TECHNICAL INFORMATION

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Eurofoam

TECHNICAL FOAMS

RECTICEL
The passion for comfort

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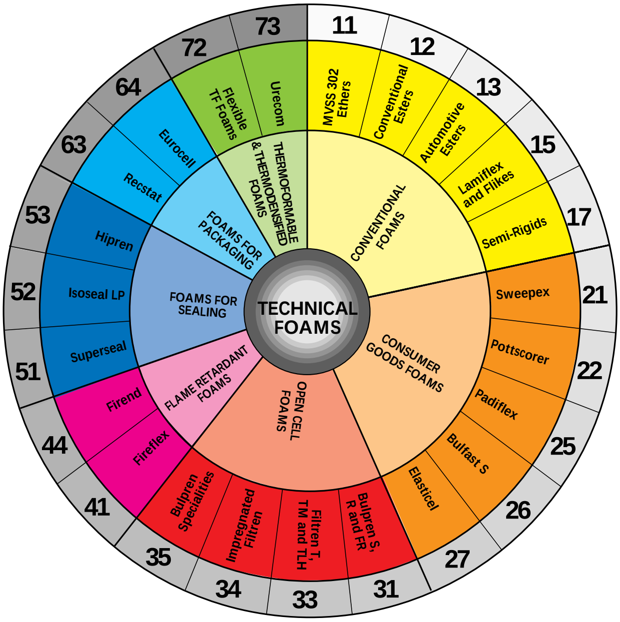

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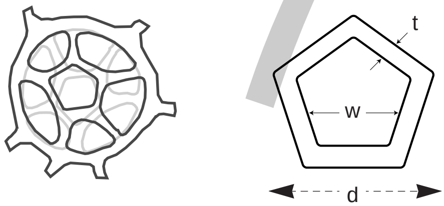
1. CELL STRUCTURE

A foam consists in a large number of interconnected cells, forming a cellular network. The cell is the basic unit of the foam ; its morphology and the chemical composition of the struts both define the final properties of the foam. The study of the cell is therefore a key approach to develop and design new foams according to given specifications and requirements.

The cell is a dodecahedron, constituted by 12 windows (pentagon shape) and 30 struts :



The properties of the foam depend on the properties of each individual cell, in particular :

1) The nature of the polyurethane elastomer itself, which constitutes the struts
2) The thickness of the struts (t)
3) The overall size of the cell (d)
4) The size of the window, which is the size of the opening itself (w)
5) The presence of residual membranes in the window and their thickness
6) The anisotropy of the structure and the morphology (shape) of the cell

The foam remains a complex assembly of an elastomer and air, in which all these parameters are interdependent.

1.1 The nature of the PU polymer :

The struts are made of polyurethane elastomer. The nature of the elastomer influences directly the properties of the struts, such as the hardness, the elasticity, the fatigue, the UV resistance, the chemical resistance.

Some examples :

- The hardness and elasticity are influenced by the crosslinking level of the polymer, depending on the formulation type and the concentration of reactive sites in the basic raw materials.

- The UV resistance is mainly influenced by the chemical nature of the isocyanate and by the anti-oxydants or UV additives.

- The chemical resistance is mainly influenced by the nature of the polyol.
  Polyester polyol based foams are sensitive to water, while less sensitive to organic solvents. The contrary is noticed for polyether polyol based foams.

1.2. Struts thickness, overall cell size, size of the window, foam density :

Struts thickness, overall cell size, size of the window and foam density are related.

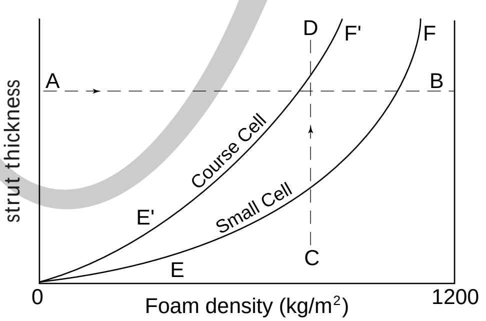
- When the overall cell size is constant, an increase of the foam density leads to an increase of the thickness of the struts, but to a decrease of the window opening and air content in the foam.

If	Overall cell size 1	=	Overall cell size 2
	Density 1	<	Density 2
Then	Thickness of strut 1	<	Thickness of strut 2
	Opening window 1	>	Opening window 2
	Air content 1	>	Air content 2

- For a given density, the decrease of the overall cell size leads to a decrease of the thickness of the struts, but the air content in the foam is the same.

If	Density 1	=	Density 2
	Overall cell size 1	>	Overall cell size 2
Then	Thickness of strut 1	>	Thickness of strut 2
	Opening window 1	>	Opening window 2
	Air content 1	=	Air content 2

The relation can be summarized in a graph.



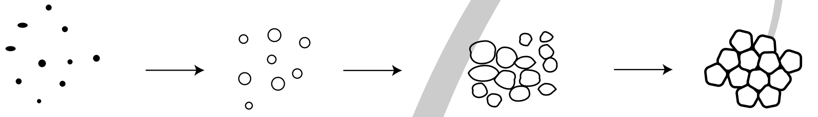
The graph can be interpreted from A to B (simultaneous increase of density and decrease of the overall cell size at constant thickness of the struts), from C to D (simultaneous increase of the thickness of the struts and increase of the overall cell size at constant density) and from E to F (or E' to F') (simultaneous increase of density and increase of the thickness of the cell struts at constant overall cell size) ;

At density 1200 kg/m^3, i.e. approximately the density of the full elastomer, the thickness of the struts becomes "infinite". In reality, there is no cell anymore ... and also no struts.

1.3. Residual membranes :

The blowing reaction, i.e. the formation of the cellular structure itself - starts from nucleation points which become the future individual cells.

At each nucleation point, gas molecules are formed. These nucleation points become “microcells”, which will increase in volume. Spherical at the beginning, the cells will reach a dodecahedric structure at the end of the foaming process :



Nucleation point Microcells Cells during growing Dodecahedric structure

During these steps, the cells are closed volume, otherwise the gas would escape and the foam would not grow anymore. It is a “condition sine qua non” of the foaming process. However, at the end of the foam rise, the membranes of the windows blow open - at least partially. This is an essential step in the production of flexible foam ; if the cells remain closed, the foam would shrink during the cooling. We have to remember here that the foam formation is an exothermic process and that the temperature inside the fresh foam can easily reach 150°C. During the cooling, the gas which would remain encapsulated in a closed cell, would exert a depression force, leading to the contraction of the cell, and the shrinkage of the foam.

Therefore, fresh flexible foam always contains open windows. The ratio between closed and open windows affects the physical properties of the foam, such as the air permeability, the hardness at the first compression, the acoustical performance.

1.4. Anisotropy :

The foaming process is a “free rise” process. The foam expends the fastest in the easiest direction, which is in the case of one shot process, in the vertical direction. The shape of the cell, instead of being spherical, is elliptical (circle and ellipse are defined as an overall approximate shape ...).

The shape of the cells can be visualized in the vertical section of the block.

Following this theory, the cross section of an individual cell would vary, depending of the section angle, from a circle to an ellipse with the maximum excentricity.

At angle 0 (vertical cutting)	:	ellipse with maximum excentricity
At angle 90° (horizontal cutting)	:	circle

The small diameter of the ellipse is constant (and could be the standard to define the cell size) and identical to the diameter of the circle.

The anisotropy of the foam is the variation of the shape of the cell in function of the cutting angle. It is an important parameter, which has not been enough investigated.
It is quite evident that the mechanical properties of each single cell - like the hardness, elongation - depend on the anisotropy. Therefore, the overall properties of the foam also depend on the cutting direction.

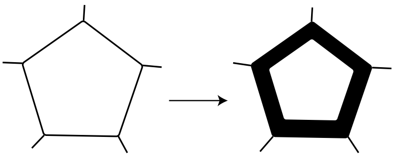
1.5. Modification of the cell :

The cell morphology can be further modified, either by reticulation, impregnation or by heat compression.

a) Reticulation :

It is the thermal process which melts all the residual "windows". The morphology of the foam remains the same (the struts become a little thicker), but the air permeability increases substantially due to the complete opening of the tri-dimensional cell structure.

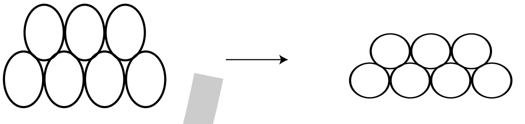
b) Impregnation :



By impregnation, the overall dimension of the cell remains the same ; the window opening becomes smaller, the struts become thicker, and the overall density of the foam increases, due to the extra coating material of the visual PU struts.

c) Heat Compression :

By heat compression, the cells are reduced and horizontally deformed.



The density of the foam increases, while final cell size decreases. As a result, air permeability decreases and the capillarity increases !

1.6. Air content :

The total weight of polyurethane foams, F, per cubic meter, is the sum of the weight of the polyurethane elastomer, U, and the air, A.

$$F = U + A$$

The weight of the air is very small towards the weight of urethane elastomer and can be considered as zero value. Therefore :

$$F = U$$

It only means that a foam, for example, of 30 kg/m^3, contains 30 kg of polyurethane elastomer per m^3. The density of a polyurethane elastomer is approximately 1200 kg/m^3.

Therefore, the real volume, V, occupied by the elastomer, is :

$$V = U / 1200$$

For a foam of 30 kg/m^3, the volume occupied by the elastomer is 30 kg/1200 kg/m^3 = 0.025 m^3. The volume occupied by the air is therefore (1 - V), which, in case of a foam of 30 kg/m^3, is 0.975 m^3.

The relation is therefore :

Content of air in % volume =

$$(1 - V) * 100 = (1 - U/1200) * 100 = (1 - F/1200) * 100$$

Example :

Foam density (kg/m^3)	Content of air (%)
10	99.2
20	98.3
50	95.8
100	91.7
300	75.0

1.7. The cell size unit :

The cell count is actually expressed in number of cells per linear cm or in PPI (number of pores per linear inch).

In reality, the definition is confused because the cell is a volume (tridimensional unit), which is reduced, by visual inspection, to a one-dimensional value. Moreover, the volume of each individual cell presents a high dispersion. To properly characterize a foam, 2 parameters should be mentioned :

- The average volume of the individual cells, from which the number of cells per volume (per m^3) can be easily calculated.
- The dispersion of the volume of each individual cell.

Studies are going on on this subject.

1.8. The number of cells per m^3 :

This can be calculated from the average volume of each individual cell.
For example, the average volume of a cell of a 60 ppi foam is 0.2 mm^3 which means that such a foam contains 5 billions of cells per m^3.

The number of cells per m^3 for different ppi value is :

PPI	Number of cells/m^3
90	Approx. 17,000,000,000
60	Approx. 5,000,000,000
30	Approx. 600,000,000
10	Approx. 20,000,000

2. SALES OF FUNCTIONS

PART 2

2.1. Definition :

Sales of Functions is the key marketing concept of the Business Development of Technical Foams.

The function of a Foam refers to its application field as part of an end product or during an industrial process. Typical examples are : Fireflex as an acoustical part in a compressor; Isoseal LP as an interliner in the pour-in-place process.

The functions of Technical Foams are extremely diversified : water sealing, air sealing, water retention, acoustic, filtration, flame-barrier, design, cavity filling, Nickel-carrier, ... The analysis of the function for any new development is therefore an important step before developing a new formulation or a new product. The analysis of the function is also important to fix the appropriate specification in accordance with end use or transformation process.

From a scientific point of view, the function can be defined as the behaviour of the foam under the influence of an external force. The external force is designed as the "action" ; the behaviour of the foam as the "reaction".

ACTION ⟶ FOAM ⟶ REACTION

All the functions can be related to this general mechanism.

Examples :

- Comfort is obtained by the deformation of the foam (reaction) under the weight of the body (action).
- The shock absorption is obtained by a fast compression of the cells (Reaction) under the gravity force of a falling object (action).
- The water sealing is obtained by repulsion of the foam to water (reaction) under the pressure of water (action).
- The acoustic absorption is obtained by the visco-elastic deformation of each individual PU cell (reaction) under the air pressure of the sound (action).

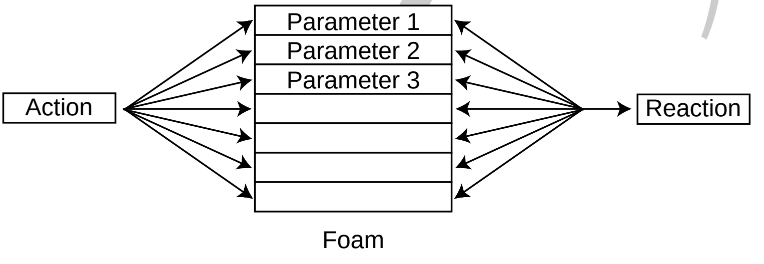
Besides the general survey of all the functions, the study of the mechanism of the function will therefore be the best guide to performant research.

2.2. Mechanism of functions :

The study of the mechanism of a function is a difficult task. It requires a wide scientific experience and prospective investigation on physics and physico-chemistry. It is certainly the aim of the Research Center to initiate such a study.

The most relevant example is the Foam Barrier function for the pour-in-place technology. The barrier protects the fabric from the penetration of the pour-in-place emulsion. The efficiency of the barrier is regulated by many parameters : density of the foam barrier, its closed cell content, its pore size, its thickness, its chemical nature, its contact angle, the nature of chemicals of pour-in-place, their viscosity, their reactivity, ...

The methodology of the study of the mechanism is based on a systematic analysis of the influence of each parameter on the function itself, which is illustrated as follows :



The example of Isoseal as barrier may appear difficult. But it is not because Isoseal is a complex case, that the study of other functions is simple. For example, the water retention in a sponge is an extremely complex story : how the performance of water retention can be combined with the ease to release it . What is the influence of double cell, closed cell, soft polyol, wettability, ... ?

Nothing is simple. Everything is so fascinating !

2.3. Acoustical treatment :

2.3.1. The nature of the sound :

The sound is a physical vibration, transmitted by the air in a frequency range to which the human ear is sensitive.

The sound is characterized by :

- Its amplitude : the higher the pressure of vibration, the higher the amplitude, the higher the loudness. The amplitude is typically expressed in decibel (dB).
  The Decibel scale is logarythmic ; a doubling of the intensity corresponds to an increase of approximately 3 dB.

  Few examples: the loudness of a pneumatic drill is 100 dB ; a near take-off of a jet aircraft is 130 dB ; quiet countryside is 15 dB ; 140 dB becomes painful and dangerous.

- Its frequency : Ultrasonic frequency refers to high frequency ; a bass to low frequency. The frequency is expressed in Hertz, it is the number of vibrations per second. In music, the note “la” is the reference at 430 vibrations per second. The human ear is sensitive between 20 and 18000 Hz.

2.3.2. Difference between music and noise :

The music is an organized sound. Only well-defined frequencies
- based in our occidental culture on 12 notes - and their harmonics
(i.e. their multiples) - are emitted in a well-defined rhytm and order.
The noise is a non-organized sound. All types of frequencies are present, without any order.

2.3.3. Acoustical treatment types :

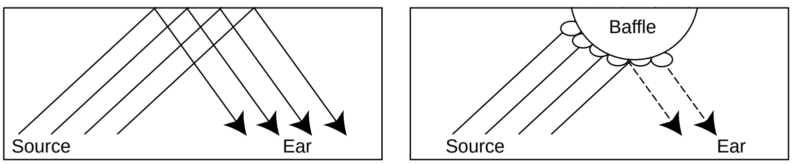
2.3.3.1. Correction :

The correction is the control of the sound inside a room.

Typical examples are :

- Reduction of the reverberation in a recording room ;
- Reduction of the noise level in a workshop ;
- Control of the reverberation time in a concert hall.

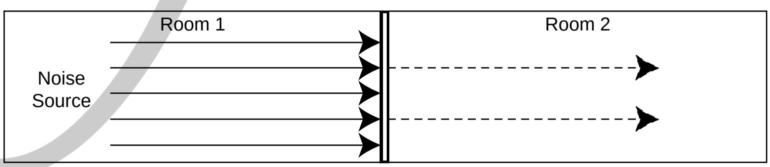
The noise (or music), emitted in a room by an orchestra or a machine is reduced or controlled for the best convenience of the auditor or the worker ;



This is achieved by "absorbers" ; they may be baffles, which are suspended to the ceiling, or by absorbers fixed in the walls. The performance of each absorber depends on the frequency spectrum. Anyway, flexible foam, by its cellular structure, is an excellent absorber to reduce or control the reverberation inside a room.

2.3.3.2. Insulation :

The insulation is the reduction of the transmission sound from one room to another.



It can be achieved by increasing the mass of the separating wall and/or by including the visco-elastic material, which really breaks the transmission at a certain frequency. PU foam is a good absorber and contributes to the reduction of the transmission, especially when it is associated to other materials.

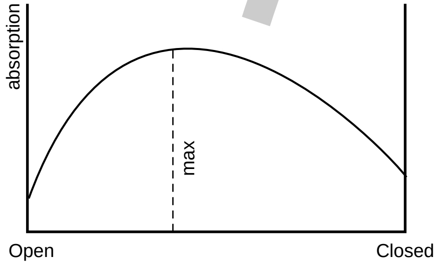
2.3.4. Foam as Absorber :

Flexible foams are excellent absorbers. The flexible nature of the foam acts as a tridimensional membrane.
Moreover, the cellular nature of the foam acts as a noise trap.

Two parameters influence the performance of the foam as absorber :

- Cell size : The smaller the size, the higher the absorption surface and the acoustical performance of the foam.

- Air permeability : Completely open cell structure transmits the wave with only little attenuation. On the other hand, a completely closed cell structure reflects the incident wave. The absorption characteristic is also bad. In both extreme cases, there exists an air permeability for which the acoustical absorption is optimal.



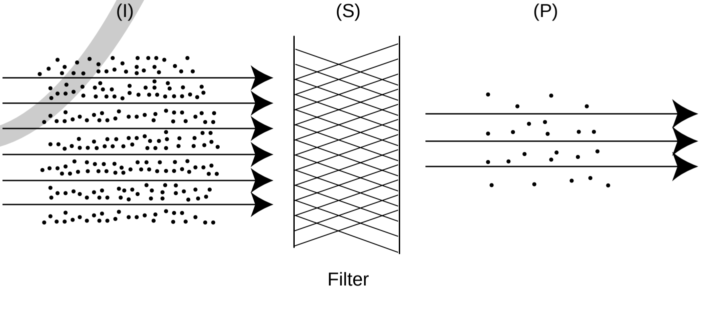
The parameters, cell size and air permeability, always act together.

2.4. Air filtration :

By its tridimensional open structure, reticulated foams are ideal support for air filtration.

Main parameters of Air Filtration

Particles in suspension in air are partially or totally arrested by the filter. Filtration is characterized by two parameters : the efficiency and the resistance to air flow, illustrated by the following figure :



- Efficiency : The efficiency (E) is the ratio of the number of particles stopped (S) by the filter related to the number of incident particles (I) :

  $E = S/I$

  The number of particles passing through (P) the filter, is calculated by difference :

  $P = I - S$

  The efficiency is generally expressed in % : 100 indicates that all the particles are stopped, and none are passing through the filter (I = S and P = O), while 0 % indicates that all the particles are passing through the filter (P = I and S = O).

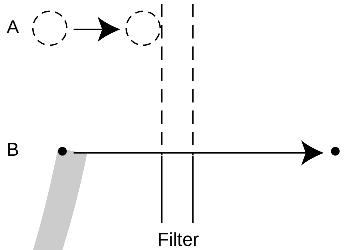
- Resistance to air flow : the resistance of the filter to the air flow is an important engineering factor. The higher the resistance, the higher the power of the ventilation system.

  The air resistance is generally measured by the pressure drop before and after the filter :
  $\Delta P = P1 - P2$, where ΔP = Pressure drop
  P1 = Pressure before the filter
  P2 = Pressure after the filter

<u>Mechanism of filtration :</u>

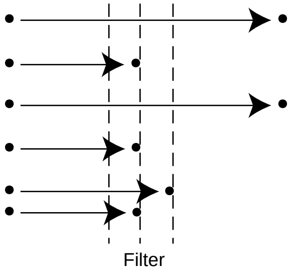
The particles are removed from air and accumulated in the filter structure by 3 basic mechanisms :

<u>- Sifting :</u> When the diameter of the particles is higher than the pore size of the filters, the particle is mechanically arrested by the filter.



Particle A is arrested ; particle B can pass through.

<u>- Collision :</u> Any particle, even when its diameter is smaller than the pore size of the filter, may hit the filter structure and stick on it.

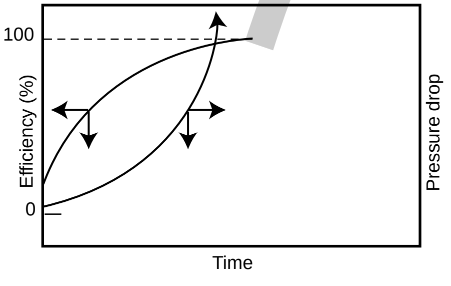


- Interception : By electrostatic force, the particle is attracted by the filter structure. The interception may be increased by surface treatment of the filter (active charcoal) or by loading the filter with electrostatic current.

Behaviour of the filter

By absorbing particles, the filter becomes heavier ; the pore size of the filter decreases. The efficiency of the filter increases but the air flow resistance increases too. At saturation, the filter is “full” and all the particles are arrested ... but there is no air flow anymore passing through the filter, therefore no filtration. Then, the filter has to be cleaned and/or replaced.

The standard diagram of the filter characteristics in function of the time is :



Polyurethane foam

In comparison with other filter media, polyurethane foams present the advantage of a tridimensional structure, which allows the accumulation of high amount of particles without being blocked. However, the efficiency of polyurethane foam for small particles is relatively low, due to the large pore size of the filter. Polyurethane foam filter is mainly used for prefiltration and/or filtration of coarse particles.

2.5. Air Sealing :

As such, conventional flexible PU foams are not suitable for air sealing purposes.
The foams are too open. To be used as airtight gasket, it is necessary to decrease the air permeability of the foam :

- By increasing the closed cell content ;
- By reducing the cell size ;
- By compressing the foam.

The advantage of Flexible Foam is its low resistance to compression, which facilitates its application in the assembling. The use of Flexible Foam for air sealing is however limited to low pressure (ventilation, refrigeration, doors, ...).

ISOSEAL LP is the most common PU foam of Recticel for Air Sealing.

2.6. Antistatic and Shielding :

Antistatic : The function of the foam is to prevent accumulation of electrostatic charge, which can damage electronic components. To reach the function, one enhances the electrical conductivity of the foam by a factor of 10 to 100.
Static electricity is therefore permanently dissipated.
RECSTAT is the Recticel name for antistatic flexible foam.

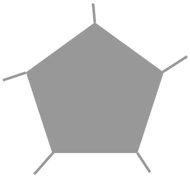
Shielding : Electromagnetic interferences are stopped by shielding.
The shield has to be electroconductive ($10^3\ \Omega$ cm).
The property can be reached by impregnation of active charcoal or by laminated metal foil (aluminium foil) on the foam.

2.7. Carrier :

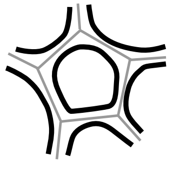
By its cellular structure, a foam is an ideal support to carry and transport liquids or powders. Sponges are the typical application. Other applications are powder puff, ceramic filter, biofiltration, impregnation, ...

Adsorption and Absorption

The basic mechanism of the carrier function is reached either by absorption which consists in filling the cell or by adsorption which consists in “coating” the rib of the cells.



Absorption of a liquid



Adsorption of a liquid

Sponges

The mechanism of the interaction between the water and the sponge (foam) structure is not simple. At first, water has to be absorbed during the immersion as fast as possible by the sponge structure. Then, in a second phase, the retention of the water during the transport operation becomes the key parameter. Third property : by pressing or squeezing, the sponge has to release the water (desorption).
Finally, the sponge will be perfect if it can “sweep” the surface.

Absorption, retention and desorption are the three mechanisms of the use of a sponge. All these requirements are contradictory ; one still expects the miracle to have the perfect sponge, based on a PU foam.

Powder Puff

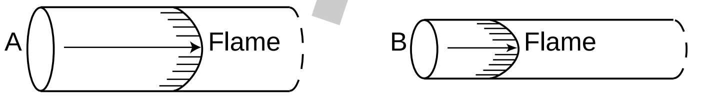
Powder Puff is another example of the carrier function. In this case, the function of the foam is to transport powder. The same mechanism - absorption (adsorption), retention, desorption - may be applied ... but there is no theory on the efficiency of PU foam for this function. The main property of the foam is its softness, ...

Ceramic Filter, nickel foam

PU foam is used as the basic structure to coat it with ceramic paste (by impregnation), or with nickel metal (by electrolysis). In both cases, the foam is burned after treatment and the ceramic or nickel residues keep the original structure of the filter. Ceramic filter is used as filter for metal injection ; nickel foam as electrode for rechargeable battery. In both cases, the function of the foam is assimilated to a “carrier” function.

2.8. Flame Barrier :

The flame propagation within a tube is strongly dependent of the diameter of the tube, due to the interaction of radical reaction of the flame and the walls of the tube.
The smaller the diameter of the tube, the slower the propagation of the flame ... up to complete extinction.



The flame propagation is faster in tube A than in B.

A window of a cell of polyurethane foam can be considered as a thin section of a tube, and the foam as a 3-dimensional network of tube sections. The flame propagation in such a structure is therefore reduced as in a single tube, and in some cases up to complete extinction of the flame.

Recticel produce two foam grades which are used as foam and flame barrier :
FIREND and SAFOM.

FIREND is an impregnated foam, used in thin layer (10 mm) to protect mattress, cushions, seats. The FIREND carbonizes at high temperature and protects the core of mattress, cushions or seats from burning.

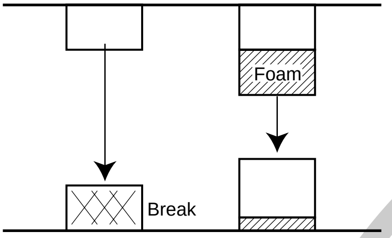
FIREND is, for example, used as flame barrier for aircraft seatings, complying with the FAR regulations.

SAFOM is a reticulated foam with coarse cell. It is used as anti-explosive for fuel tanks by filling completely the cavity of the tank. SAFOM itself has no specific fire retardant properties ; its function consisting in “quenching” the flame in its cellular structure.

2.9. Shock absorption (1)

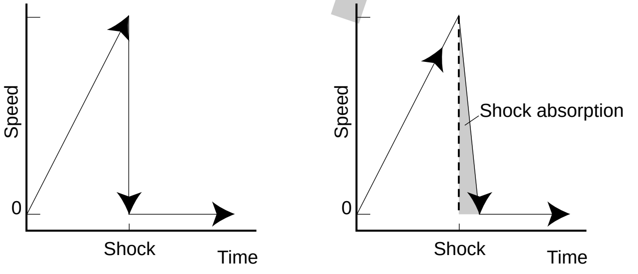
What is shock absorption ?

When an object is falling at a speed of 50 km/h on a concrete floor, its speed is reduced from 50 km/h to 0 km/h in a fraction of a second. The deceleration is extremely fast, causing damage to the object. By high deceleration, the object is compressed on itself, causing the breakdown and damage.



If the object is protected by a foam layer, the deceleration is reduced.
By contact with the floor, the foam is compressed and absorbs a part of the kinetic energy. The time to reduce the speed from 50 km/h to 0 km/h is much longer ; the deceleration is much slower.

The deceleration is illustrated as follows :



Factors, influencing the shock absorption :

The function of the shock absorber is to decrease the deceleration force and therefore, to increase the time between the speed of the object at the moment of the collision and the speed "0" after the collision. Several factors influence the performance of the absorber : its nature, its thickness, its contact surface :

* Hardness of the foam : a too soft foam doesn't present any resistance to compression. When the object is falling, the foam is compressed at the same speed as the falling object and doesn't offer any protection. On the reverse, a too hard foam is not compressed, and doesn't present any protection either.

* Contact surface of the foam : if the contact surface of the foam to protect the object is too small, the foam is compressed instantaneously, leading to no protection. If the surface is too high, the foam is only slightly compressed due to the high overall resistance. In such a case, the foam doesn't offer the appropriate protection.

* Thickness of the foam : when the thickness of the foam is too small, the foam is compressed to "bottoming" and doesn't protect the object.

Therefore, for each case, the nature of the product, its surface and its thickness have to be carefully studied in function of the weight of the object, its falling height and the specification to be reached. The approach to fix the ideal shock protection is really an exact science.

Other packaging protection

* **Blocking :** it avoids that an object moves in its own packaging.

* **Anti-vibration :**
It prevents that the object is subject to a continuous thrilling, which may be assimilated to a succession of small "shocks". Thrilling, when the vibration frequency of the component is the same as the external vibration, may lead to an amplification of the vibration, called "resonance", which can cause damage. Specific absorbers will reduce this phenomenon.

2.10. Impact protection :

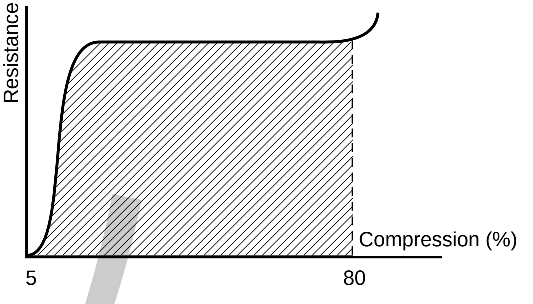
Impact Protection is defined here as the protection of the body against shocks.
In a certain way, the general theory of shock absorption may be used.

However, in impact protection, we consider that the protecting material can be destroyed during the impact and therefore limited to "one shock".

Ideal PU foam for impact protection is brittle foam - like foam glass - of density between 30 and 80 kg/m3 and cell size from 1 to 5 mm.

By impact, the foam is compressed and completely destroyed.
The energy absorption is due to the break-down of the cells.

The graph of "Resistance to Compression" and % compression is represented as follows :



After initial contact, the resistance to compression remains stable up to 80 %.
In this way, a maximum of energy is absorbed.

2.11. Thermal insulation :

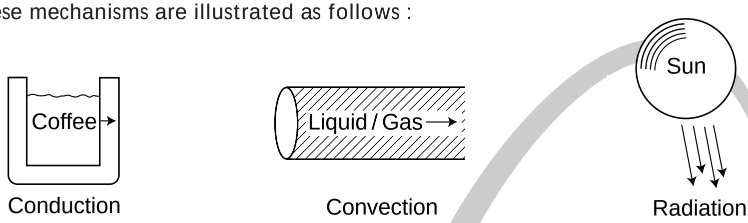
The transfer of heat takes place by 3 mechanisms :

- Conduction : It is the transfer of heat within material, from molecule to molecule. By pouring hot coffee in a cold cup, the exterior of the cup becomes hot by conduction within the ceramic of the cup.

- Convection : It is the transfer of heat by displacement of a fluid or gas. Central heating system occurs by the transport of hot water or hot air through the pipe system.

- Radiation : It is the transfer of heat by electromagnetic forces.
The sun burns the skin by radiation !

These mechanisms are illustrated as follows :



Polyurethane foam

Polyurethane foams present good insulation properties : the heat transfer by conduction is low because the foam is made of 3 % solid and 97 % of air. Moreover, the heat transfer by convection is also low because the air is trapped in the cellular structure.

Therefore, the insulation of a PU foam increases by :

- Fine cell structure
- Close cell structure
- Low density

2.12. Water filtration :

Water filtration is similar to air filtration.
Suspended particles in water are arrested by the filter, either by adsorption at the surface of the ribs, or by sifting.

Reticulated PU foams, based on polyether, are excellent mechanical water filters for various applications : aquarium, drains, swimming pool, ... As for the air filtration, reticulated PU foams can accumulate an important amount of dust and mechanical impurities before being blocked or saturated.

Reticulated PU foams present other advantages :

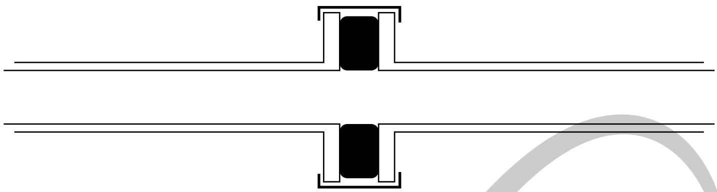
- Easy cleaning (with water jet)
- Easy handling and positioning in a given structure
- Long life

Reticulated PU foam is however not convenient for filtration of important water flow or high water pressure, neither for the purification of drinkable water.

2.13. Water sealing, liquid barrier :

Water sealing problems are encountered in all types of markets : building, appliance, automotive, refrigeration, transport. The water, by its low viscosity, penetrates everywhere and always takes the shortest way. Watersealing is not difficult : however, it requires some care.

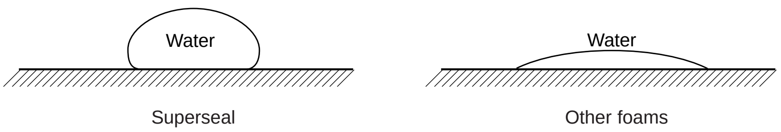
In most of the cases, water sealing is reached by a joint, which - by compression - penetrates the irregularities of the surface and prevents water leakage.



In the water sealing applications, it is absolutely necessary to specify the pressure of the water.

Most of the joints are made of flexible or semi-flexible materials : rubber, EPTM, leather ; the profile of the joints contributes to the sealing function.

SUPERSEAL is the only flexible PU foam - produced by the one shot process - which can be used for water sealing applications. To reach the properties, one uses hydrophobic chemicals ; this can be easily observed by placing a drop of water on the surface.
The spheric shape indicates a water repulsion effect :



Moreover, SUPERSEAL has a very fine cell structure, which contributes to the water repellancy by a negative capillarity process.

Flexible foam as sealing material has the advantage of low hardness.
Assembling of structures, using soft joints, becomes easy.

Liquid barrier (pour-in-place)

Barrier for pour-in-place application is a derivative function of liquid sealing.
The foam prevents penetration of the pour-in-place emulsion, and protects the textile.
To reach these properties, the foam will have low permeability, closed cell content and small cell size.

2.14. Miscellaneous :

Foams are also used in miscellaneous applications, which do not require extensive explanation.

Function	**Example**
- Housing	- RIM products
- Design, Padding	- Shoulder Pads
- Cavity Filling	- Sunvisors
- Gasketing (anti-noise)	- Any small piece
- Polishing, Scouring	- Pottscorer disk
- Protection against dust	- Any foam with skin
- Acoustical transparancy	- Bulpren HiFi

3. PHYSICAL TESTING

As explained in the previous part of this book, the micro structure of polyurethane foams is not homogeneous. Two cells are never completely identical, and the tri-dimensional assembly of the cells is purely random, leading to a wide dispersion and specification range of the physical and mechanical properties.

Therefore, the key issue of the quality of Technical Foams is to guarantee that the foam can be used for a final use function and for its converting process, based on the conformity to key parameters and not to the secondary properties.

The physical testing of Technical Foams is classified in four groups :

1. **First group : The Density :**

   The density of the foam - which is an "apparent density", since the foam contains more air than material - is a key parameter which influences all the other parameters.
   On a general point of view, the higher the density, the better the physical and mechanical properties. But, the higher the density, the higher the price ...
   Therefore, most of the foams are produced at the lowest possible density, which can still guarantee the quality of its use and function.

2. **Second group : The Mechanical Properties :**

   They are defined as the behaviour of the foams against external force like compressing, tearing, ... Most of the mechanical properties are important for the processing of the transformation and converting of the foam into finished products.

3. **Third group : Functional properties :**

   They are defined as the performances of the foam in its final use and application :
   air thightness, acoustical performances, antistatic properties, ...

4. **Fourth group : Environmental and external requirements :**

   They are defined as the "conditions" of the use of the foam for a given application in given conditions. Low fogging, low flammability, ageing test, ... are typical examples.

The list of physical testing of Technical Foams is given below :

Group 1
Density

Group 2
Compression Deflection Hardness (CDH)
Indentation Load Deflection (ILD)
Ultimate Elongation (ER) and Tensile Strength (RR)
Tear Resistance (TR)
Clickability
Compression Set (CS)

Group 3
Cell Diameter
Cell Count
Cell Structure of Sponges
Pressure Drop
Air Resistance (Acoustics) (Rs)
Air Resistance (Sealing)
Air Permeability
Water tightness
Water absorption
Electrical Resistivity
Die Cut Weldability

Group 4
Fogging by Reflection
Fogging by Gravimetry
Blue scale colour fastness
Flammability : MVSS 302
Flammability : UL 94 horizontal
Flammability (Epiradiateur)

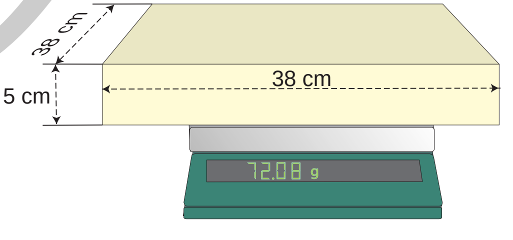
3.1.1. Density (D) :

- **Definition :** Weight per volume unit. The result is an apparent density since air is included in the volume.

- **Equipment and/or method :** Balance

- **Formula :** $\text{Density (D) (kg/m}^3\text{)} = \dfrac{\text{Weight (W) (kg)}}{\text{Volume (V) (m}^3\text{)}}$

- **Norm :** ISO 845

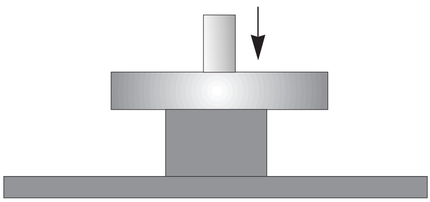


3.2.1. Compression Deflection Hardness (CDH) :

- **Definition :** The force required to compress the foam with a compression plate bigger than the sample (10 cm x 10 cm x 5 cm).
- **Equipment :** Universal tester
- **Formula :** CDH (kPa) = $\frac{\text{Force (N)}}{\text{Surface of the samples (cm}^2\text{)}}$ x 10
- **Norm :**

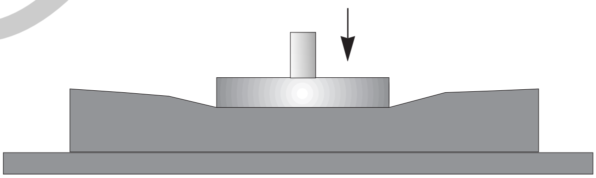
	ISO 3386/1 or DIN 53577	Renault 1003	Rect. (*) SS/T.006.0	Rect. (*) SS/T.005.3
Precompression	3 x 70 %	4 x 75 %	No	No
Measurement	25 % 40 % 60 %	25 % 50 % 65 %	25 % 40 % 65 %	- 40 % -

(*) Specific for S.R. foams



3.2.2. Indentation Load Deflection (ILD) :

- **Definition :** The force required to compress the foam with a compression plate (diameter : 20 cm) smaller than the sample (38 cm x 38 cm x 5 cm)
- **Equipment :** Universal tester.
- **Formula :** Results are expressed in Newton (N)
- **Norm :** ISO 2439 B or BS 4443, part 2, method 7



3.2.3. Ultimate Elongation (ER) and Tensile Strength (RR) :

- **Definition :** By extension, measurement of elongation at the rupture point (ultimate elongation) and maximum strength reached at this point (tensile strength).

- **Equipment :** Universal tester.

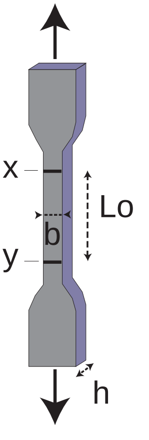
- **Formula of ultimate elongation (ER) :** $ER\ (\%) = \frac{L1 - Lo}{Lo} \times 100$

Lo = initial length (distance xy in cm)
L1 = length at rupture point (cm)

- **Formula of tensile strength (RR) :** $RR\ (kPa) = \frac{F1}{b \times h} \times 10$

F1 = the force at rupture point (N)
b = width of the sample (cm)
h = thickness of the sample (cm)

- **Norm :** ISO 1798



3.2.4. Tear Resistance (TR) :

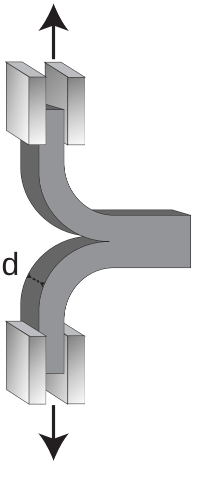
- **Definition :** Determination of the maximum forces at which the tear rupture takes place.

- **Equipment :** Universal tester

- **Formula :** $TR\ (N/cm) = \frac{Force\ (N)}{d}$

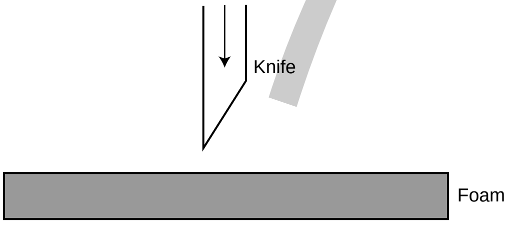
d = width of the sample in cm

- **Norm :** ASTM D 3574/F



3.2.5. Clickability :

- **Definition :** Evaluation of the edges deformation after die-cutting.
- **Equipment :** Normalized die-cutter
- **Evaluation :** Class 1 : Thickness loss of the edge < 10 %
  Class 2 : Thickness loss of the edge between 10 and 30 %
  Class 3 : Thickness loss of the edge > 30 %
- **Norm :** Recticel SS/T.012.0

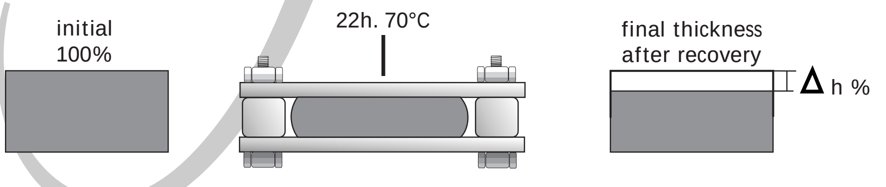


3.2.6. Compression Set (CS) :

- **Definition :** Loss of thickness after compression in given conditions of time, temperature and humidity.
- **Formula :** $CS (\%) = \frac{H_O - H_1}{H_O} \times 100$

H_O = original thickness (mm)
H_1 = thickness after compression

- **Norm :** ISO 1856/A (compression at 50, 75 or 90 % ; 22 h - 70°C ; measurement 30 minutes after decompression).



3.3.1. Cell diameter : Visiocell

See part 4
- **Norm :** Recticel SS/T.013.4

3.3.2. Cell Count :

- **Definition :** Determination of the number of pores per inch (ppi) by visual comparison with reference sample or by 3 point measurement of the cell size.
- **Equipment :** Microscope.
- **Formula :** Results are given in PPI.
- **Norm :**
  - Visual comparison : Recticel SS/T.013.0
  - Microscope : by 3 point measurement : Recticel SS/T.013.3

3.3.3. Cell structure of sponges :

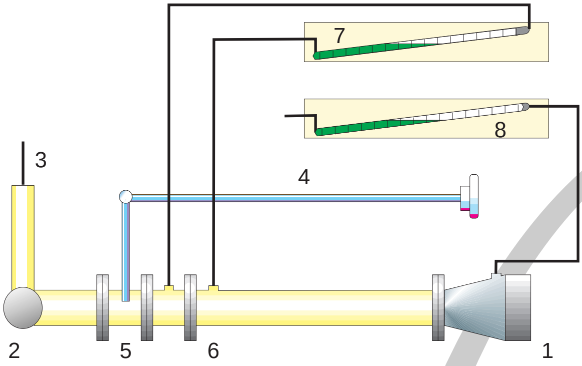
- **Definition :** Determination of the double cell structure of sponges by visual comparison with reference samples.
- **Formula :** Classification is done by sponges grade, namely :

  - EF = extra fine
  - F = fine
  - M = Medium
  - C = Coarse
  - EC = extra coarse

- **Norm :** Recticel SS/T.013.2

3.3.4. Pressure Drop :

- **Definition :** Measurement of the pressure drop at a fixed air flow speed.
  This measurement was previously used for cell count measurement.
- **Equipment :** Specific pressure drop device.
- **Formula :** The evaluation is done by direct measurement of the pressure drop in inch water column.
- **Norm :** Recticel SS/T.013.1



1. Sample holder
2. Blower
3. Exhaust
4. Air flow adjustment
5. Slide valve
6. Aperture
7. Aperture manometer
8. Sample manometer

3.3.5. Air Resistance (Acoustics) (R) :

- **Definition :** Air flow resistance, calculated from the measurement by the air velocity to reach a pressure drop of 1 inch water column.

- **Equipment :** Specific device.

- **Formula :**

$$R\ (N.sec/m^3) = \frac{P \times 249{,}174}{V}$$

R = air resistance

P = pressure drop in inch of water

V = velocity (m/sec)

- **Norm :** Recticel SS/S.015.2

3.3.6. Air Resistance (Sealing) :

- **Definition :** Measurement of the air resistance at a fixed air flow through O-ring sample compressed at 75 %.

- **Equipment :** Specific device.

- **Formula :** Results are expressed in cm water column.

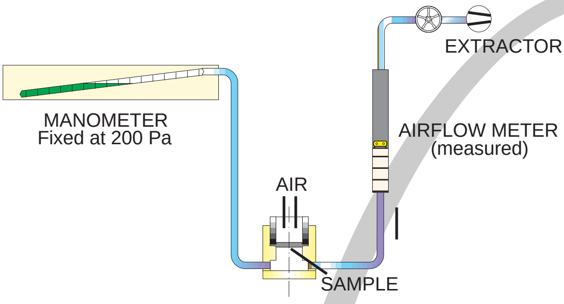
- **Norm :** Recticel SS/T.015.1.

3.3.7. Air Permeability :

- **Definition :** Measurement of the air flow through a sample at constant air resistance of 200 Pa for a test surface of 20 cm^2.
  Other air permeability methods can be correlated to this one.

- **Formula :** Results are expressed in liter/dm^2 min.

- **Norm :** DIN 53887.



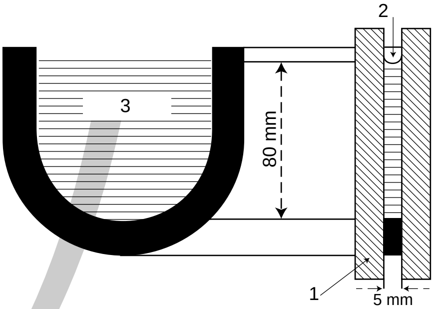
3.3.8. Water tightness :

- **Definition :** Measuring of the water sealing properties of U-shape sample, compressed at 50 % and variable water column level for a period of 24 hours.

- **Equipment :** Specific device

- **Formula :** Results are given in “Pass” or “Not Pass”, mentioning the water column level, the compression factor of the foam and the duration of the test.

- **Norm :** Recticel SS/T.020.2.



1. Acrylic plate
2. Sample
3. Water

3.3.9. Water absorption :

- **Definition :** Measurement of the absorption of water in a sample compressed and immerged in water for a given duration.

- **Equipment :** Specific device.

- **Formula :** - Absorption in weight (%) $W\% = \dfrac{W_1 - W_0}{W_0} \times 100$

W_1 = final weight (g)
W_0 = initial weight (g)

- **Absorption in volume (%) =** $V\% = \frac{W\% \times d}{1000}$

d = density of the foam (kg/m^3)
Compression of sample, height of the water and duration of the test are reported.

- **Norm :** Recticel Method SS/T.019.0

3.3.10. Electrical Resistivity :

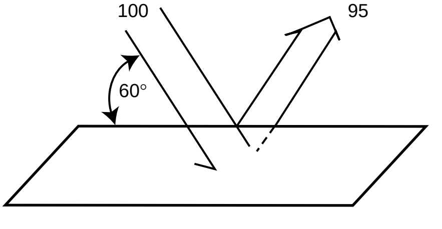
- **Definition :** Electrical resistance determined by measurement of the current or by the voltage drop.
- **Equipment :** Ohm-meter.
- **Formula :** The volume resistivity is expressed in Ohm.cm while the surface resistivity is expressed in Ohm.
- **Norm :** ASTM D 257

3.3.11. Die Cut Weldability :

- **Definition :** Weldability of the edges by die-cutting
- **Formula :** The performance is classified as follows :
  - Class K : The complete contour remains sticky
  - Class KN : No sticking or partially sticking
  - Class K1 : Valid for SF 272 EW : partially sticking.
- **Norm :** Recticel SS/T.012.1

3.4.1. Fogging by Reflection :

- **Definition :** Measurement of the condensed volatiles on a glass plate by reflection of incident light.
- **Equipment :** Specific device.
- **Formula :** The reflected light is expressed in %
- **Norm :** DIN 75201/A



3.4.2. Fogging by gravimetry :

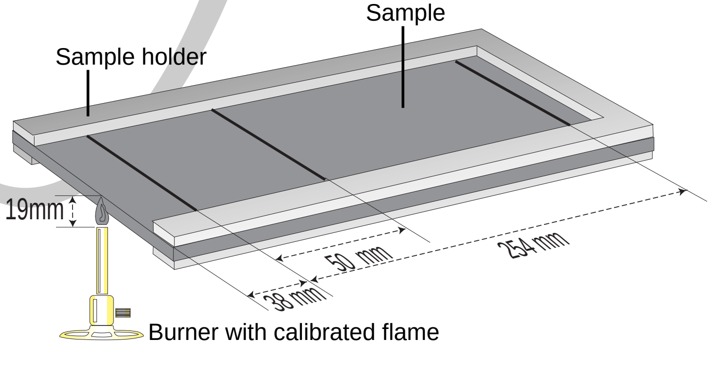
- **Definition :** Measurement of volatile components on an aluminium film by weight.
- **Equipment :** Specific device.
- **Formula :** The results are expressed in weight (mg)
- **Norm :** DIN 75201/B.

3.4.3. Blue scale colour fastness :

- **Definition :** Resistance to UV light, compared with a standard blue scale.
- **Equipment :** Weatherometer.
- **Formula :** The results are reported in the blue scale from 1 to 8.
- **Norm :** GM 9125 P

3.4.4. Flammability : MVSS 302 :

- **Definition :** Flame behaviour of the foam by measurement of the horizontal propagation of a calibrated flame after 50 seconds ignition.
- **Equipment :** Specific device.
- **Formula :** The results are reported in burning rate (mm/min) at a given thickness (mm).
- **Norm :** MVSS 302



3.4.5. Flammability : UL 94 horizontal :

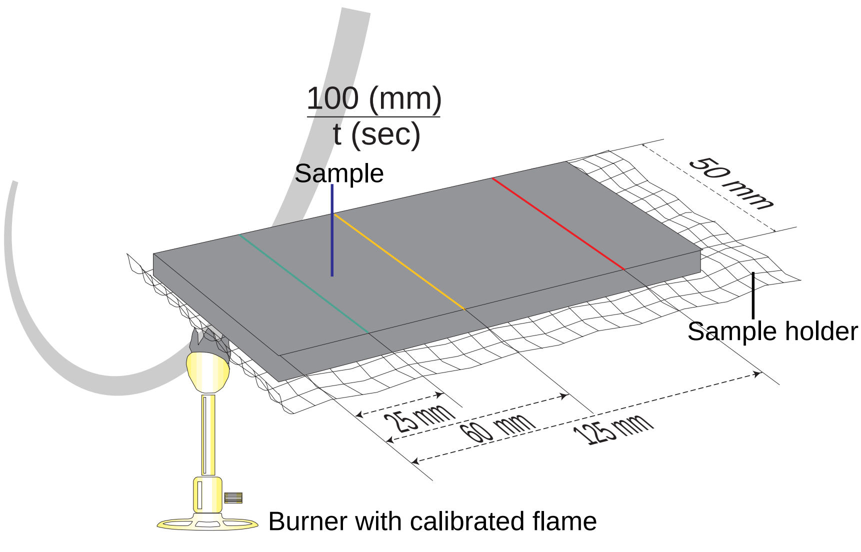
- **Definition :** Flame behaviour by the horizontal propagation of a calibrated foam after 1 minute ignition.

- **Equipment :** Specific device.

- **Formula :** The foam classified in 3 classes as follows :

Classification	Criteria
HF1	t max. 2 sec : 4/5 samples t max. 10 sec. 1/5 samples l max. 60 mm
HF 2	Idem HF 1 Ignition of cotton by falling drops acceptable
HBF	60 mm < l < 125 mm or l = 125 mm ; v < 40 mm/min over a distance of 100 mm with v (mm/min) = $\frac{100 \text{ mm}}{t(s)} * 60$

- **Norm :** UL 94 (Underwriters Laboratory)



3.4.6. Flammability (Epiradiateur) :

- **Definition :** Behaviour of the foam irradiated by a radiator of 500 W during 20 minutes.

- **Equipment :** Specific device.

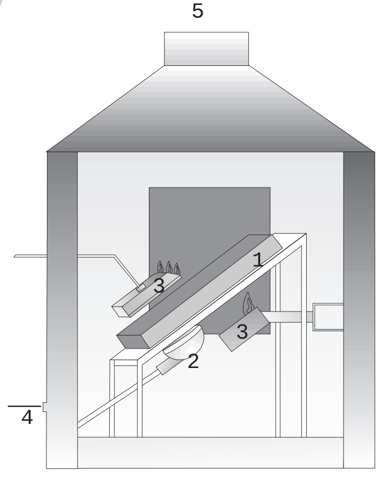
- **Formulation :** Index $Q = \dfrac{\sum h}{ti \times \sqrt{\Delta t}} \times 100$

  ti = ignition time
  $\sum$ h = sum of height of the flames
  Δ t = burning time

  The foam is classified as follows :

  - M1 for Q < 2.5
  - M2 for 2.5 <= Q < 15
  - M3 for 15 <= Q < 50
  - M4 for 50 <= Q

- **Norm :** NFP 92-501

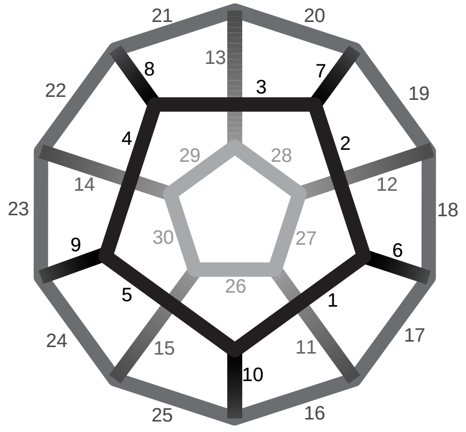


4. VISIOCELL

4.1. The cellular structure of polyurethane foams:

A polyurethane foam is a tri-dimensional structure of interconnected cells. The cell is the basic unit of the foam. The number of cells varies from 20 million up to 20 billion per cubic metre of foam.

The cell presents the shape of a dodecahedron (see figure) made of 30 struts and 12 pentagonal windows. The window is the surface bounded by 5 struts (for example: struts 1, 6, 17, 16, 10).



The strut is the solid material (the polyurethane elastomer) of the foam. The rest of the foam is filled by air.

The properties of the foam depend on the properties of the individual cells, namely:

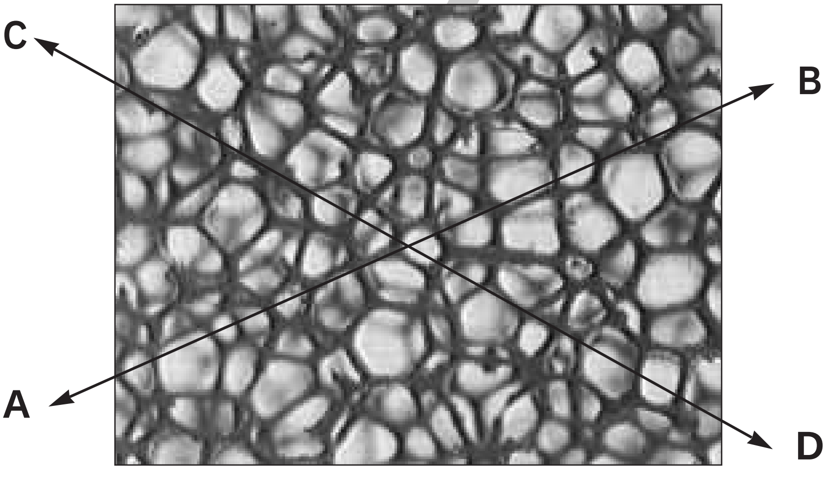
1. The chemical nature of the polyurethane elastomer.
2. The thickness of the struts.
3. The volume of the cell.
4. The presence of residual membranes on the window.
5. The anisotropy of the cell.

The influence of these parameters on the foam properties is fully described in the brochure “Technical Information on Technical Foams”.

4.2 “PPI”: an obsolete unit

The dimension of the cell is a key parameter of the properties of the foam. For many applications, the performance of the foam is directly influenced by the cell size.

For more than 25 years, the cellular structure and the cell size have been defined by the unit “PPI”: pores per inch. The number of pores is counted on a standard length of 1 inch.



This unit can be a little confusing and subjective:

- The “pore” has never been clearly defined. It can be a window or the full section of the cells.
- The size of pore, if it is a window, depends on the vision angle; if it is a cell section, it depends on the location of the section (top, middle or bottom).
- The dispersion of the results is very high. Counting from A to B or from C to D (see picture) can lead to an important difference.
- A cell is a “VOLUME” while the “PPI” is the reduction of this volume to a linear counting of a non-defined unit (the pore).

It is therefore not surprising that the “PPI” has never been recognised as an international unit, neither the methods (direct counting, pressure drop, 3 points methods,...) to evaluate it. It is not surprising too, that each foamer has its own reference scale, and that a foam defined as 80 ppi by one foamer could be defined as 110 PPI by an other, leading to confusing situations in the specifications.

4.3. A new concept

The PPI unit is not accurate enough to satisfy the specification requirements of the new “high tech” developments and application fields of technical foams. A better control of cell size of the foam during the foaming process can therefore only be achieved if the method to measure it is more accurate. This is the background of the new method, “Visiocell”, introduced by Recticel.

The development of the Visiocell method is based on 4 criteria:

- Accuracy of at least 1.5 to 2 %.
- Applicable for any foam with regular structure: non reticulated, reticulated, any colour,...
- Cheap equipment to measure the cell diameter.
- Fast and operator independent.

4.4. Schort description

1. Preparation of a horizontally cut foam sample (perpendicular to the foaming rise direction).

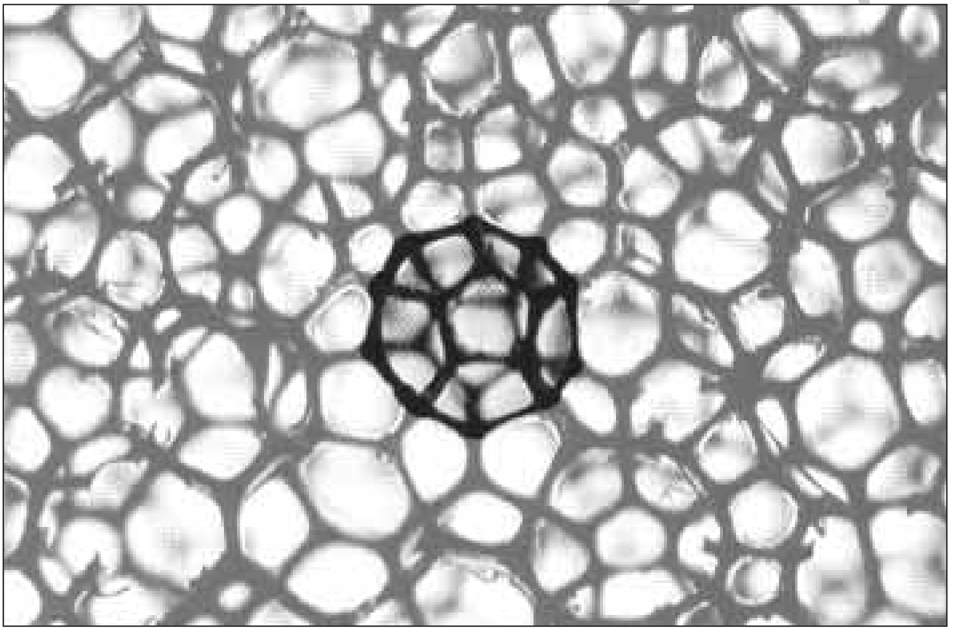
2. Printing a picture with a magnifying camera.

3. Selection of a representative cell showing the maximum diameter. Such a cell is identified by its circular shape made of ten struts and by one or two small pentagon(s) in its centre. These pentagons are the underside and/or upperside window(s).

4. Measurements of the cell diameter by superimposing calibrated rings, printed on transparent paper, on the selected cell.

4.5. Example

A typical picture of a product “Bulpren S” with a cell diameter of approximately 1000 micron is represented below:



The cell in the center of the picture is selected and identified in “bold”. This cell presents a circular shape and also shows both small pentagons in its center (windows on upper- and underside).

By superimposing the slide enclosed in the brochure on this cell, one can select the ring of which the size is the closest to the cell.
In the worst case, one can be unsure between 2 rings; the difference of the diameter between 2 rings is maximum 4 %. It means that the cell diameter is measured with an accuracy of approximately 2 % (in the case of this Bulpren S, the accuracy is approximately 20 micron).

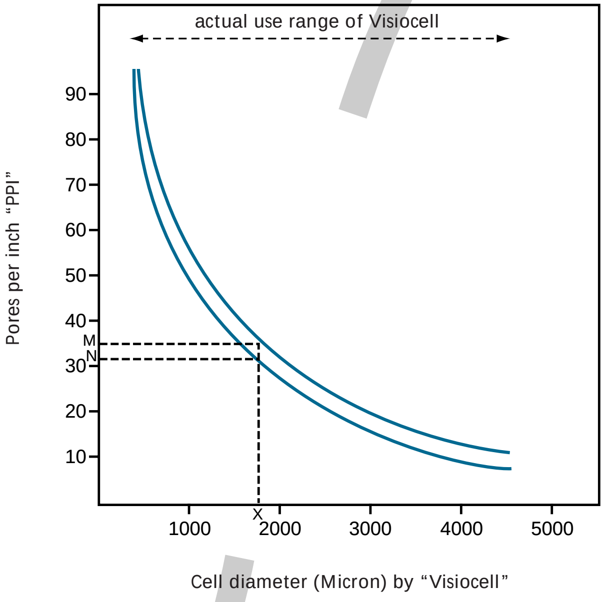
The cell diameter is the average between the internal and external circle of the ring!

It should be noted that the picture and the rings as printed in this example are not calibrated. They are only published to understand the concept of the method. The reason of this non-calibration is explained further.

4.6. Relation between cell diameter by Visiocell and PPI

It is impossible to define or calculate the accurate correlation between the cell diameter by the Visiocell method and the PPI scale because the measurement of the PPI itself is inaccurate.

The graph below gives only a rough indication between the scales:



The function (type $y = 1/x$) is represented by a double line to express the non-accurate definition of PPI. For a given cell diameter in micron, for example the value X, the PPI may vary from N to M.

4.7. Narrower specifications

As explained above the Visicocell method is very quick and accurate. This allows consequently to reduce the dispersion of the cell diameter within the foam, especially from run to run. It therefore enables Recticel to produce foam within a narrower range of the specifications and to achieve extremely accurate foaming for “high tech” application fields. New technologies have been developed to reach such targets.

Let’s take two extreme examples:

Coarse cell: Bulpren S 20

According to the previous ppi scale, the specifications of Bulpren S 20 were 15 to 25 PPI. This PPI range corresponds to a cell diameter (according the Visiocell method) between 3400 and 2200 micron. It means a difference between the maximum and minimum value of 1200 micron on an average value of 2700, i.e. 1200/2700 = 44 %.

With the Visiocell method, one can produce the same standard foam within the range of 3000 and 2400 micron. The range of specifications is 600 micron, i.e. 600/2700 = 23 % of the average value.

It is even possible to further reduce the range of specifications for “high tech” application fields to 400 micron, i.e. 14 % of the average value.

Fine cell: Bulpren S 75

We obtain similar improvements for fine cell structures.

Following PPI scale:
- PPI range: 65-80
- corresponding cell diameter: 750 - 520 micron
- range of specifications: 170 micron on 580 micron average, i.e. 30 %

With Visiocell, for standard foam grade:
- cell diameter range: 640 - 520 micron
- range of specifications: 120 micron on 580 micron average: 20 %

With Visiocell, for high tech foam grade:
- cell diameter range: 620 - 540
- range of specifications: 80 micron on 580 micron average: 14 %

4.8. New identification of reticulated foams

Up to now, most of the reticulated foams were identified by the PPI value. For example, Bulpren S 20 is a standard polyester of 20 PPI.

Since the ppi scale will not be used anymore, we have defined a new denomination code to identify the reticulated foams introducing the cell diameter concept according to the Visiocell method. From now, we will also include in the denomination the density of the foam.

The reticulated foams will therefore be identified by:

Family Name	x	x	y	y	y

- the family name refers to the nature of the formulation and the basic properties of the material, as for example Bulpren S, Bulpren D, Bulpren B,...

- xx refers to the density according to the Recticel Rule: maximum net density plus one (in kg/m^3)

- yyy refers to the cell diameter target in micron measured by the Visiocell method, <u>divided by 10</u>: the higher the number, the higher the cell diameter (For the PPI-scale, the higher the number, the smaller the cell diameter).

The cell diameter, yyy, is always specified by 3 digits, even for values smaller than 1000 micron. A cell diameter, for example of 860 micron, is expressed by the digits 086.

Example: Bulpren S 28112
- Bulpren S = standard polyester reticulated
- 28 = maximum net density: 27 kg/m^3
- 112 = target cell diameter: 1120 micron

<u>Rules of specification range</u>
The cell diameter target - as defined by the code itself - is always the average between the minimum and maximum value of the specification.

Example: for Bulpren S 28112, the target value is 1120 micron.

The minimum and maximum of the specification could be for example 1020-1220 micron or 1000-1240 micron, but never 1000-1220 micron or 1000-1280 micron.

4.9. Actual limitations of the method

The Visiocell method can only be applied for foam with regular cell structure such as for conventional ester foams or specific ether foams with controlled cell size.

Therefore the Visiocell method cannot be applied for:

- foams with extremely fine structure (lower than 400-450 micron). The structures are always irregular. Studies are going on to define a dispersion factor of the irregularity
- foams with double cell structure (“sponge structure”)
- standard ether foams (mostly irregular structure)

4.10. “Slides”: exclusive properties of Recticel

The Visiocell method is mainly based on calibrated magnified pictures and calibrated rings, presented on transparent slides.

- The slides are the exclusive property of Recticel. They are printed sheet by sheet from a standard software program.
- The slides are only published by Recticel and identified by a 3D-stamp.
- A slide may never be copied, photocopied or reproduced. Any reproduction can affect the scale... and the results of the measurement.
- The slides and pictures are controlled by a calibrated line.
- Moreover, the diameter of both circles of each ring is calibrated according the cell diameter and the density of the foam.

The calibration of all the documents is essential in the method.
Any non-calibrated document can lead to wrong interpretation on results.

4.11. Procedure for new product development

The specifications of the cell diameter for a new development and application can be defined by 2 different approaches:

1. Calibrated sample:

Recticel has published "Calibrated Sample Boxes". Each box contains a sample of which the cell diameter has been measured by the Visiocell method.

2. Mini-Max reference samples:

The cell diameter of mini-max reference samples from the customers is measured.
The specification is defined afterwards.

In most of the cases, the definitive specifications of the cell diameter of a new product are defined by trial-error approach. Foams are produced according to a given target and afterwards the target is adapted following the experience of the customer.

5. PRODUCTION TECHNOLOGIES

5.1. Chemistry :

From a chemical point of view, a “urethane” is the ester from a carbamic acid

$$R'-NH-\underset{\underset{\displaystyle O}{\|}}{C}-OR$$

A polyurethane is the repetition of this group in a macro-molecular chain and may be obtained by the polymerization reaction of a polyalcohol (polyol) with a poly-isocyanate

$$n\ HO-R-OH + n\ OCN-R'-NCO \rightarrow -(R-O-\underset{\underset{\displaystyle O}{\|}}{C}-NH-R'-NH-\underset{\underset{\displaystyle O}{\|}}{C}-O)_n -$$

In order to obtain a POLYURETHANE FOAM, this polymerization reaction is combined with an expansion reaction, done

- Either by a chemical process : water is added to the blend, reacting with the isocyanate and generating carbon dioxide gas

$$R - NCO + H_2O \rightarrow R-NH_2 + CO_2 \nearrow$$

The amine itself reacts also with another isocyanate molecule to form an urea function which contributes to the overall structure of the polymer :

$$\left[R-NH-\underset{\underset{\displaystyle O}{\|}}{C}-NH-R'\right]_n$$

- or by a physical process, using a low boiling agent which is transformed into its gaseous state under the influence of the temperature rise, developed during the exothermic polymerization reactions.

The main feature of the chemistry of the polyurethane foams - in reality much more complicated than described here above - is the very high reactivity of the isocyanate :

- It can be combined with an infinitely large variety of polyols leading to foams of a different hardness : flexible, supersoft, rigid, semi-rigid.
- It can be combined with whatever quantity of blowing agent leading to a density from 0.007 to 1 (7 to 1,000 kg/m^3)

- high production speed : all the components are mixed together leading in one step to a polymer and a foam. This is a unique process.

- Versatility of production processes : continuous slabstock, double conveyor laminator, moulding and spraying processes.

Depending on the nature of the polyol, flexible polyurethane foams are generally divided in two main families : polyether and polyester :

- Polyether polyol : mainly derived from a blend of propylene oxyde and ethylene oxyde.

$$R - \left[O - (\underset{\displaystyle CH_3}{\underset{|}{CH}} - CH_2 - O)_x - (CH_2 - CH_2 - O)_y - H \right]_n$$

- Polyester polyol : as for example condensation polymer derived from di-ethylene glycol and adipic acid.

$$R - \left[O - (\underset{\displaystyle O}{\underset{\|}{C}} - (CH_2)_4 - \underset{\displaystyle O}{\underset{\|}{C}} - O - CH_2 - CH_2 - O - CH_2 - CH_2 - O)_x - H \right]_n$$

Generally, for flexible foams, the nominal functionality, n (number of hydroxyl groups per molecule), is 3 in case of flexible ether foams are 2.5 till 3 in case of flexible ester foams.

5.2. Raw materials :

The raw materials for the production of PU foams are classified in 5 families.

The most important are :

1. Polyol :

- Polyether polyol, based on propylene and/or ethylene oxyde : mainly used for comfort applications.

- Polyester polyol, obtained from the condensation between a polyalcohol (as ethylene glycol) and an organic acid (as adipic acid)

2. Isocyanate :

- Toluene diisocyanate (TDI) : 80/20 or 65/35 (ratio of isomer 2.4 and 2.6) : mainly used for flexible foams.
- Methylene diphenyl diisocyanate (MDI) : used for several applications, including rigid foams.

- Isophoron diisocyanate (IPDI) : used for several light UV stable PU products. Other aliphatic isocyanates may be used.

3. Water :

- Water is the chemical blowing agent (reaction with isocyanate to form carbon dioxyde gas).

4. Fixed additives :

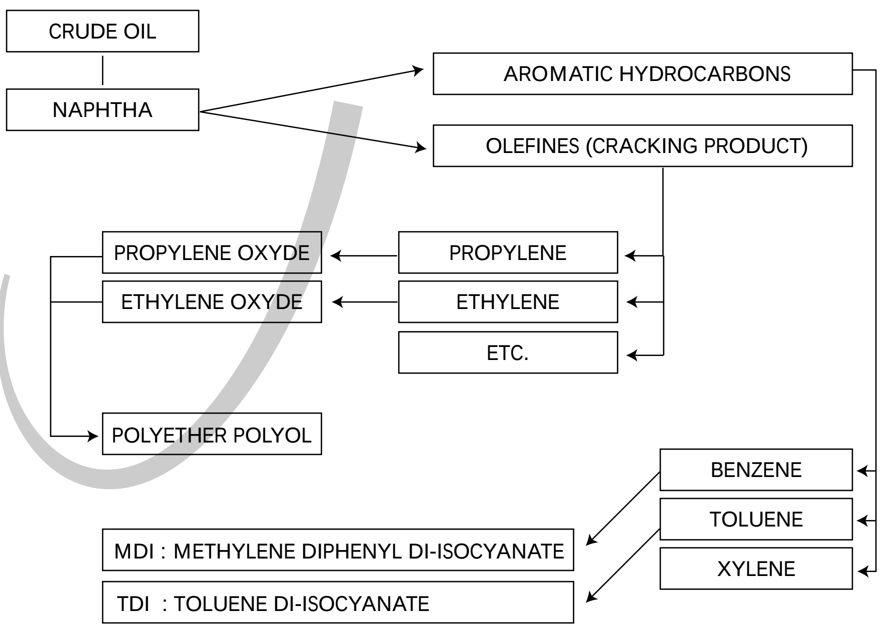
- Catalysts based on amines and organometal derivates.

- Stabilizers based on silicones or non silicones.

5. Optional additives :

- Physical blowing agents
- Fire retardants
- Anti-oxydants
- Colorants
- Crosslinkers
- etc...

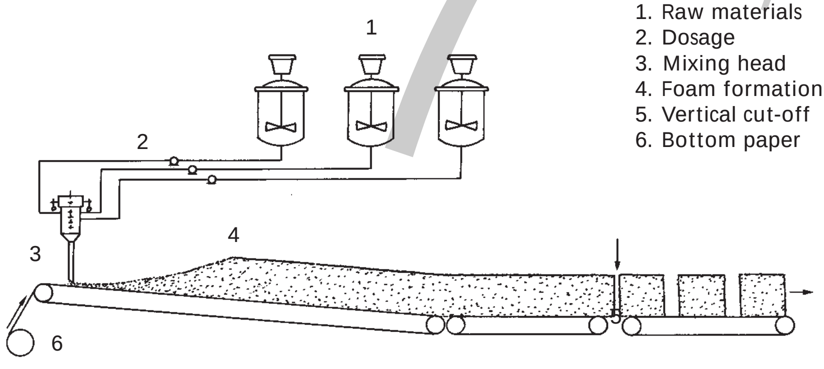
5.3. Raw materials chart from crude oil to Polyol and Isocyanate :



5.4. Continuous slabstock foaming technologies :

5.4.1. Inclined Conveyor.

The emulsion resulting from vigorous mixing of the raw materials is poured onto a rolling conveyor with vertical variable walls.
After a few seconds, a cream is formed, the volume expands and the foam reaches in about one to three minutes its maximum height.
Polyether and polyester polyurethane foams may be produced by this technology.
By variation of the formulations, a wide range of qualities may be obtained.



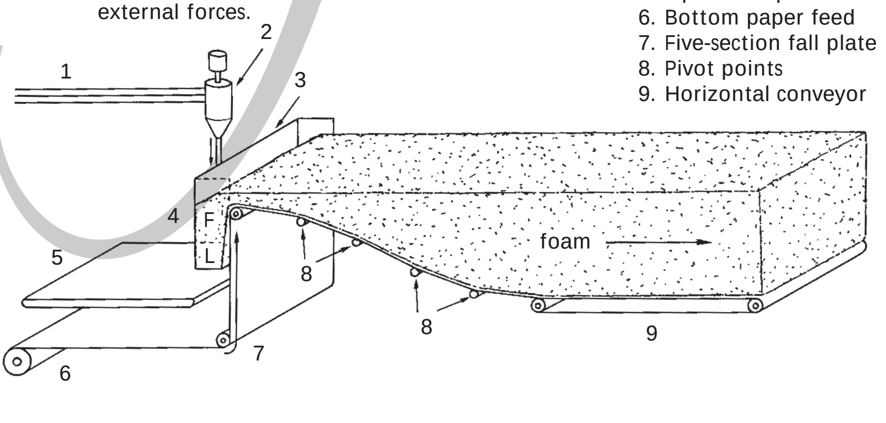
1. Raw materials
2. Dosage
3. Mixing head
4. Foam formation
5. Vertical cut-off
6. Bottom paper

The production of square block shape is a key issue in the slabstock process. By free rise foaming, one obtains blocks with “round tops”, like a bread, due to the mechanical resistance of the side walls. Square blocks are obtained by pulling the foam with a foil on the sides or by pressing the top with a plate.

5.4.2. Downwards foaming

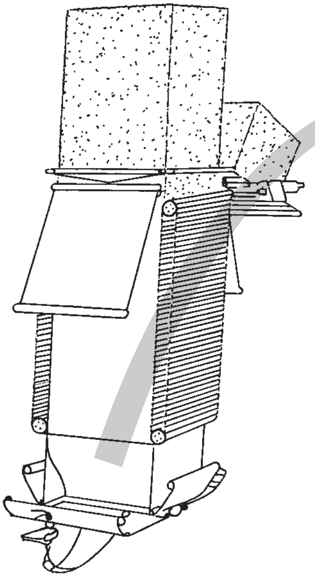
This process is similar but the emulsion “falls” down. By this process, one obtains square blocks without external forces.

1. Raw materials
2. Mixing head
3. Trough
4. F-foam - L-liquid
5. Operator’s platform
6. Bottom paper feed
7. Five-section fall plate
8. Pivot points
9. Horizontal conveyor



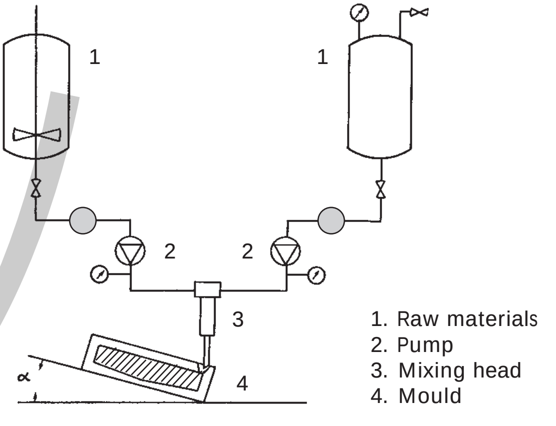
5.4.3. Vertical Foaming.

By this process,
one obtains also square blocks.



5.5. Discontinuous (Moulding) :

Here, the emulsion is poured into a closed or open mould and the foam is formed. This discontinuous process allows to obtain in one step, finished cushions. The process, in terms of “volume” is slower than the slabstock, but avoids the cutting scrap.



R.I.M. (Reaction Injection Moulding) is similar. The raw materials are injected in a closed mould in order to obtain finished pieces of higher density (steering wheel, computer housing, ...).

The moulding technology allows to place an insert in the mould before foaming in order to reinforce the structure of the finished piece.

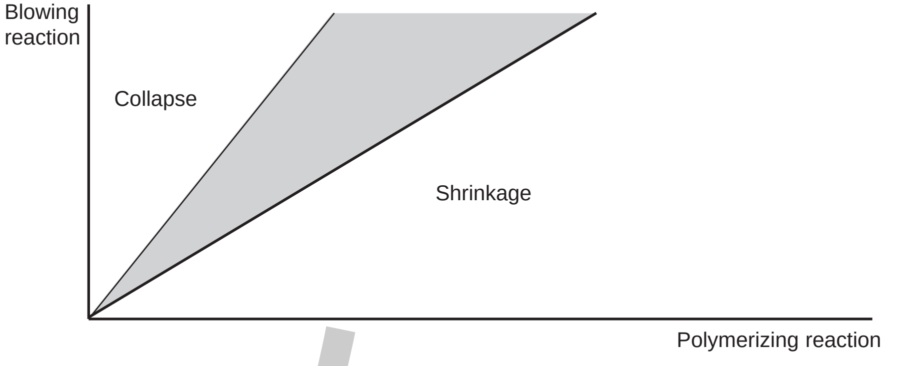
5.6. Foaming : Critical curve (process) :

Foaming remains an “art” : it combines two simultaneous reactions in 5 steps.
The two reactions are the polymerization reaction and blowing reaction.

The five steps are :

* Mixing the liquid raw materials
* Nucleation start
* Start of the reaction
* Stop the reaction (end of rise) while the cells are blowing
* Curing : to finish the polymerization and allowing the hot blocks to cool down

The ratio between the blowing reaction rate and the polymerization reaction rate is the key process parameter : when the first is fast, the foam “explodes” and collapses. When the second is too fast, the blowing is retarded, the foam remains closed and shrinks during cooling. This is illustrated by the “Foaming Critical Curve” : only an appropriate ratio (specific for each foam type) will lead to an appropriate foam.



5.7. Comparison Ether <-> Ester PU foams :

1. Typical advantages ester vs ether :

* Cell structure homogenity / cell count control
* Mechanical properties (hardness / mechanical strength)
* Flame bonding adhesion
* Thermal and HF welding / Thermoforming
* Resistance to photo-oxidative UV ageing (degradation /discolouration).
* Acoustical absorption (lower air permeability)
* Inherent fire resistance
* Resistance to organic solvents (swelling)
* Shock absorption (higher hysteresis)

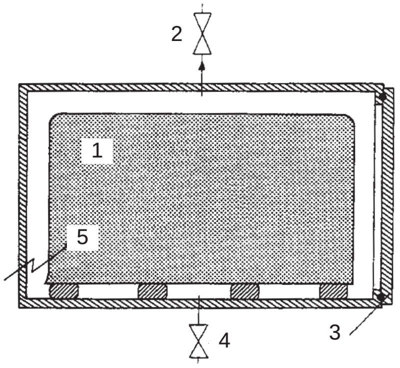
2. Typical disadvantages ester vs ether :

* Price : raw materials and block size = (block yield)
* Humid ageing (hydrolysis)
* Clickability (unless non-clickable applications !)
* Fogging (unless treated ester polyols)
* Smell (unless selection lower odour amine catalysts)
* Comfort properties

3. Air Permeability :

Mostly lower in case of ester -> advantage or disadvantage, depending on applications.

5.8. Reticulation :



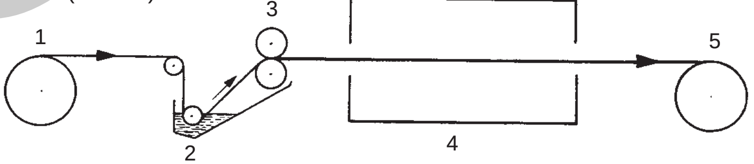
The flexible foams obtained from slab-stock production partially contain closed cells.
By a thermal process - explosion of oxygen-hydrogen in a closed reactor - all the residual cell membranes are melted and a completely open cellular network is obtained.
In principle, all types of flexible foams can be reticulated.

1. Foam
2. Vacuum line
3. Reactor door
4. H_2 and O_2 inlet
5. Ignition plug

5.9. Impregnation :

The impregnation consists in dipping the foam into a bath, squeezing and drying it afterwards in an oven.
Following the nature of the chemicals used for the impregnation, specific new properties are conferred to the foam : flame resistance, HF welding, self-supporting.

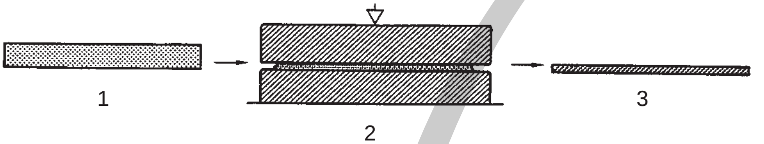
1. PU-foam (non treated)
2. Impregnation bath
3. Nip-rollers
4. Oven
5. PU-foam (treated)



5.10. Densification :

By compression and heating the foam up to a permanent deformation, new cellular materials with a higher density and mechanical properties are obtained.
All types of flexible foams can be densified by this process.

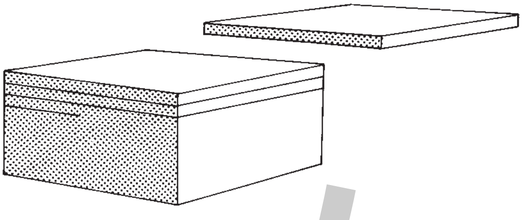
Densification may be alternatively limited to the surface of the foam, leading to a skin formation on one or both sides.



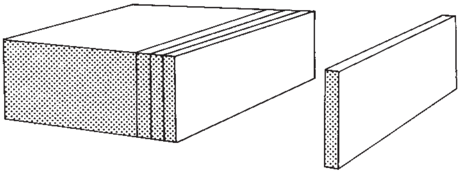
1. Foam sheet before densification
2. Heat press
3. Foam sheet after densification

5.11. Cutting technologies :

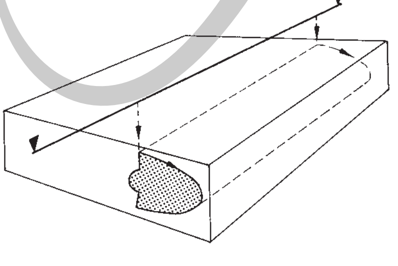
HORIZONTAL SPLITTING



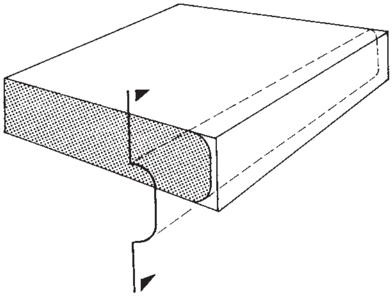
VERTICAL SPLITTING



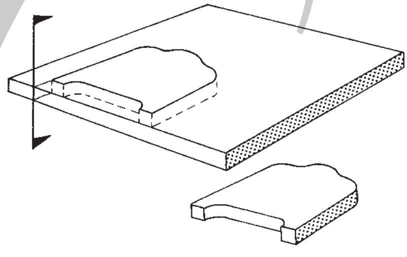
CONTOUR CUTTING



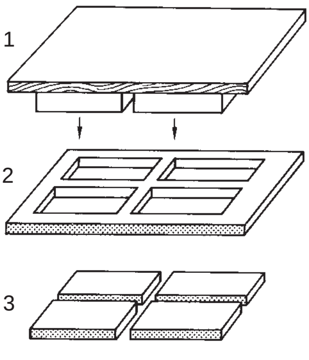
RADIUS CUTTING



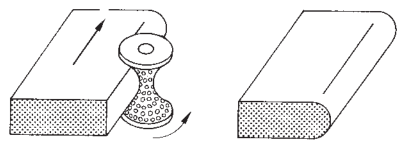
MODEL CUTTING



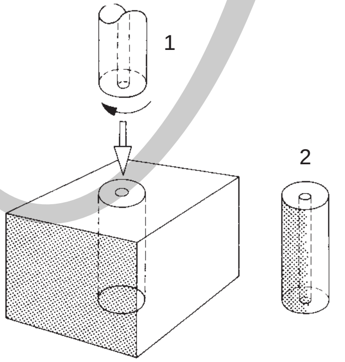
DIE CUTTING



MILLING

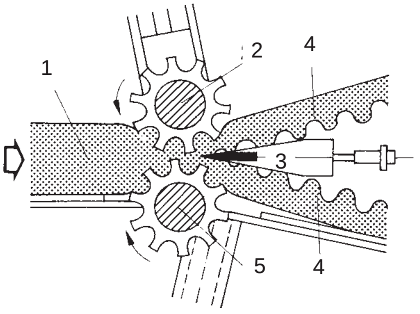


BORING



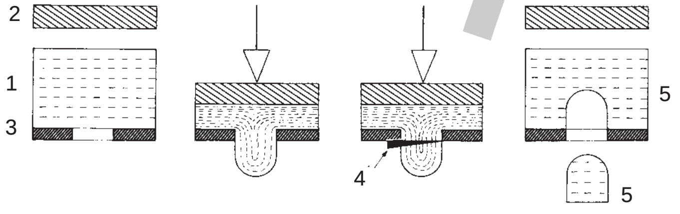
1. Boring tool
2. Finished piece

DEFORMATION CUTTING CONTINUOUS



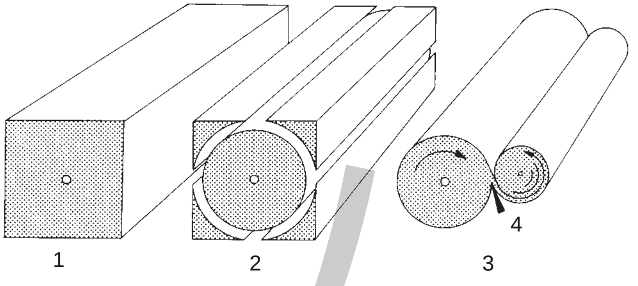
1. Foam sheet
2. Deformation rollers
3. Knife
4. Finished sheets

DEFORMATION CUTTING DISCONTINUOUS



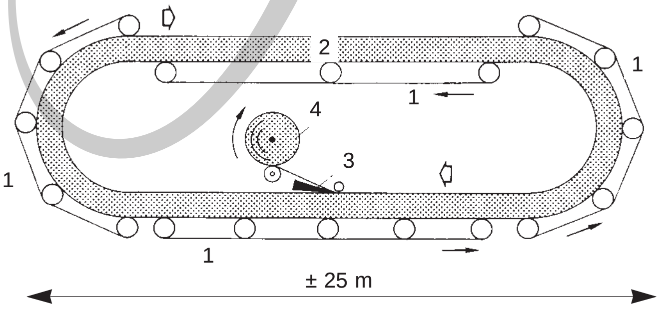
1. Foam
2. Press
3. Deformation tool
4. Knife
5. Finished piece after deformation cutting

PEELING



1. Block
2. Pre-cutting
3. Peeling
4. Knife

ROLL CUTTING



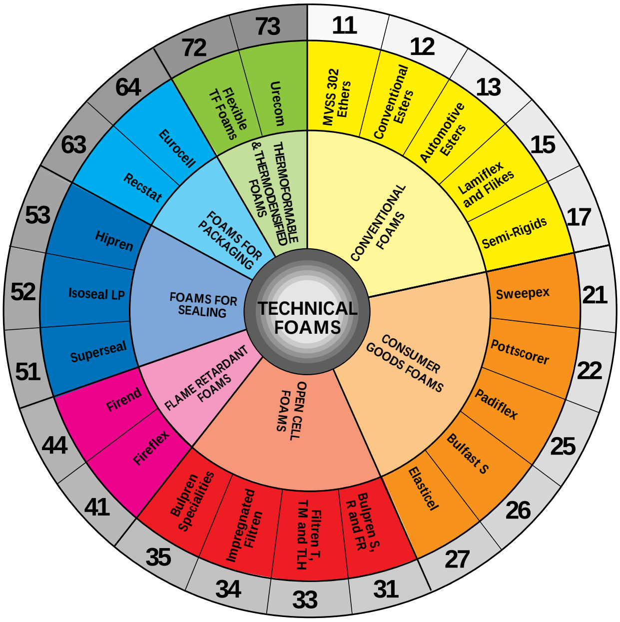
1. Belt
2. Foam
3. Knife
4. Foam roll after cutting

5.12. Conversion table :

		UNIT	SYMBOL	CONVERSION
Length		METER	m	× 3.28084 = ft × 39.3701 = in
		Foot	ft	× 0.3048 = m × 12 = in
		Inch	in	× 0.0254 = m × 0.08333 = ft
Mass		KILOGRAM	kg	× 2.2046 = lb
		Pound	lb	× 0.45359 = kg
Force, weight		NEWTON (= kg.m/sec^2)	N	× 0.10197 = kgf × 0.22481 = lbf
		Kilogramforce	kgf	× 9.80665 = N × 2.20462 = lbf
		Poundforce	lbf	× 4.44822 = N × 0.45359 = kgf
Temperature		Degree Celsius	°C	°F = 9/5 °C + 32
		Degree Fahrenheit	°F	°C = 5/9 (°F − 32)
Volume		Cubic meter	m^3	× 423.789 = bd ft
		Board foot	bd ft	× 0.00236 = m^3
Density	Weight per unit of volume	KILOGRAM PER CUBIC METER	kg/m^3	× 0.06243 = lb/cu ft
		Pound per cubic foot	lb/cu ft	× 16.0185 = kg/m^3
Speed	Displacement per unit of time	Centimeter per minute	cm/min	× 0.03281 = ft/min
		Foot per minute	ft/min	× 30,48 = cm/min
Flow	Volume per unit of time	Cubic meter per hour	m^3/h	× 35.3147 = cu ft/hr
		Cubic foot per hour	cu ft/hr	× 0.02832 = m^3/h
—	Force per unit of length	Newton per linear centimeter	N/cm	× 0.571015 = pli
		Pound per linear inch	pli (lbf/in)	× 1.75127 = N/cm
Pressure, Tension	Force per unit of surface	PASCAL (= Newton per square meter)	Pa	× 0.001 = kPa
		KiloPascal	kPa	× 0.14504 = psi

			× 0.01020 = kgf/cm^2 × 4.01463 = in wg
	Pound per square inch	psi (lbf/in^2)	× 6.89476 = kPa × 0.07031 = kgf/cm^2 × 27.6807 = in wg
	Kilo per square centimeter	kgf/cm^2	× 98.0665 = kPa × 14.22334 = psi × 393.712 = in wg
	Inch of water gauge	in wg	× 0.24909 = kPa × 0.03613 = psi × 0.00254 = kgf/cm^2

Capital letters = International Standard Units



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