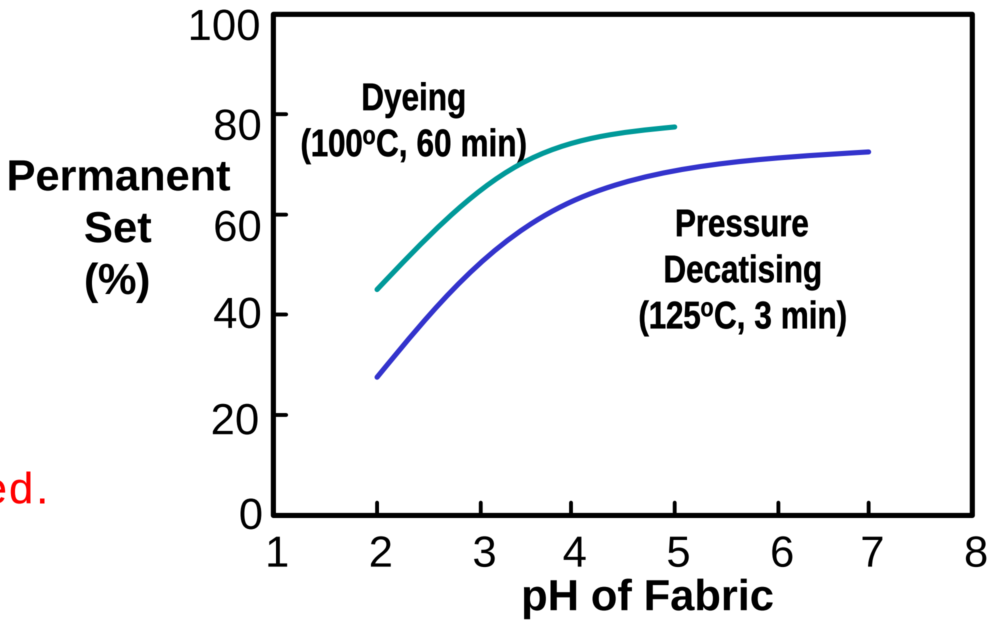


The Figure shows the approximate conditions of temperature and regain that are required to achieve 50% permanent set within 10 minutes at pH 5.5, with untreated wool. These represent approximately minimum conditions for batch treatments.

Permanent setting of wool

All these processes introduce permanent set into wool:

- crabbing
- pressure decatising
- wet decatising
- chemical setting
- dyeing.



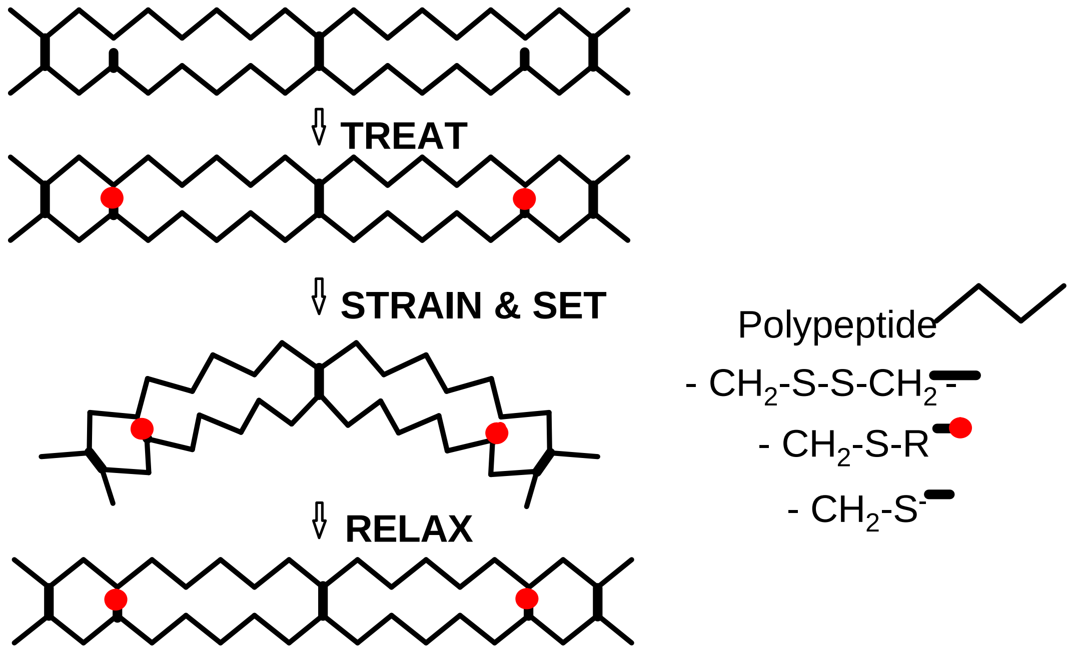
pH determines the amount of permanent set introduced.

Need to prevent unwanted permanent setting during processing

- During processing, permanent setting of distortions should be avoided whenever practicable.
- It may not be possible to completely remove permanently set faults.
- For example, running marks permanently set into fabric during scouring or piece dyeing may not be completely removed by any subsequent permanent setting processes.

Permanently set running marks seen in a jacket after it has been wet and dried.

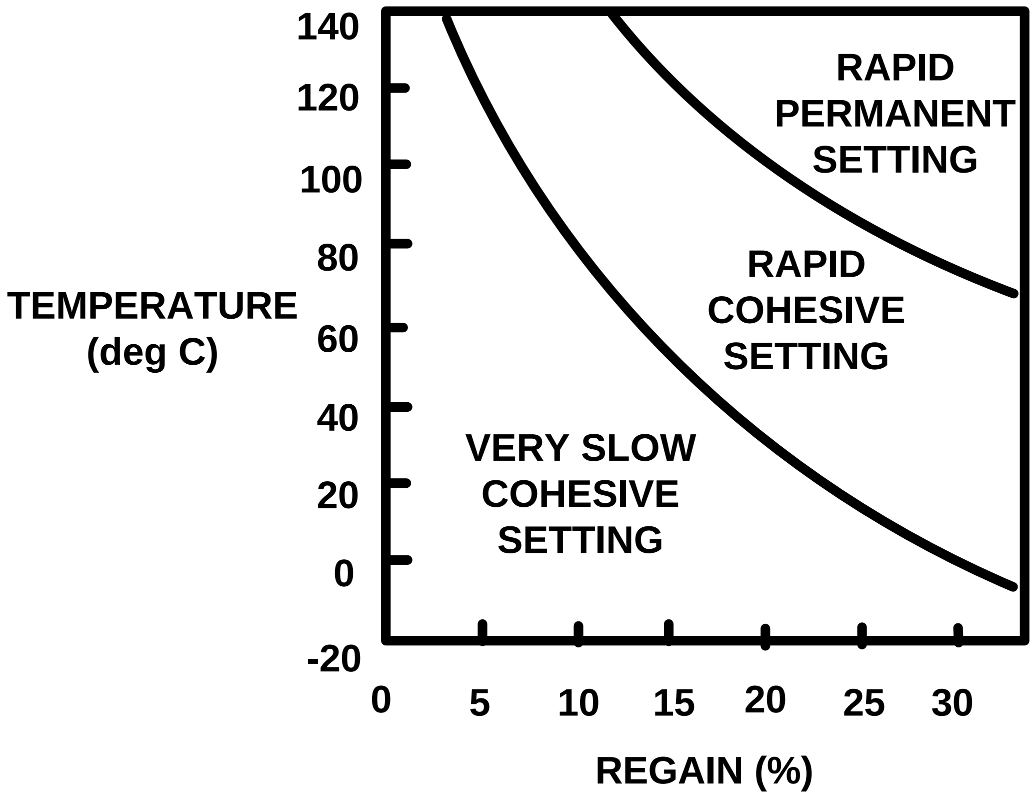
Prevention of permanent set by blocking thiolate groups



Prevention of permanent setting of fibres during dyeing will be discussed in the lectures on dyeing.

Setting of wool

The complete picture



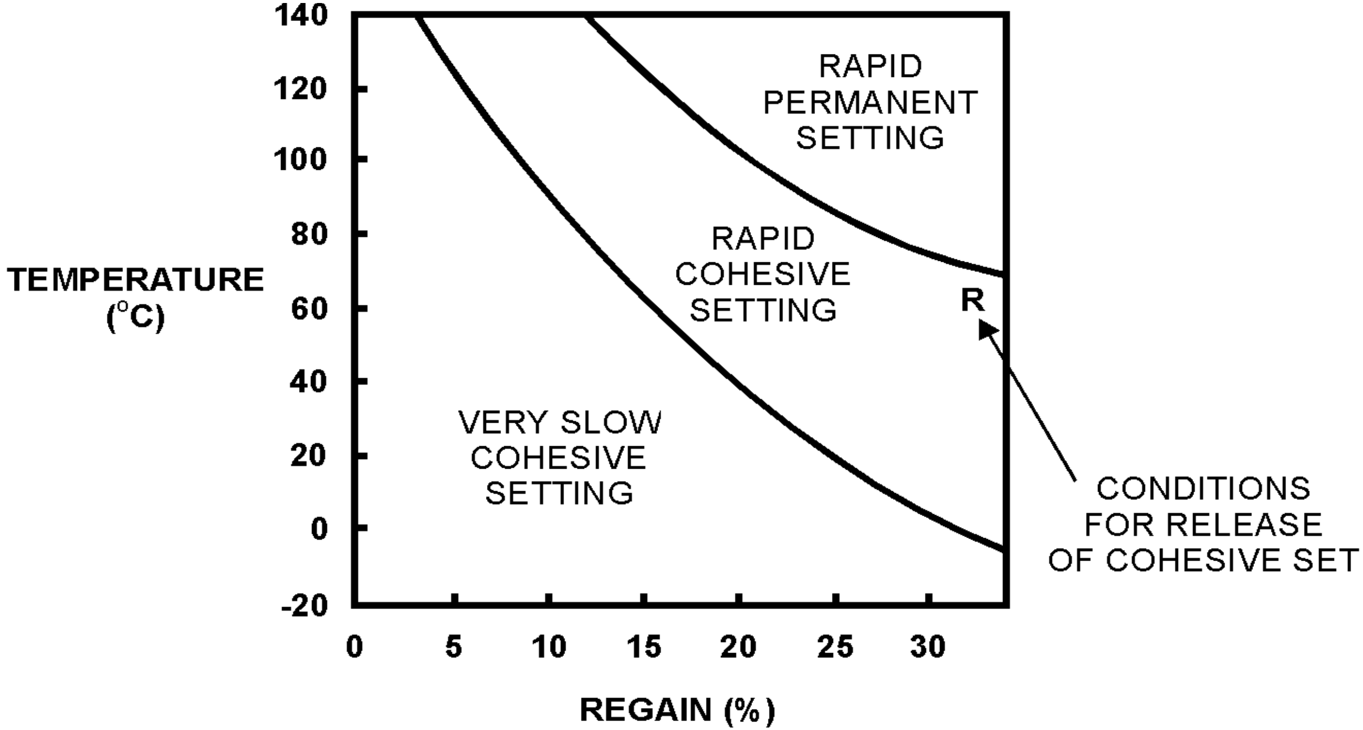
Measurement of permanent set

For practical purposes, permanent set is defined as:

***The set that is not released when wool is relaxed in water at 70ºC after 30 minutes*.**

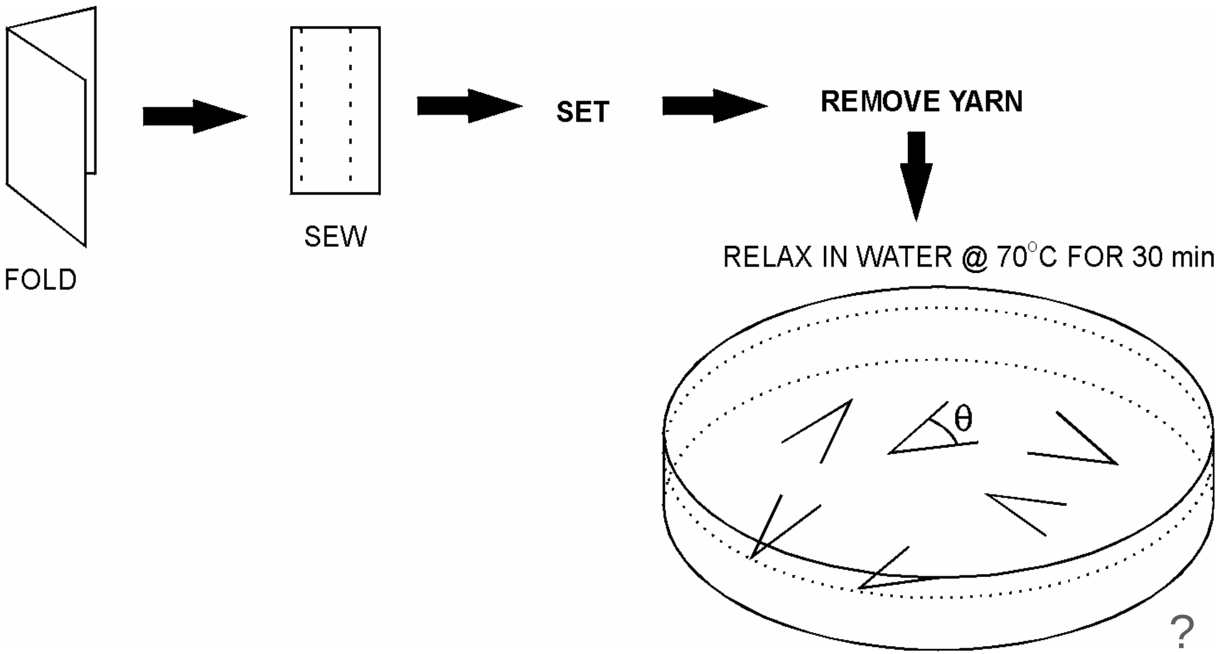
The reason for the choice of these relaxation conditions can be seen when the curves describing cohesive and permanent set are plotted on the same diagram

Conditions for release of cohesive set



Measurement of permanent set

Crease angle method



? in degrees

% Permanent Set = 100(1 - ?/180)

Hygral behaviour of fabric

Definition of hygral behaviour

- The dimensions (i.e. the length and width) of a piece of wool fabric are never permanently fixed.
- They change with the water content (regain) of the fibres which is determined by environmental factors – mainly the ambient relative humidity.
- The change in fabric dimensions with regain is called hygral behaviour.

Hygral expansion of fabric

- *Hygral expansion* is the change in dimensions of a previously relaxed fabric that occurs when the regain goes from dry to wet.
- This terminology is not always very appropriate to describe the behaviour of a fabric, as ‘expansion’ implies that the fabric always becomes larger.
- Changes in dimensions with regain are often far from linear.
- Dimensional changes due to hygral effects are reversible.

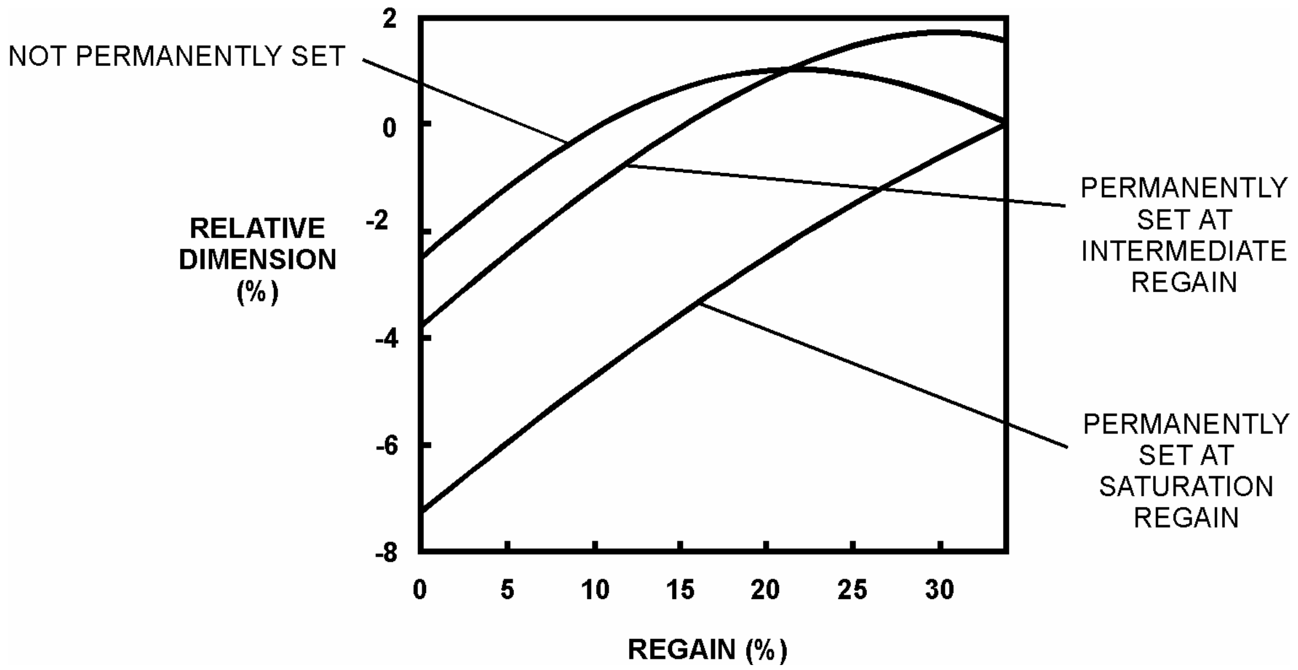
% HE = 100 x (wet relaxed dimension - dry dimension) / (dry dimension)

The relationship between permanent set and hygral expansion

- Permanent set and hygral expansion are closely related.
- This section discusses that relationship in terms of fabric, yarn and fibre mechanics, as an aid to understanding the changes to fabric properties that occur as a result of permanent setting processes.

Hygral behaviour of fabric

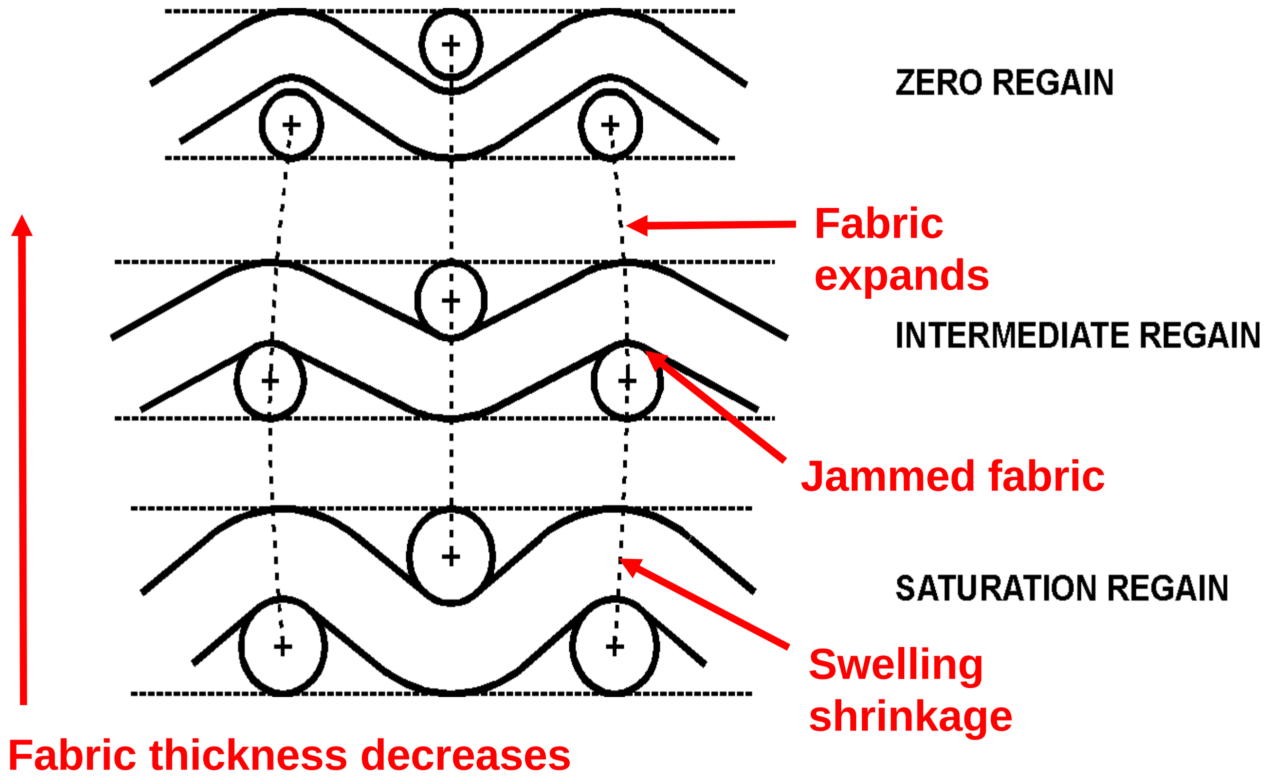
The hygral behaviour of fabric changes depending on the permanently set state of the fibres in the fabric.



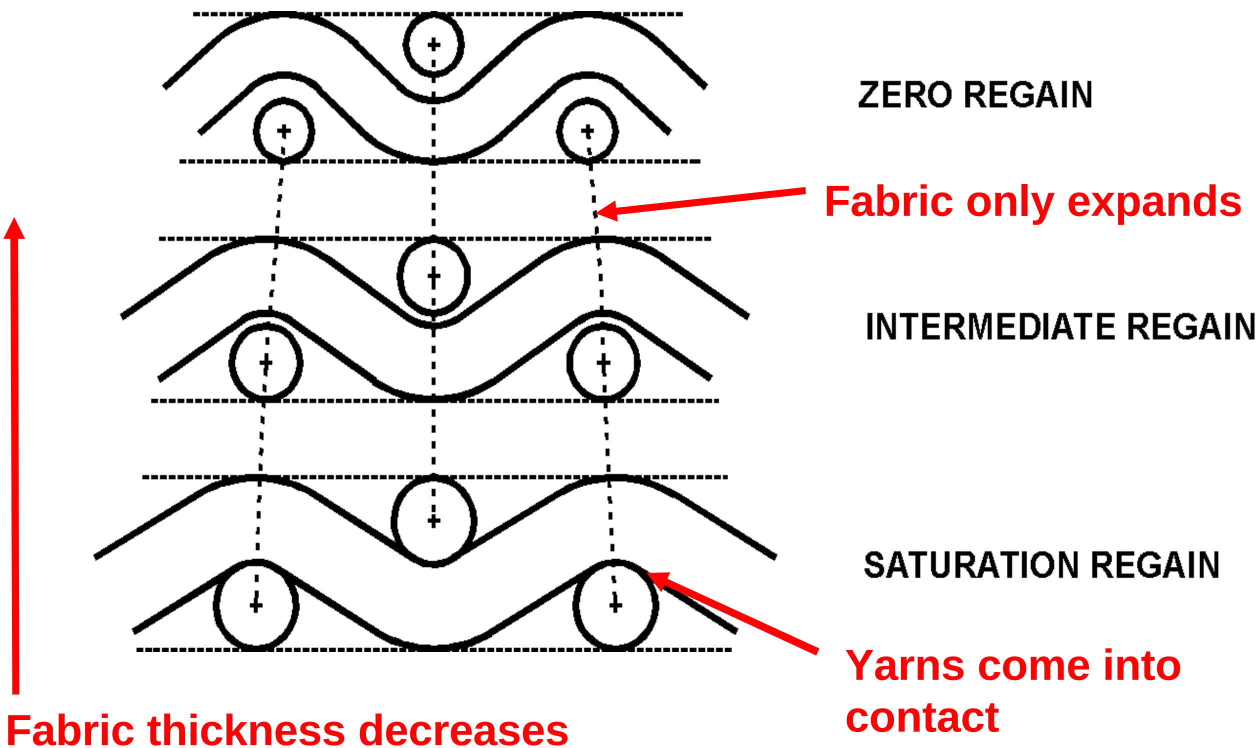
Causes of hygral behaviour of fabric

- Hygral behaviour can be explained in terms of the changes in fibre diameter and fibre curvature with regain.
- As wool fibres absorb water, they expand. In going from dry to saturated, the fibres increase about 17% in diameter but the fibre length increases by only about 1%.
- As the fibres swell, they tend to straighten and the fabric expands. The amount of free space between the yarns decreases as the regain rises. Finally if the yarns come firmly into contact, the fabric becomes “jammed” because there is no free space left between the yarns.
- After the yarns have come into contact, further fibre swelling can only be accommodated if the fabric thickness increases and the dimensions contract. This is called “fabric swelling shrinkage”.
- In worsted yarns, fibres can be considered to be largely in parallel and in contact, so the yarns in a fabric behave in much the same way as the fibres.

Schematic representation of an unset fabric at three different regains



Schematic representation of a fabric at different regains, that has been permanently set at saturation regain



Fabric which has been permanently set at saturation regain

- In this case, the only regain at which the yarns are approximately in contact is at saturation.
- As the regain decreases below saturation, the free space between the yarns increases, but the fabric thickness is reduced only slightly.
- This allows the fabric to contract as the curvature of the yarns increases with decreasing regain.
- The increase in the measured value of hygral expansion (dry to wet) is actually due to increased contraction of the fabric during drying.

Temporary and permanent setting in finishing processes

Setting in finishing processes

- In the following sections, various setting processes are discussed in terms of the chemical and physical processes involved.
- Diagrams of temperature and regain are used to show how changes in these parameters affect the type of set introduced.
- Changes in dimensional properties are illustrated by diagrams of dimensions as a function of regain.

Summary of how re-setting of fibres occurs

- **Temporary set**

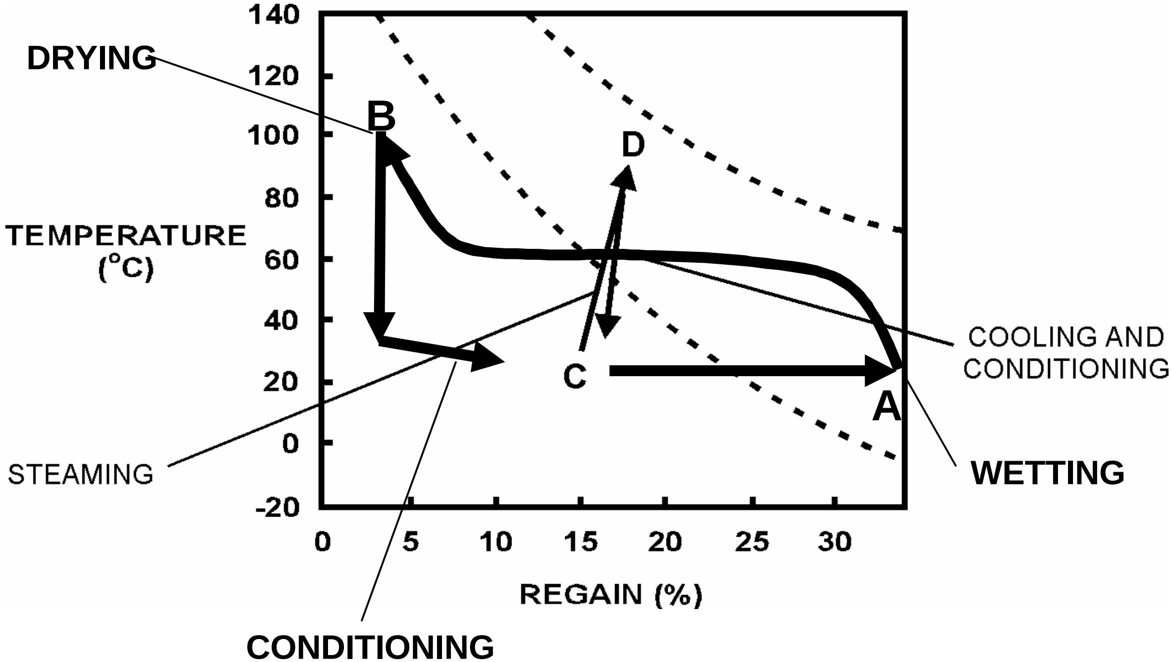
  Hydrogen bonds have low energy and can be rearranged whenever the fibre becomes wet, even at room temperature. By wetting and drying, the shapes of fibres can be temporarily set but this set is lost when the fibres again become wet.

- **Permanent set**

  Disulphide bonds have high energy, and changes in fibre shape can only take place by rearrangement of these covalent bonds by chemical treatments carried out at relatively high temperatures.

Fabric relaxation

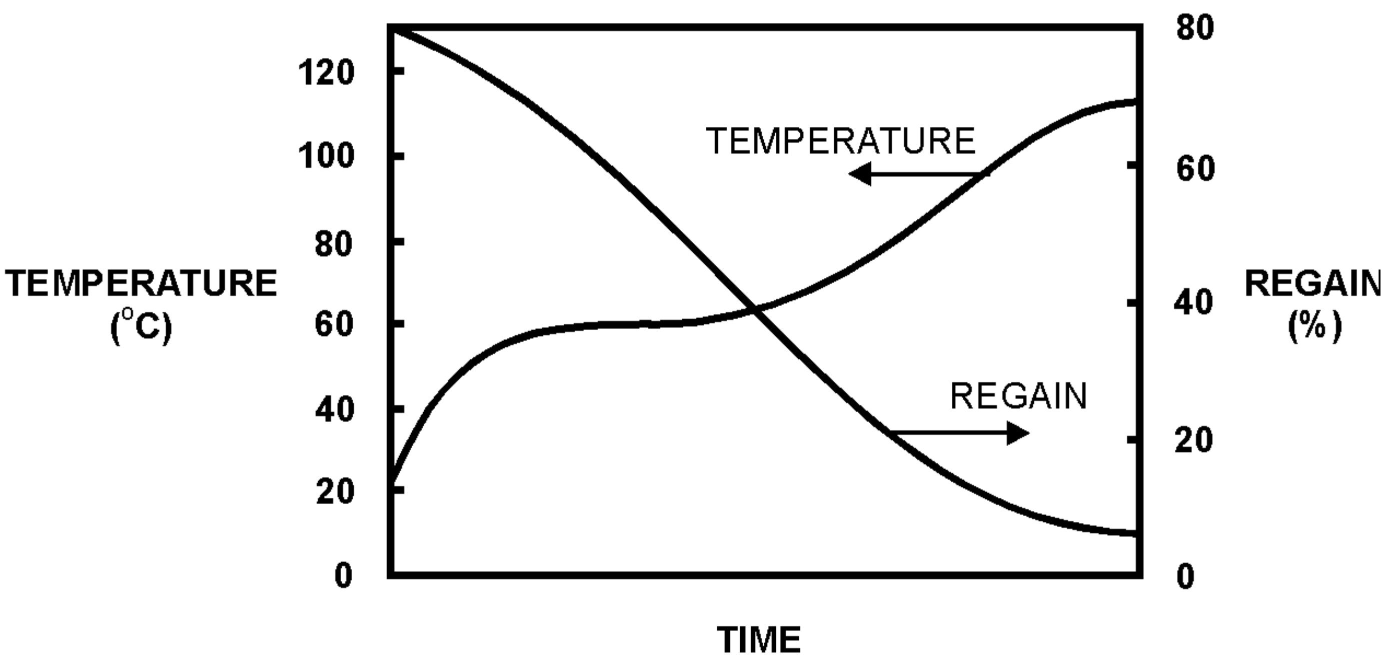
By steaming C-D-C and wet sponging C-A-B-C.



Several steaming cycles may be required to obtain the same effect as wet relaxation followed by drying.

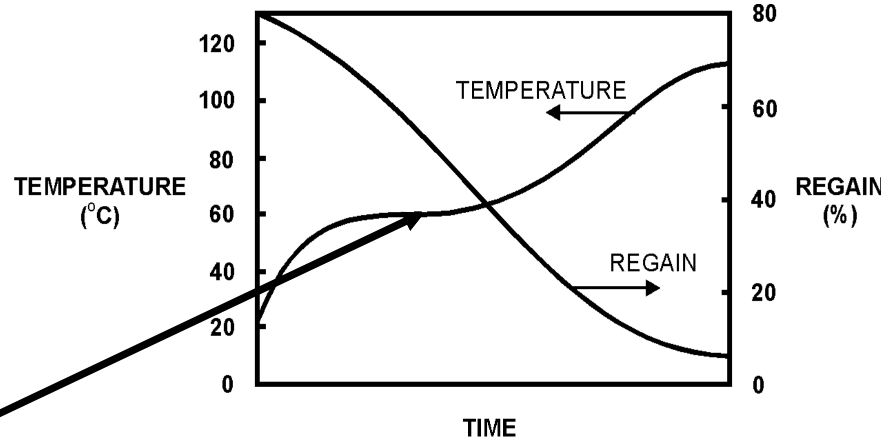
Drying of fabric

This diagram shows typical variations in fabric temperature and regain with time during drying in hot air in a stenter at around 130ºC.



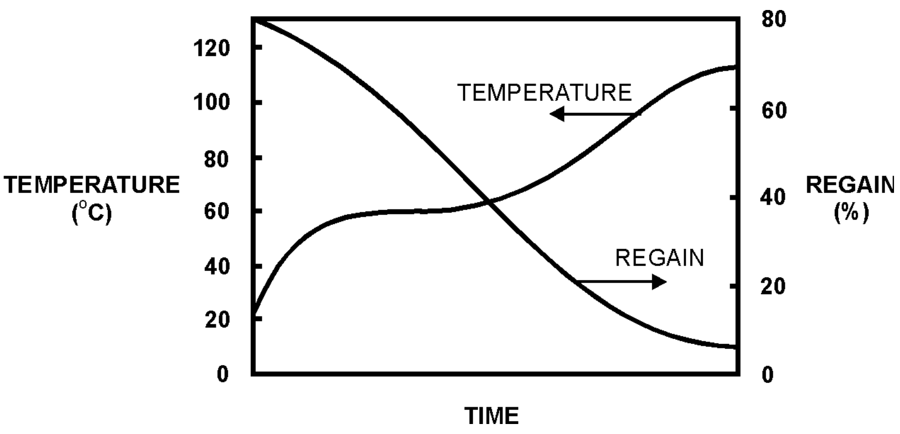
Drying of fabric

- As the fabric temperature rises during drying, water is first lost from the capillary spaces between the fibres.
- While the capillary water is evaporating, the temperature of the fabric remains relatively constant, usually between 40ºC and 60ºC.
- The actual value is determined by the operating parameters of the stenter that affect heat and mass transfer.



Drying of fabric

- When all the capillary water has been removed, absorbed water will be lost from within the fibres and the temperature of the fabric will increase.



- For optimal performance, drying should be stopped when the regain of the fibre reaches the value at the ambient temperature and regain (~14% for wool).

Control of stenters

- It has been found (Harber, Int. Dyer 147 (1972) 102) that a 9^{o}C difference between the fabric temperature and the wet bulb temperature at the fabric exit corresponded with the fabric coming to standard regain.
- Modern stenters are equipped to make these measurements and they are used to control the operation of the machine.
- Fabric regain can also be monitored using microwave detectors.

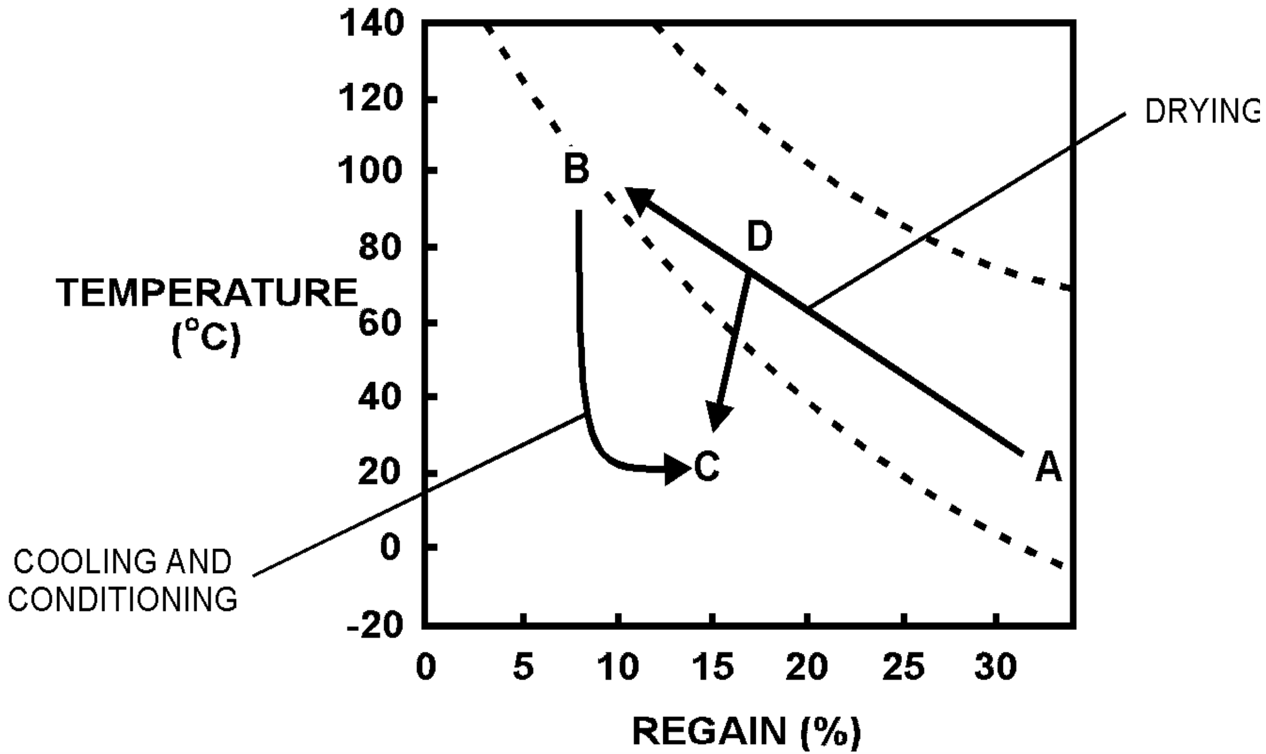
Setting during drying

Only cohesive set can be introduced into a fabric during stenter drying.

- Stenter drying can only influence the **relaxation shrinkage** of a fabric.
- The **wet relaxed dimensions** of a fabric **remain** substantially **unchanged**.
- The **hygral expansion** of the fabric **is not altered.**

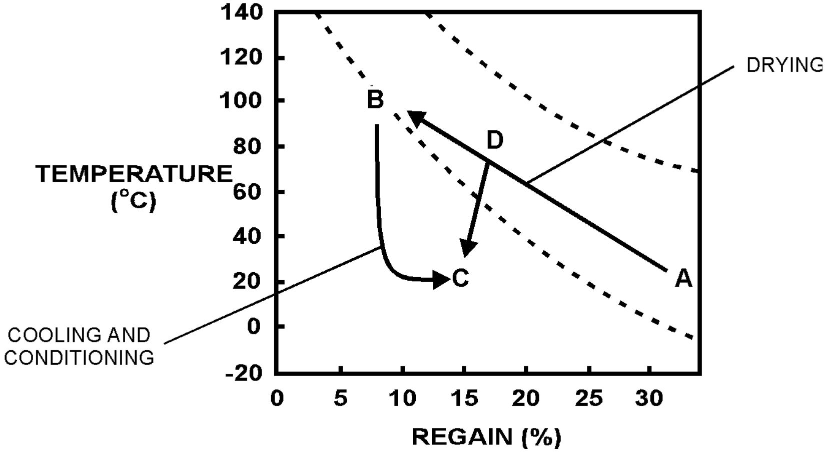
Fabric temperature and regain changes during drying of wool

This figure illustrates typical changes in temperature and regain that may occur during drying.



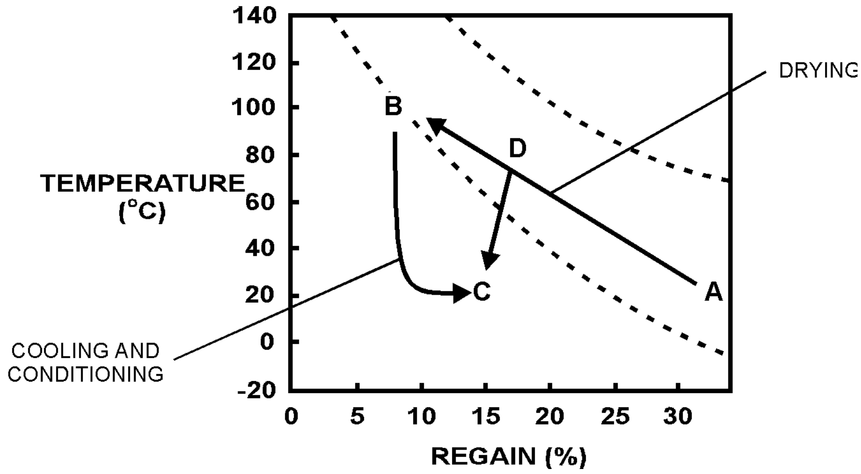
Temperature and regain changes during drying of wool

- The position of wet fabric at ambient temperature is shown at point A. As the fabric dries, the temperature increases and regain falls until the fabric exits from the heating bays of the stenter (at point D or B), after which the fabric cools and conditions to point C.
- For optimal drying, the fabric should emerge from the stenter when it has reached 14% regain (D). At this point it would be above its glass transition temperature.
- For controlled cohesive setting of the fabric dimensions to take place, it is necessary for the fabric to be cooled to below about 60ºC before removal from the stenter pins.

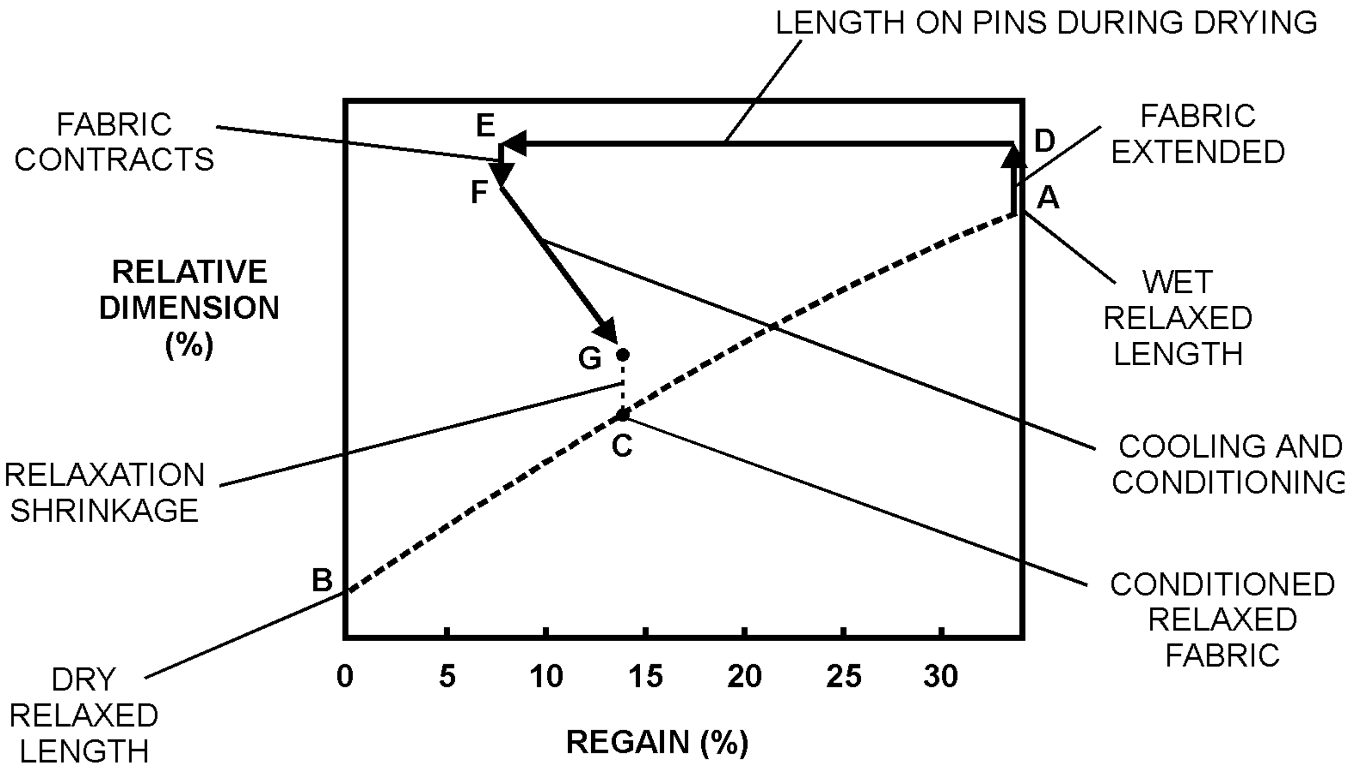


Temperature and regain changes during drying of wool

- Cooling on the pins is often assisted by blowing or sucking ambient air through the fabric or by the use of cold rollers. If fabric is above the glass transition temperature when it is removed from the pins, it will become cohesively set while its dimensions are relatively uncontrolled, during cuttling or rolling up.
- In practice, wool fabric is almost always over-dried, with the regain being reduced to between 2% and 8%, in an attempt to ensure that no wet patches are left in fabric.
- At a regain of 8% (B) or lower, wool at 100^{o}C is below its glass transition temperature. Under these conditions, fabric will be cohesively set in the heating zone of the stenter.

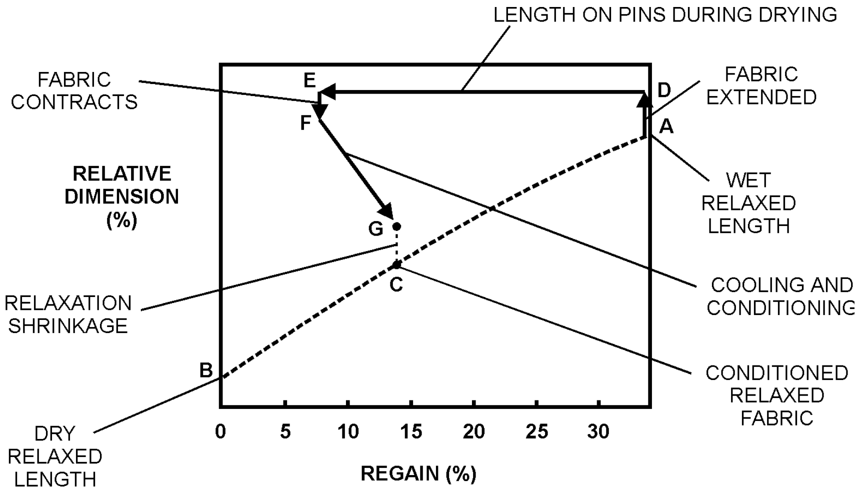


The change in dimensions of a stretched fabric with regain during drying

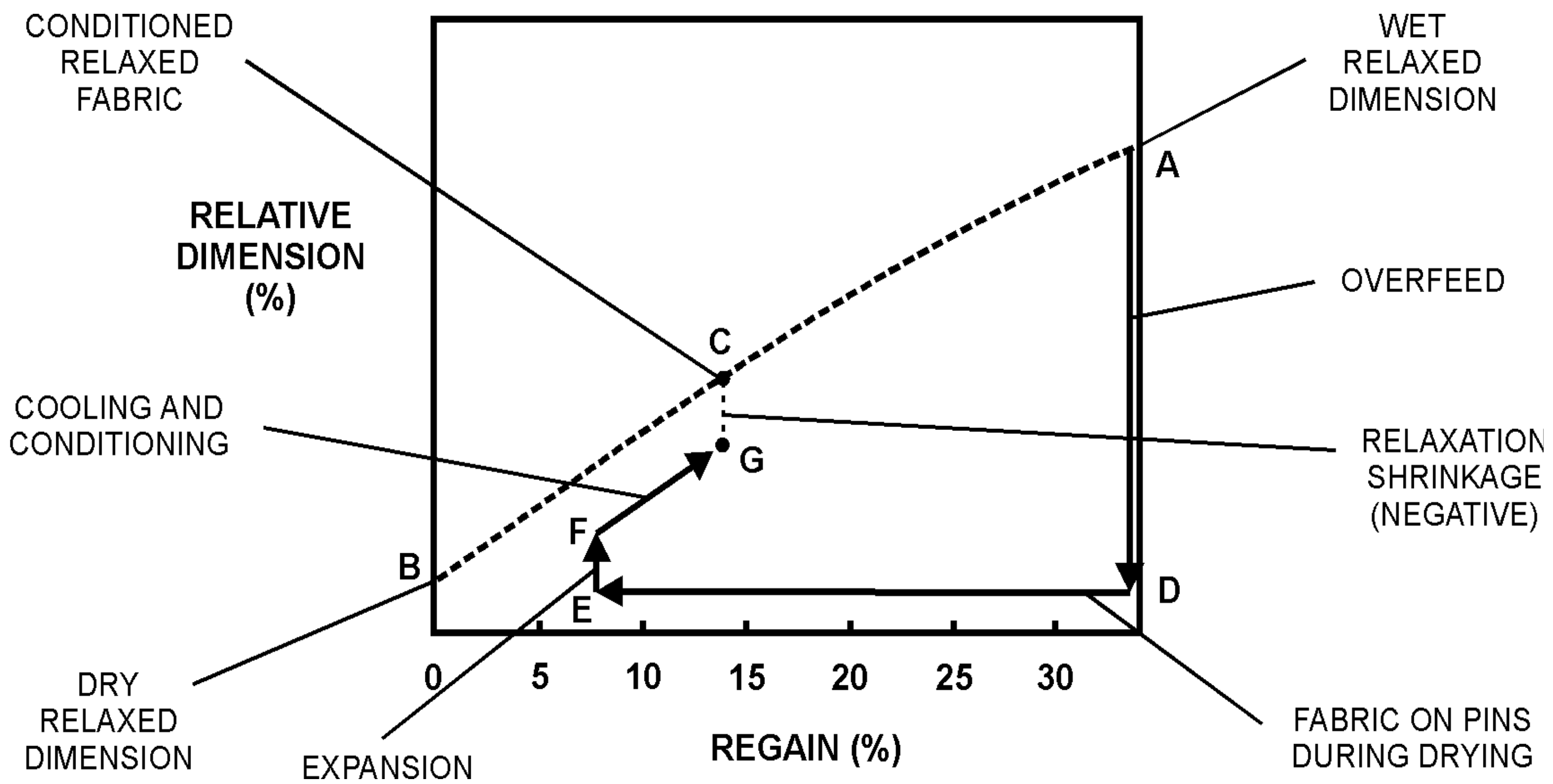


How relaxation shrinkage is introduced into fabric during stenter drying

- Wet fabric is usually stretched slightly in the weft direction (to assist in keeping it on the pins).
- The fabric may be either stretched or overfed in the warp direction.
- Once the regain of the wool falls below its saturation value, the fabric will try to contract due to hygral effects and the resulting strains add to the strains already introduced if the fabric was stretched as it was put onto the stenter pins.
- This results in the introduction of relaxation shrinkage as the fabric dries and this is only partially removed by relaxation as the fabric cools.



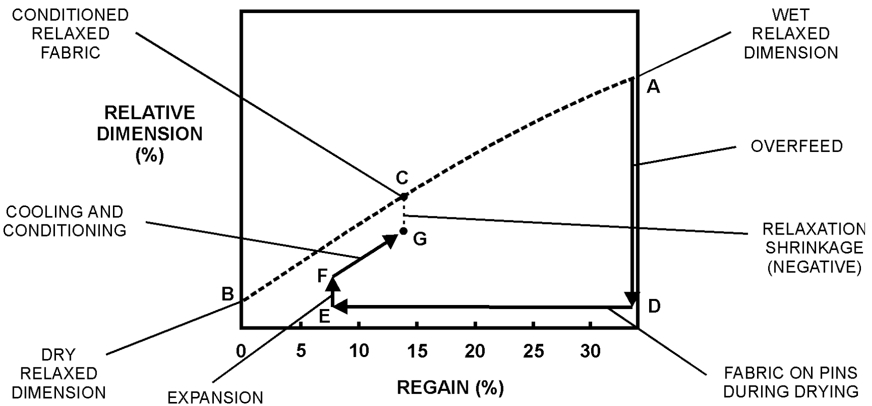
Dimensional changes when fabric is stenter dried with overfeed



Overfeed in the stenter

This is used to reduce relaxation shrinkage in the warp but it can also produce negative values of RS.

- Wet fabric (at point A) is overfed onto stenter pins, its new length is given by the dimension at D.
- In this example, after drying in the heating bays of the stenter (point E), the fabric is still at less than its relaxed length.
- When the fabric is removed from the stenter pins, it may immediately relax to a slightly greater length (point F).
- During conditioning to 14% regain, it may again increase in length, depending on the way the fabric is restrained but the relaxation shrinkage could be negative and is determined by the difference between the fabric dimension at G and the corresponding relaxed dimension shown at C.



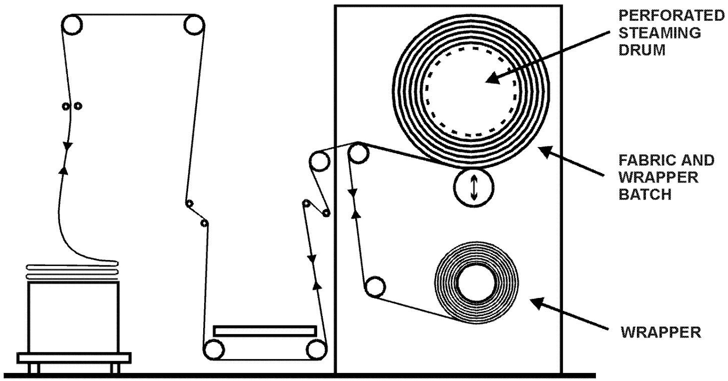
Summary of the effects of drying

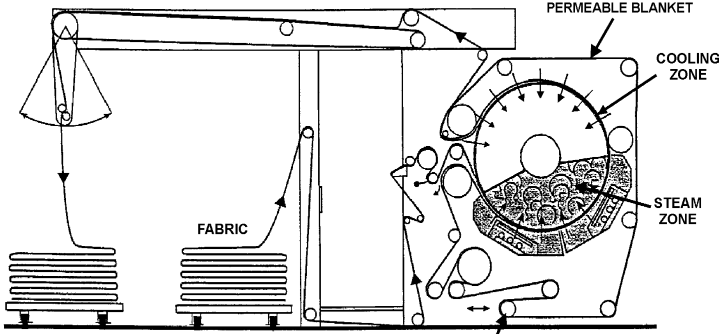
- The relaxation shrinkage introduced during drying in any particular practical situation is difficult to predict because it depends on a number of parameters:
  - the weft extension and warp overfeed of the wet fabric on the stenter pins
  - the regain at which drying ceases
  - the cooling of the fabric
  - the relaxation of the fabric as it comes off the stenter pins
  - the relaxation of the fabric as it conditions after drying
  - the hygral behaviour of the fabric.
- In practice, stenter settings (of width and underfeed/overfeed) required to obtain desired values of relaxation shrinkage, are usually found by trial and error.
- Machine settings may not give an accurate value for extension or overfeed in the warp direction, since fabric often can be inadvertently stretched as it is fed to the stenter.

Atmospheric decatising

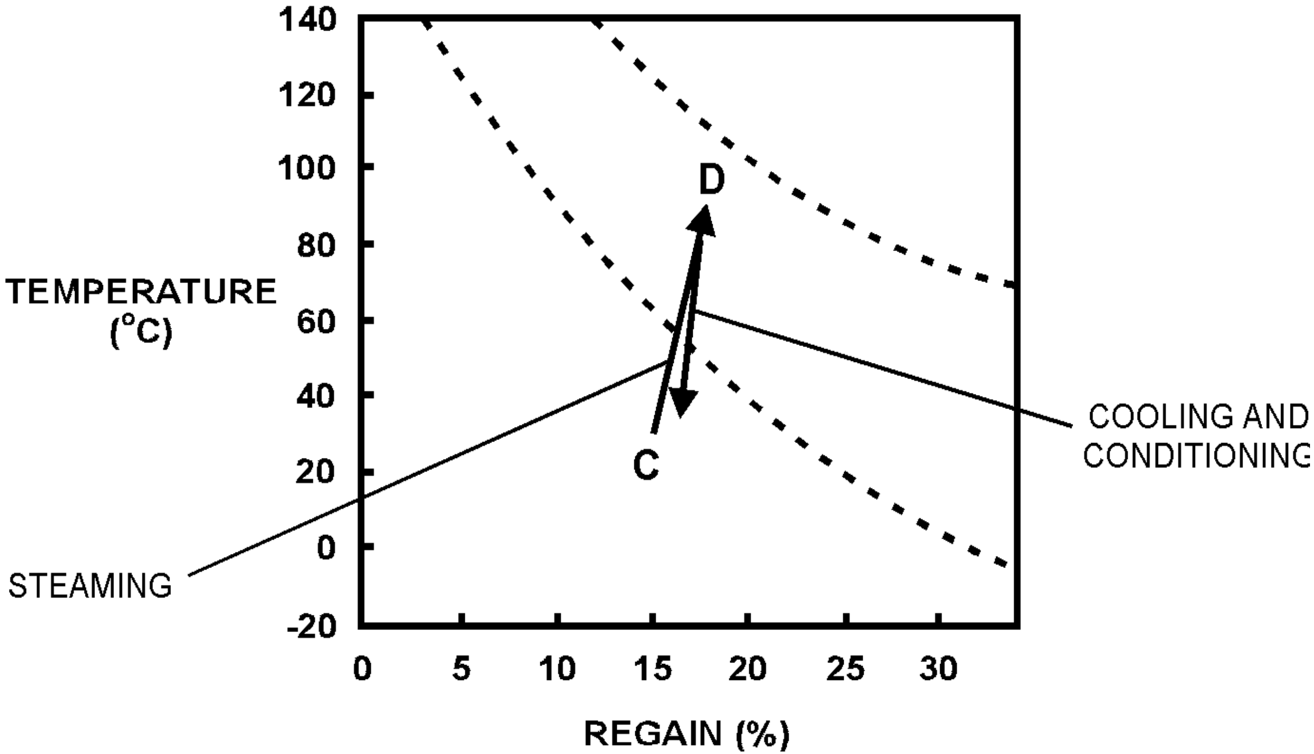
The main purpose of atmospheric decatising is to cohesively set fabric flat.

The dimensions of the fabric are kept constant because the fabric is interleaved with a tightly rolled up wrapper or held against a drum by a wrapper in continuous machines.



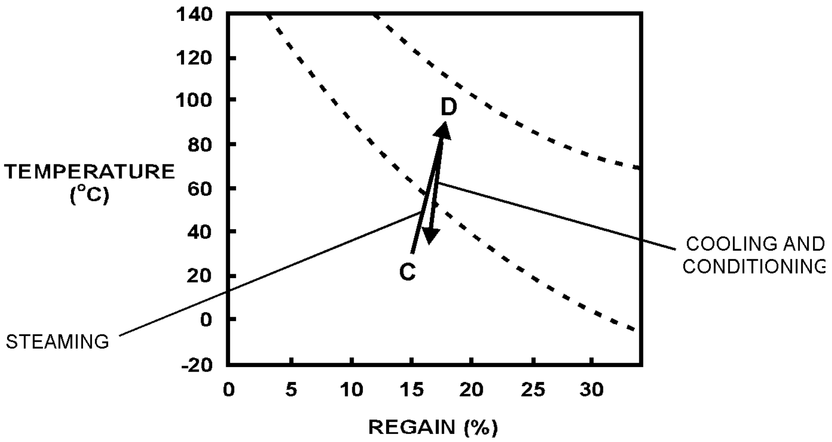


Temperature and regain changes in atmospheric decatising and steam framing



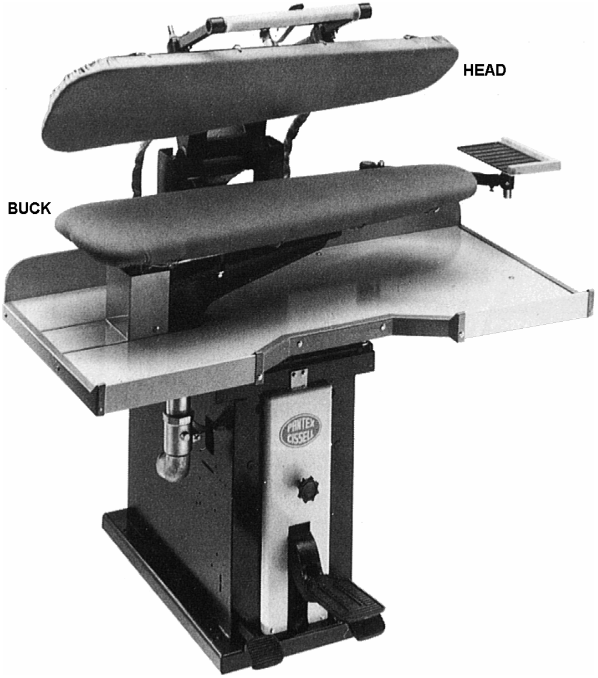
Cohesive setting during atmospheric decatising

- When fabric at 20°C and 14% regain (point C) is heated with steam to 100°C for up to a minute while being held firmly with a wrapper.
- Condensation of steam during heating of the fabric will increase the regain to about 20% (point D).
- Under these conditions, the wool is above its glass transition temperature.
- The fabric will be rapidly cohesively set when the fabric is cooled, (while still being held by the wrapper).



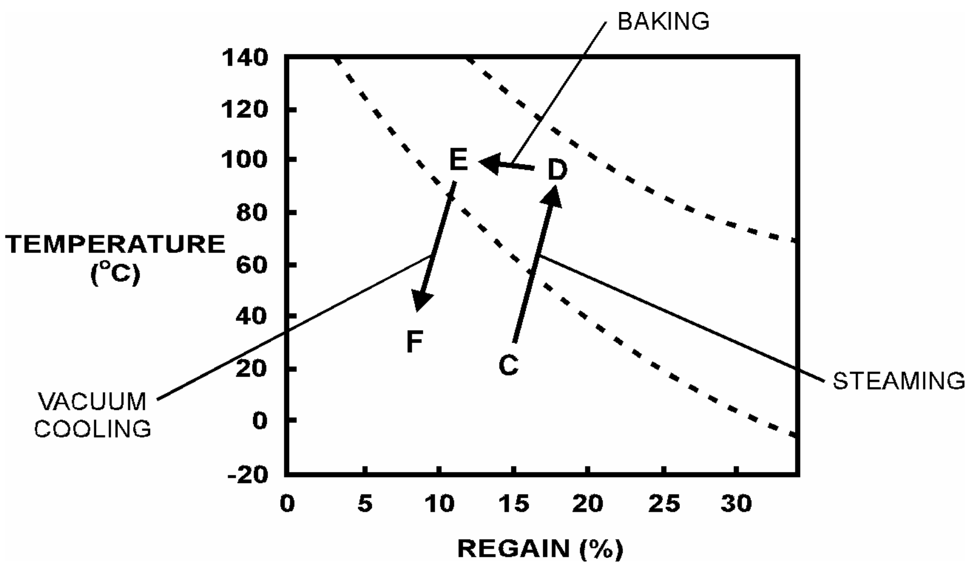
Steam pressing

- This garment setting method is carried out under similar conditions to atmospheric decatising.
- Garments are held under slight pressure between the buck and head of the press and steamed and cooled before removal from the press.



Temperature and regain changes during steam pressing

- If the steam is turned off after some time the fabric may dry to some extent.
- Only temporary set is introduced.

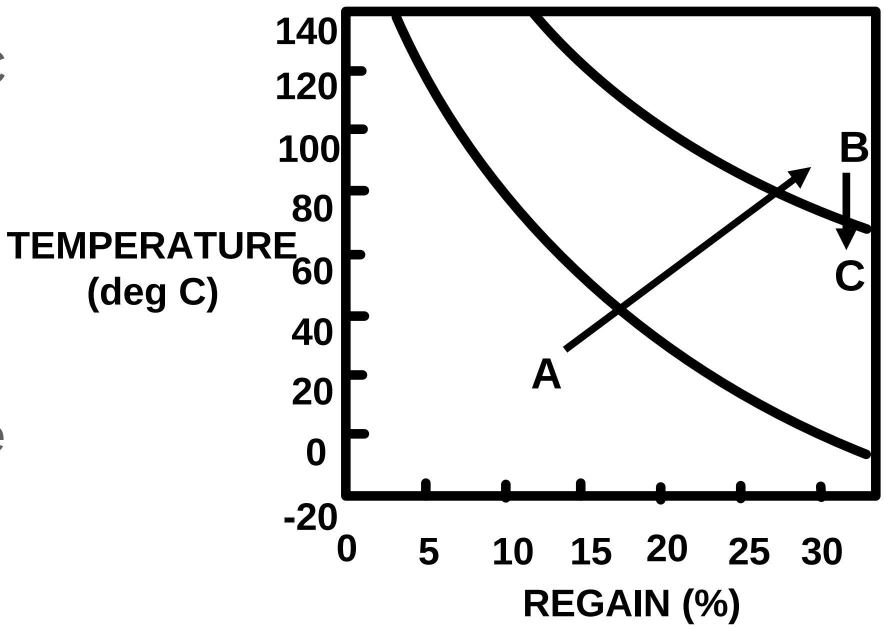


Steaming on a pin frame

- By steaming on a pin frame, the dimensions of a fabric may be changed and cohesively set with greater accuracy than in atmospheric decatising.
- As in stentering, the dimensions are controlled by feeding the fabric onto a pin frame at a predetermined width and with a desired amount of underfeed or overfeed in the warp direction.
- After framing, the fabric is heated for a short time (say between 20 and 60 seconds) using steam at atmospheric pressure and is then cooled by drawing ambient air through the fabric.

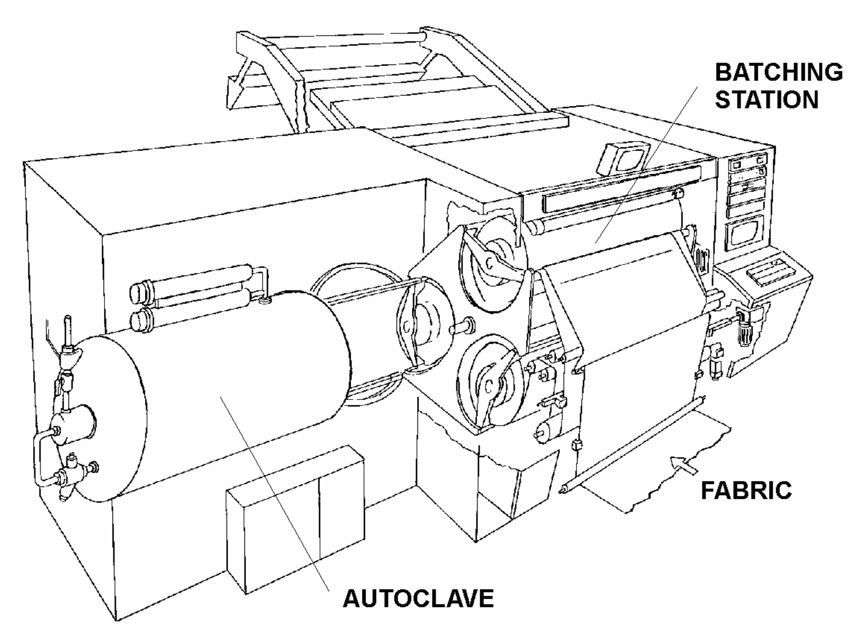
Setting during crabbing, dyeing and wet decatising

- Wool is wet out (A) and then permanently set at saturation regain (34%) in water at temperatures close to 100°C (B).
- The fabric is then usually cooled to below 70°C (C) before removal from the machine.
- Wet fabric at 100°C is above the temperature at which permanent setting occurs rapidly in water.



Pressure decatising

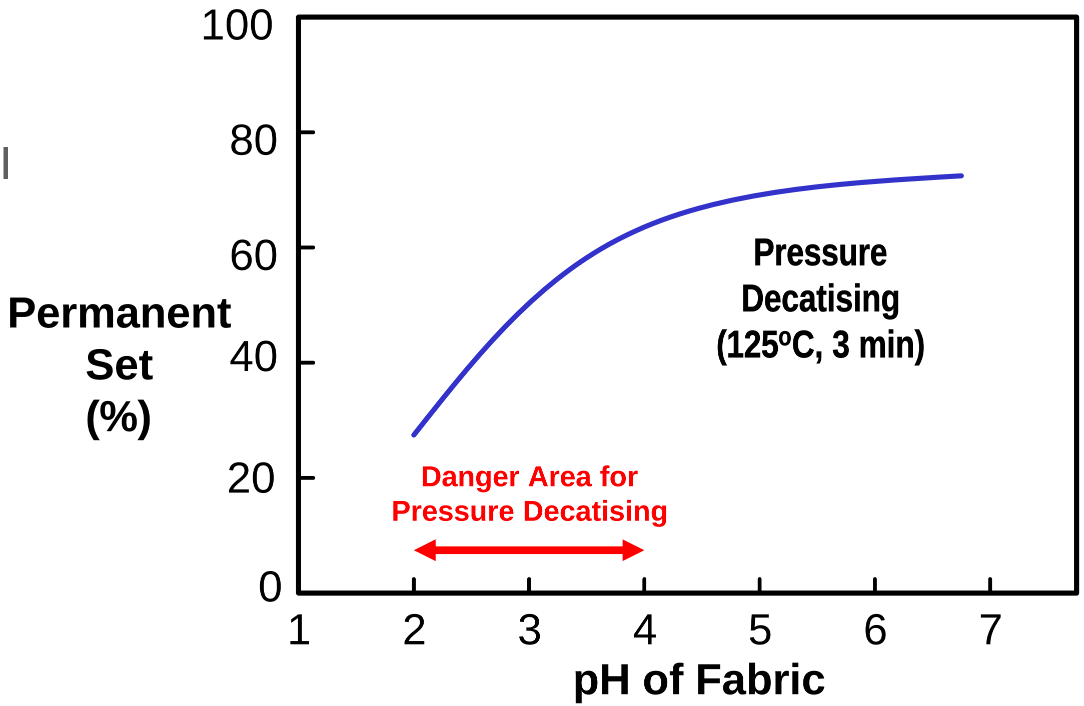
- In pressure decatising, fabric with a regain ideally greater than 14%, is interleaved with a blanket and loaded into a pressure vessel. After purging with steam to remove air, the fabric is heated in steam at temperatures between 110ºC and 130ºC for several minutes.
- The actual fabric regain and temperature depends on a number of factors that will be discussed separately under pressure decatising machinery.



Pressure decatising of wool

Fabric left in an acid condition after dyeing will have little permanent set introduced by pressure decatising.

Pressure decatising then has only a temporary pressing effect.

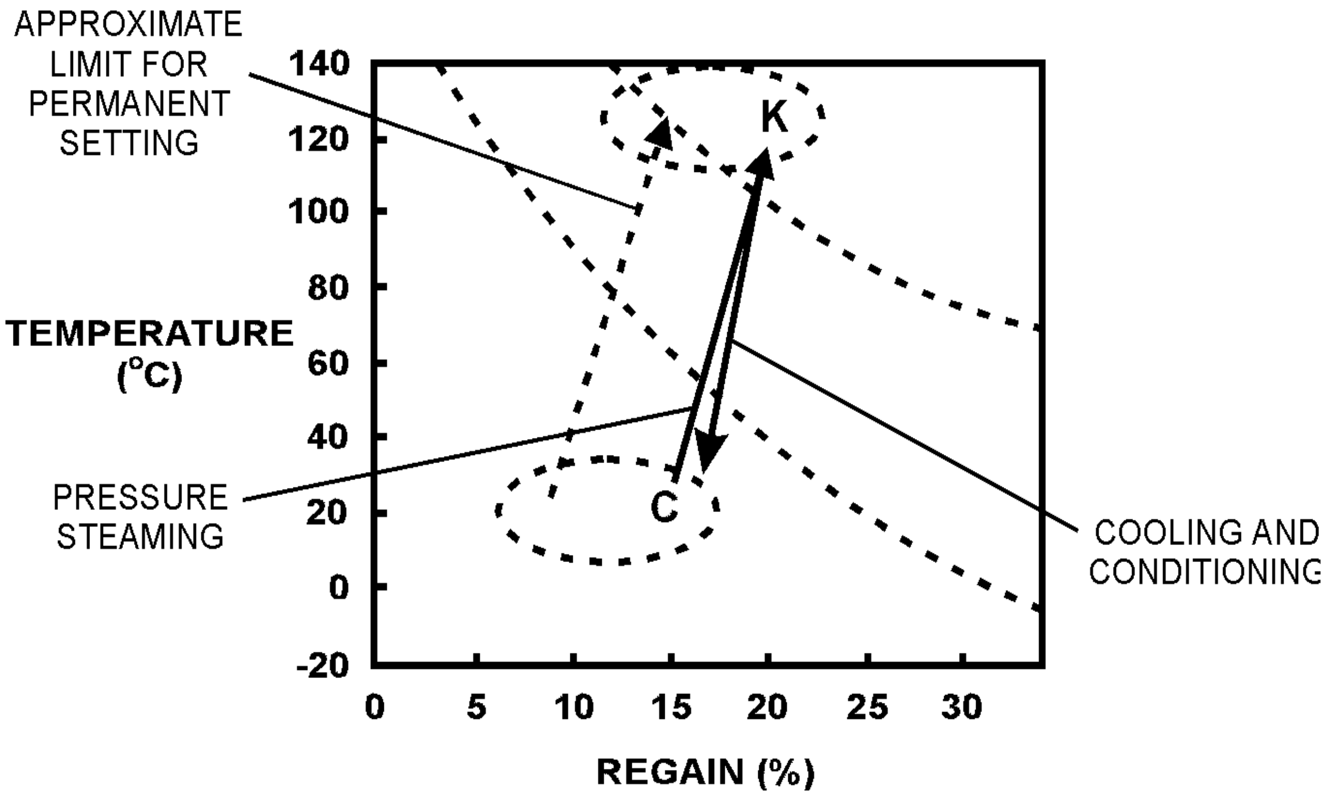


Stabilising the pH of fabric before dry finishing

- Because the amount of permanent set introduced during pressure decatising will depend on the fabric pH, it is highly desirable to adjust the pH of a fabric before dry finishing.

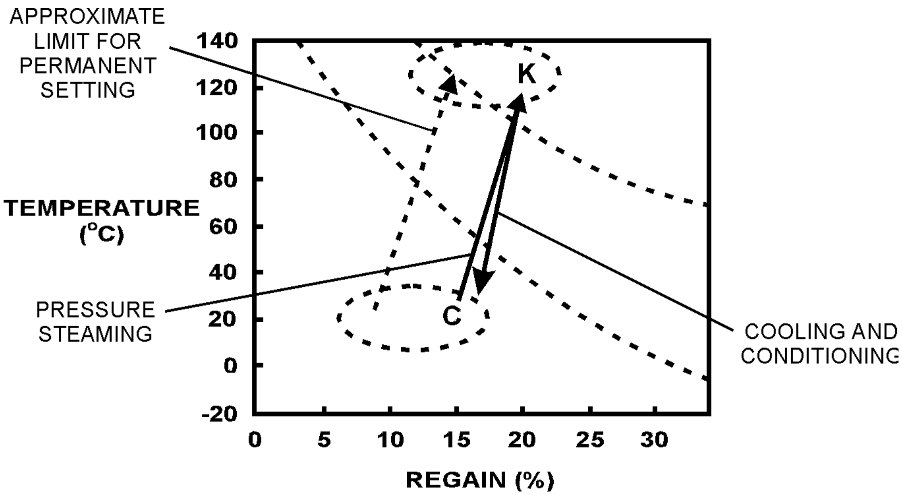
- At the end of the final wet treatment:
  - soak fabric for at least 10 minutes in a non-volatile buffer solution at a pH in the range 5 to 6, with ionic strength at least 0.05 M
  - check the external pH
  - rinse briefly.

Temperature and regain changes during pressure decatising



Temperature and regain changes during pressure decatising

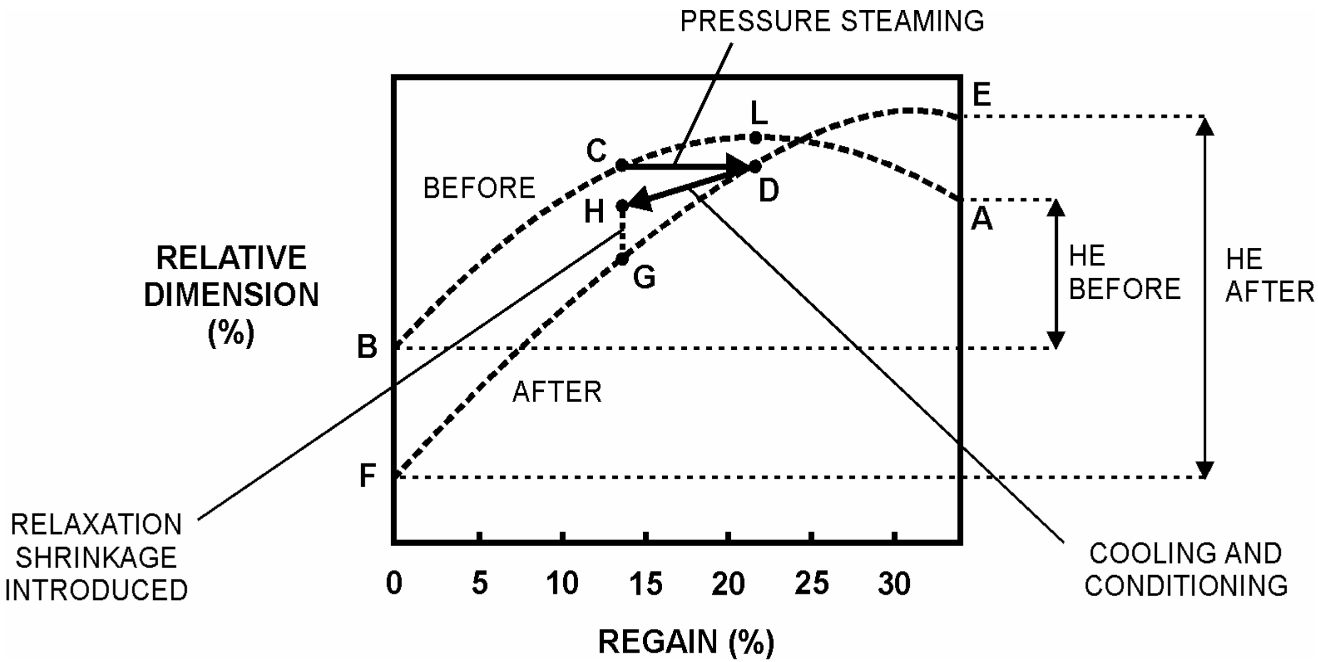
- Fabric initially at 20ºC and 14% regain (point C) is pressure steamed at 120ºC and 20% regain (point K).
- Appreciable permanent setting can occur under these conditions within a few minutes.
- On cooling, the temperature and regain of the fabric will return to near point C.
- In this example, fabric should be cooled to below 50ºC before it is unrolled.



The effect of pressure decatising on fabric properties

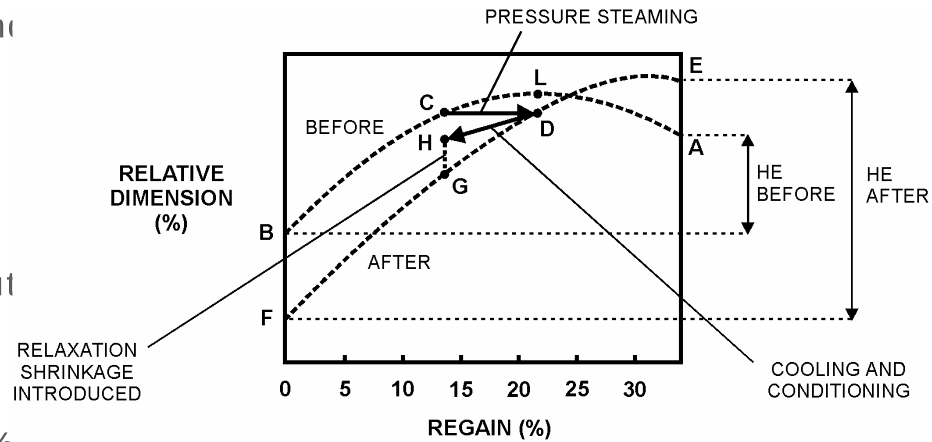
- Provided significant amounts of permanent set are introduced into fabric:
  - Relaxation shrinkage after pressure decatising is not related to the initial relaxation shrinkage.
  - Relaxation shrinkage is mostly introduced during cooling and conditioning of fabric after it has been steamed under pressure. For reproducible results, the batch should be cooled before unrolling.
- If fabric is fully relaxed and batched up without tension, the hygral expansion will be increased.
- With previously permanently set fabric, if the fabric initially contains relaxation shrinkage, or if the fabric is stretched during batching up, then hygral expansion may be reduced, but the reduction is only in the direction of stretching.

Dimensional property changes when previously unset fabric is pressure decatised



The effects of pressure decatising

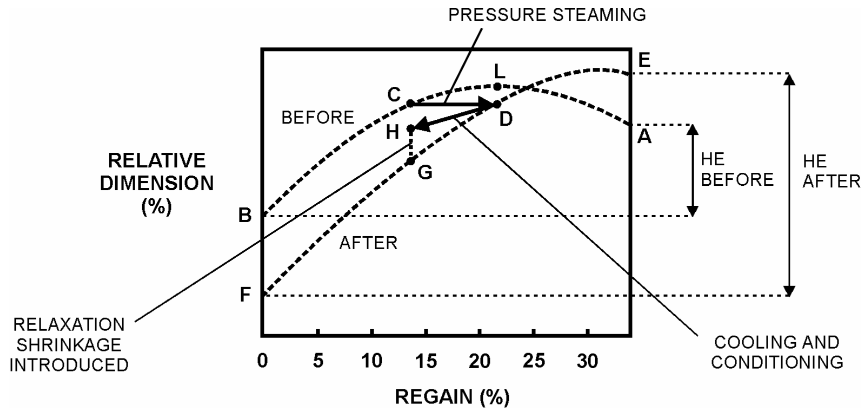
- The fabric is assumed to have been wet relaxed and conditioned at 14% regain and 20°C (at point C) and batched up with a conditioned cotton wrapper.
- The hygral curve of the fabric is shown running between B and A.
- Steaming under pressure is assumed to take place at about 22% regain (i.e. about 8%) by weight of water has been condensed on fabric to raise its temperature from around 20°C to 130°C. Permanent setting is assumed to be 100% effective.



- Since the fabric is constrained by the blanket, its dimensions cannot change when the regain is increased during steaming. Because the fabric will tend to try to expand to L due to hygral effects, it thus becomes permanently set in compression at point D.
- The hygral curve of the newly set fabric is shown as the curve FE. The relaxed length of the fabric at 14% regain is now at G. Also, the hygral expansion has increased and the wet relaxed dimension has increased from A to E.

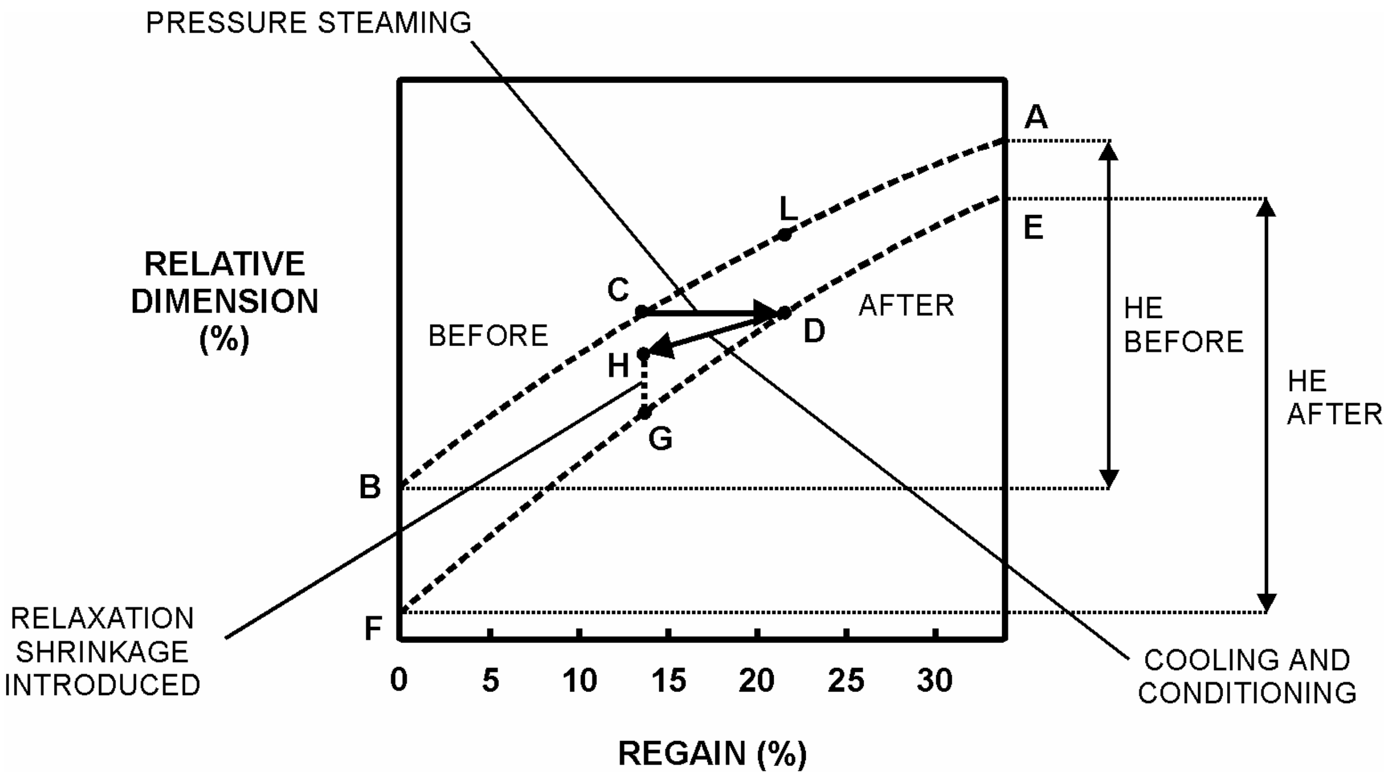
The effects of pressure decatising

- The relaxation shrinkage after pressure decatising will depend on how the fabric is constrained during cooling and conditioning to ambient regain.
- If the batch is unwrapped at room temperature and 14% regain, the dimension of the fabric will be at C, but its relaxed dimension will be at G, so the percentage relaxation shrinkage will be 100(C-G)/C. This relaxation shrinkage is caused by cohesive setting of the fabric in the batch.



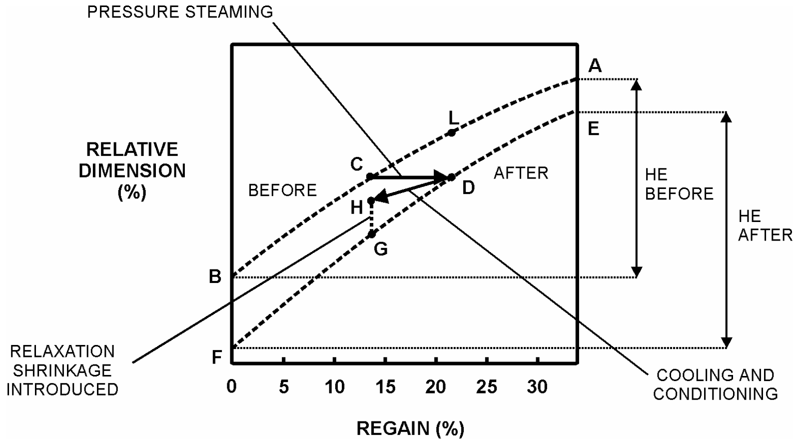
- If the batch is unrolled when still warm and while the wool fabric at higher than ambient regain, the fabric may subsequently relax as it cools and conditions and, if it is not constrained, less cohesive set will be introduced than if the fabric was cooled on the roll, and the dimension may eventually be as indicated at point H.
- The relaxation shrinkage is then given by 100(H-G)/H and this is smaller than if the fabric had been cooled in the batch.

Dimensional property changes when previously permanently set fabric is pressure decatised



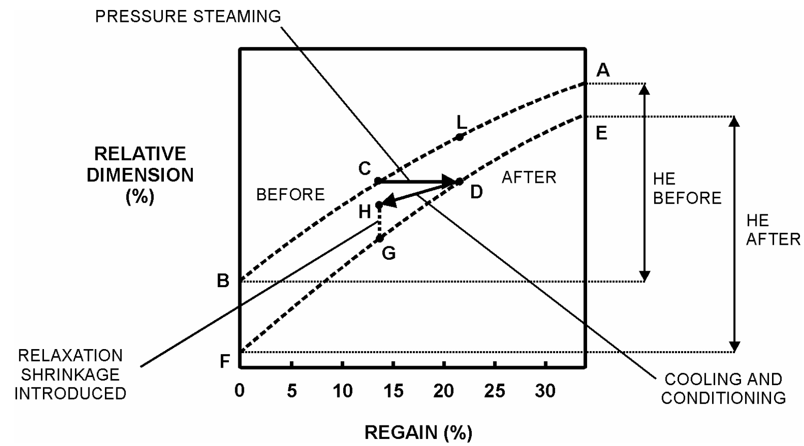
The effects of pressure decatising

- The fabric is assumed to have been wet relaxed and conditioned at 14% regain and 20ºC (at point C) and batched up with a conditioned cotton wrapper. The hygral curve of this fabric is shown running between B and A. Steaming under pressure is assumed to take place at 22% regain and permanent setting is assumed to be 100% effective.
- Since the fabric is held by the blanket, its dimensions cannot change when the regain is increased during steaming. Therefore, the fabric becomes permanently set at point D and is initially under compression, because its relaxed length at 22% regain is at L on the hygral curve BA, before it becomes re-set.

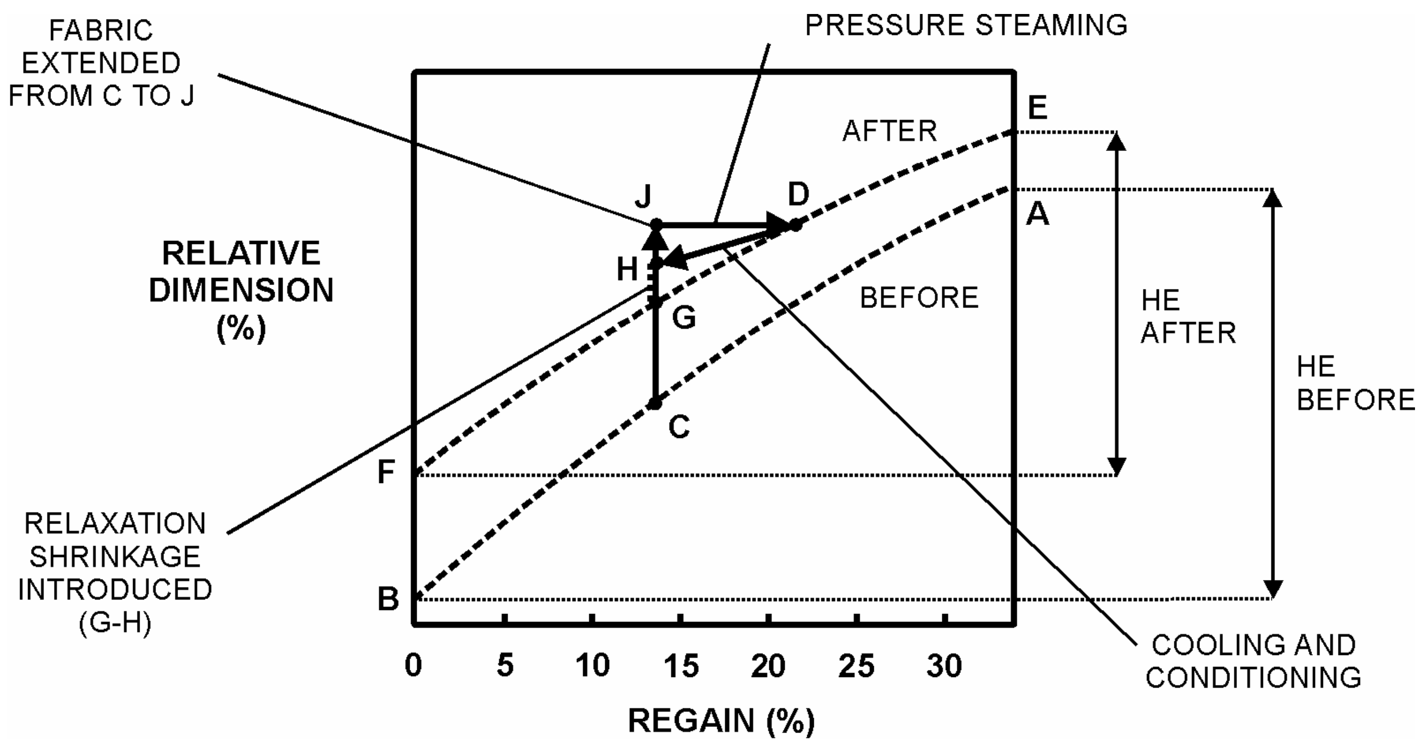


The effects of pressure decatising

- The hygral curve (FE) of the (relaxed) fabric after permanent setting (and stress relaxation at 22% regain) has a similar shape to that of the fabric before pressure decatising but lies below it and has a steeper slope. The relaxed length of the fabric at 14% regain is now at G. The hygral expansion has increased and the wet relaxed dimension has decreased slightly from A to E.
- As before, the relaxation shrinkage after pressure decatising will depend on how the fabric is constrained during cooling and conditioning to ambient regain.

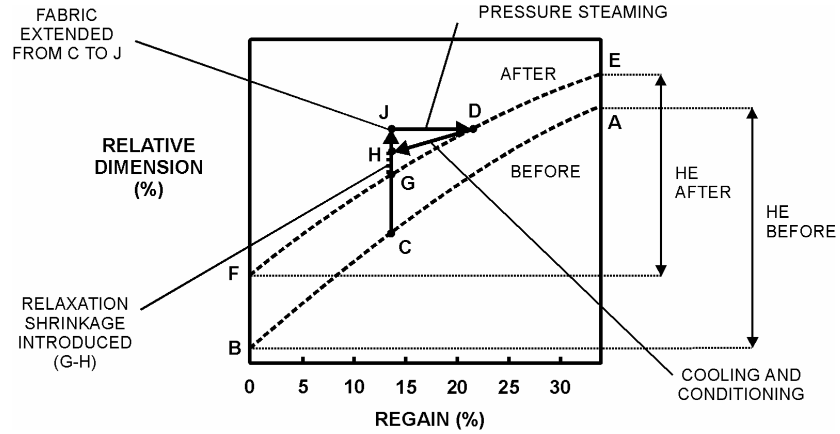


Dimensional property changes when previously permanently set fabric is stretched and pressure decatised



The effects of pressure decatising

- Supposing the relaxed dimension of a fabric at 14% regain is at C and its hygral behaviour is described by the curve BA.
- When this fabric is stretched to J and then permanently set at 22% regain (D), its new hygral curve is given by FE. It has been found that this curve lies above the curve of the relaxed fabric before pressure decatising and is invariably flatter, so the hygral expansion is reduced.
- As in the previous examples, if the batch is unwrapped at room temperature and 14% regain, the percentage relaxation shrinkage will be determined by 100(J-G)/J. If the fabric is unrolled while it is still warm the relaxation shrinkage will be 100(H-G)/H.



Summary of the effects of pressure decatising

Provided significant amounts of permanent set are introduced into fabric:

- relaxation shrinkage after pressure decatising is not related to the initial relaxation shrinkage
- relaxation shrinkage is mostly introduced during cooling and conditioning of fabric after it has been steamed
- if fabric is fully relaxed and batched up without tension, the hygral expansion will be increased
- with previously permanently set fabric, hygral expansion may be reduced
- if the fabric initially contains relaxation shrinkage or if the fabric is stretched during batching up, the reduction in hygral expansion is only in the direction of stretching.