## OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

TOGETHER
for a sustainable future

## DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

## FAIR USE POLICY

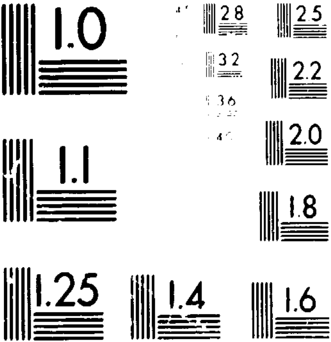
Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

## CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

13769

Distr.
LIMITED

ID/WG.426/5
4 July 1984

ENGLISH

**United Nations Industrial Development Organization**

Seminar on Furniture and Joinery Industries
Rêduit, Mauritius, 6 - 24 August 1984

# FOAMS USED IN UPHOLSTERY *

by

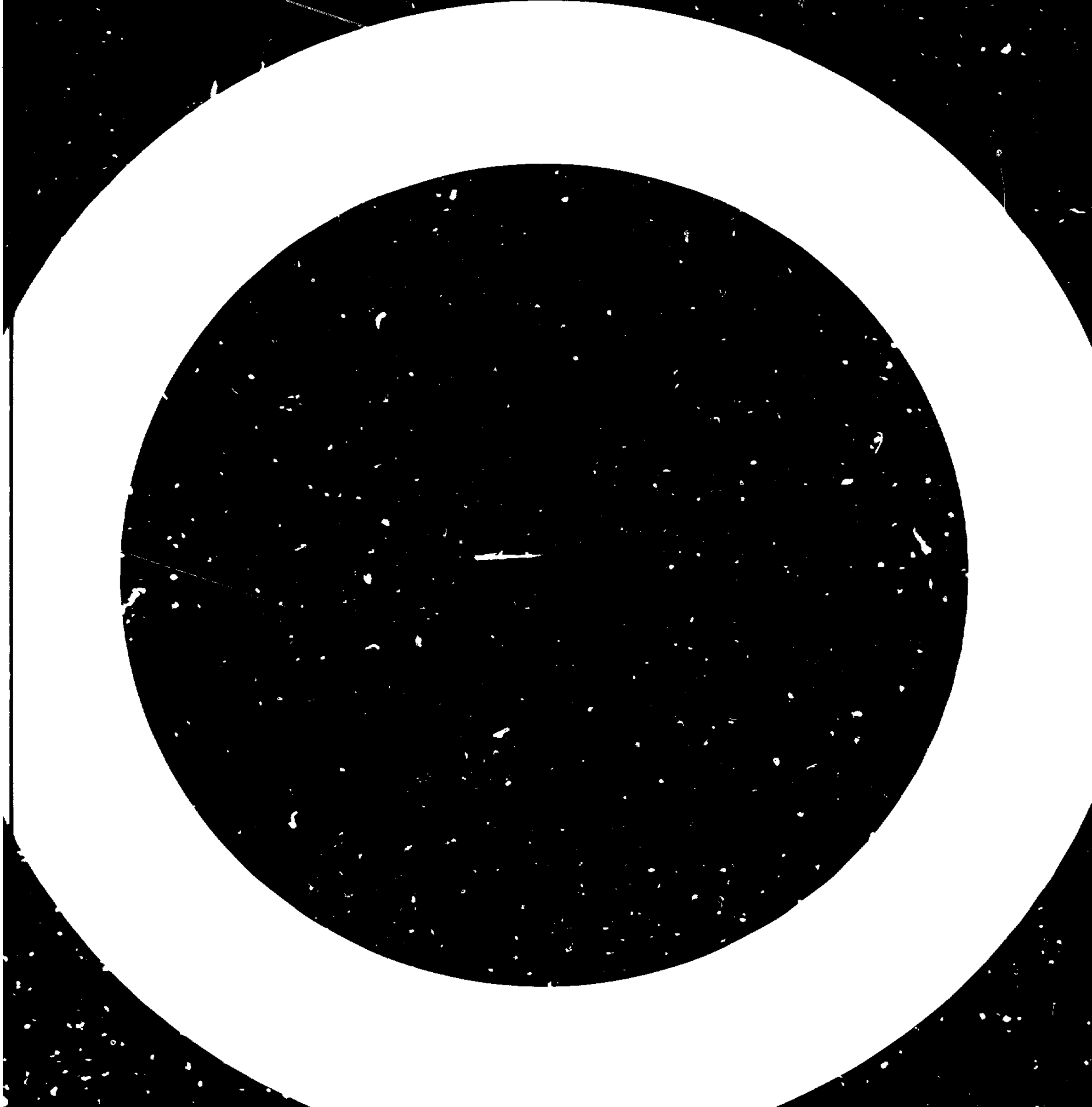
I. M. Sayed **

---

* The views expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. This document has been reproduced without formal editing.

** Manager, Ply Form, Ply Foam, Port Louis, Mauritius.

Mention of firm names and commercial products does not imply endorsement by the United Nations Industrial Development Organization (UNIDO).



## TABLE OF CONTENTS

## INTRODUCTION

This paper discusses foams used in upholstery and to be a bit more specific, about foams used in upholstery in the furniture trade. These fall in two distinct categories: foams made from natural products - mainly rubber foams, of which perhaps DUNLOPILLO is the best known trade name, and those manufactured from artificial resins such as Polyester and Polyurethane and which have come to be collectively known as "plastic" foams.

After the second world war and up to the early seventies rubber foams, though expensive, reigned supreme for seating, backrests and bedding. The plastic foams were in infancy and rather expensive; and the qualities in many cases left much to be desired. Then came a very rapid development in the chemistry and technology of artificial foams - specially on the catalyst and the stabilizer side and the advent of the one-shot process on the equipment side - and in a very short lapse of time the so-called artificial foams have but completely superseded the use of natural rubber foams in the furniture trade. Polyester and polyurethane foams developed side by side but with the highly specialized equipment required for the former and coupled with its limited qualities it soon occupied a small and very particular niche in upholstery.

The vulgarization of methods of manufacture for polyurethane foams by the one-shot process made it at the same time, more accessible and more widespread all over the world. These foams - in their rigid, semi-rigid and flexible forms - are now made by various methods which range from the very simple, mixing by hand in a couple of buckets, to the fully automated, with fully automatic machines producing blocks up to five metres in width, one to one and a half metres in height and of unlimited length.

Thus, at present, polyurethanes form the bulk of the foams used in the furniture industry, and, the discussion will centre around this particular product. Such a review can hardly be contemplated without brief reference to the technical and commercial development which contributed to the establishment of this major industry, and one may perhaps start by recording that some of the basic chemistry associated with the subject was first observed as early as the 1880's, when laboratory attention was given to some fundamental reaction of the isocyanates. At this early stage, the observations made were of little more than academic interest, and it was not until the early 1930's that any major research was directed towards the study of reactions which involved di-isocyanates and hydroxyl materials.

Such commercial objectives as existed at the time lay more in the field of synthetic fibres and elastomers, but no major break-through occured during the pre-war period. During World War II shortages of certain natural materials led to more serious consideration being given to the commercial production of elastomers, mainly intended as rubber substitutes.

In the years immediately following the war, attention shifted towards investigation of flexible polyester foams, and commercial production started in the early 1950's. Their usefulness was, however, limited in scope at that time due to prevailing high raw material costs and their relatively narrow field of application, restricted by the physical properties of the product available.

Postwar developments of the petrochemicals industry, based initially on ethylene oxide and, later on on propylene oxide, led to the investigation of polyalkylene glycols as the basis building blocks for polyurethane foams. Polyester and polyether materials were examined and, whilst in the early years polyester predominated, it was not long before the preferred economics and physical properties of polyethers enabled them, not only to find a major place in this industry, but also to overhaul and very largely replace polyesters.

The above was the history in brief of these famous additions to human comfort and now we will take the foams used in upholstery individually by groups. We will look into their uses, potential and suitability of use by those concerned. We will discuss their properties, their strengths and their weaknesses, their detailed characteristics and the cause of each change in these characteristics; in other words we will try to see how we can choose a good product among the many offered for sale in our country, and how we can make good use of it, which will eventually be for the good of one and all.

## GENERAL INFORMATION ON FOAMS

### 1. Natural rubber foams

These are mainly used nowadays where high resilience is required in a very restricted space, i.e. in aircraft pilot seats, bar stools and similar narrow based pieces of furniture. Also being used in up-market high-value items but is gradually being replaced by the new cold-cure polyurethanes which do the job at far lower costs. Also being used in countries like Malaysia where rubber is a local product and,to encourage its use, the raw material for artificial foams carry high entry duties and their manufacture is restricted.

## 2. Polyester foams

These have a restricted use as buoyancy material in life jackets used at sea and in thin form for high-frequency welding to other base material such as artificial leather for padding in furniture and road vehicles.

## 3. Polyurethane foams

Also called polyether foams: These foams which form the bulk of the foams used in furniture upholstering are manufactured from six components namely (a) Polyol resin, (b) Blowing and gelling catalysts, (c) water, (d) Isocyanate, (e) Silicone oil and (f) Fluorocarbons. Minute variations of some of the components provoke a change in one or many of the parameters set out for foams manufactured for specific end-uses such as seats, backrests, mattresses, etc.

We will now analyse the different parameters required and see how it affects the end user who, in the case of furniture manufacturers is their client, and through him, it also affects them.

### 3.1 Density

The density of a foam is important from the point of view of both the producer and user alike, because it affects the price, the comfort, the durability and to a certain extent the aesthetics of the final product, namely the piece of furniture. Theoretically a denser foam used for either a seat or a backrest gives better comfort and durability as long as other properties, substantially the resilience, are controlled. By varying the isocyanate content of a formulation for example, the resilience of a foam can be modified from hard to very soft. This is where the economics take over and manufacturers can be tempted to provide the right density but the wrong resilience. The different densities used for seats, backrests and for bedding are mainly produced more for economic reasons than material comfort.

## 3.2 Air permeability

The air permeability (air flow through foam) characteristic in a flexible foam is governed by the percentage of open cells in the finished foam, which should be between 75 to 98 percent. Air flow is controlled by (a) the amount of TDI[1] in the formulation, and (b) the proportion of gelling catalyst, as well as (c) admixture of air in the mix during manufacture. A simple test for air flow is to blow through a piece of foam after taking a deep breath; if you can blow through easily it means that the material contains a high percentage of open cells. The reason I am stressing this point for is that a foam with a high proportion of closed cells feels hard to the touch and may be thought to have a higher density. If such a foam is used, very soon all the closed cells will open up and the cushioning will be flabby and may even disintegrate.

## 3.3 Tensile strength and elongation at break

A properly formulated foam of any density should show good tensile strength - i.e. should not tear easily when pulled between the fingers. This will affect its ability to hold nails, staples or any other fastening used to hold it in place before the cover is laid on or if the foam needs to be stretched on its frame as in the case of dining room chairs. On thick sheets, the tensile strength can be fairly assessed by pressing one's mid-finger vertically into the foam. If the tensile strength is low one's finger will simply sink in as the foam tears away and practically no resistance is felt. Such foams when used in highly stressed areas as seen in furniture upholstering will give very poor results, and may not be long lasting in use.

## 3.4 Compression hardness: compression set

For any given density of foam the compression hardness, i.e. the resilience can vary over a wide range. This has partly been dis-

---

[1] TDI: Toluene di-Isocyanate

cussed under 3.1 above, even though we must admit that compression hardness, taken as such, does not reflect the quality of a foam; but taken together with other parameters such as density, will start by giving a good appreciation of quality - we can have a good idea how a foam will behave in practice. In our own country we have found that most users prefer a higher compression hardness in their seat material, but on the other hand we do manufacture, upon request, a foam of equal density, namely 25 kg/m$^3$, but with two thirds of the resilience. This quality is used only by four or five discerning manufacturers.

This implies that taste varies within a market and one should consult with one's clients, and listen to their appreciations, so one can make a good choice of seat or back of bedding material. "Comfort" is a very relative and whimsical thing.

From the above you will note that there are certain parameters which should not vary within too wide a limit as they affect the physical properties of foams as far as strength, durability and ease of use are concerned; whereas there are others which can be made to vary over wide limits as they control mainly user comfort. Generally speaking in the industrialized economies, the tendency is to use softer base material both in the furniture and bedding industries. In the lesser developed countries, the trend is towards materials of higher resistance.

## 4. Cold cure foams

These are used mainly in moulded form. These foams have been found to possess hysteresis resembling those of, and in many instances even better than those found in natural rubber foams. Their use is becoming more widespread as there is less waste, the product coming out of the mould in finished form. Their present drawback is the high cost of raw materials and their shelf-life which is limited to about six months. And also the costs of moulds, which are not justified in the restricted markets of the less developed countries.

## 5. Rigid foams

In the furniture trade, at present, the use of rigid and semi-rigid foams is restricted to the manufacture of chair shells and some cabinet components.

In some very particular cases, it is used as a packing material. These end uses have not progressed much during the last five or six years and unless some spectacular developments occur in the research laboratories, the use of rigid foams in our trade will be rather restricted. The large use of rigid foams in building components indirectly assists the furniture trade, and this symbiosis may help develop new uses of rigid foams in the furniture trade itself.

## 6. Self skinning foams

The polyurethane self-skinning foam process is one which is designed to produce both a cellular core and a non-porous outer skin in one moulding step. The skin is an integral part of the moulding, and articles of furniture made from this process present the advantage of having less steps in production from the raw material to the finished product. The snag is, of course, costs, as a different mould is required for each article to be produced, as in the case of rigid foams. Self-skinning foams are produced in both rigid and flexible form. The machinery required to produce these foams is also different, and the chemicals for the RIM (reaction injection moulding) process as this technique is known are also different from those used in current practice.

## Fire hazards

The fire hazard in polyurethane foams is no more pronounced than in other upholstery materials, but unfortunately the combustion gases are poisonous, and this has given polyurethanes a bad name. As the chemical composition of the raw materials cannot be altered, steps have been taken to prevent the rapid spread of flames in the event of a fire, by mixing additives to the foam raw materials at the time of production. The fire retardants added to the foam mixture increase the temperature at which ignition takes place and decrease the speed at which the flames spread. But the fault may not lie wholly with the foam used. For example, the resistance of flexible PUR[1/] foams to lit cigarettes is very much dependent on the upholstery combination. Covering fabrics based on part or whole on cellulose may, under certain circumstances, constitute an ignition risk when exposed to lit cigarettes. With vulnerable

---

[1/] PUR: Polyurethanes

upholstery combinations of this kind, even the inclusion of interliners which are capable of smouldering (such as cotton non-wovens) do not obviate the risk of ignition. Neither, as a rule, does the treating of the cotton with flame retardants have any significant effect on the risk. Simple protection of the upholstery material by means of non-combustible interliners, such as fibreglass fabric, is equally ineffective with regard to the elimination of the danger of smouldering fire.

Resistance to lit cigarettes and the like is greatly increased by the use of covering fabrics and interliners whose melting and heat dissipation properties effectively withdraw sufficient heat from the point of application of the glowing object. Afterglow processes of the sort familiar with cork, which, experience shows, can lead to smouldering fires and the spread of fire under cover, do not occur with insulating materials based on polyurethanes.

With regard to furniture, the combination of the materials used for the upholstery and the design have a decisive influence on the contribution to flame spread. On exposure to radiant heat (eg. components which are already burning), covering fabrics which exhibit thermoplastic behaviour tend to melt and peel giving rise to increased decomposition of the upholstery material and flashover or increased combustion.

The contribution to flame spread can be considerably reduced by selecting suitable covering fabrics with carbonizing properties, and by incorporating special protective interliners.

In addition to the ignition risk and the contribution to flame spread, the hazardous nature of combustible materials is also characterized by their contribution to the overall calorific balance of the fire. If one compares the lower calorific values for polyurethane foams with those of comparable natural products such as rubber, wood, cotton, etc., one finds that polyurethane foams can in no way be considered inferior.

Thus, given equal volumes, polyurethane foams made a similar or considerably smaller contribution to the calorific balance of a fire than do comparable products. As these foams have practically superseded all other types of upholstery material, a fire in a public, overcrowded place such as a discotheque is bound to attract more adverse publicity. All in all polyurethane foams are in no way better nor any worse than upholstery material of other sorts.

## Desirable properties of foams for upholstery

We have described in 3.1 to 3.4 above some empirical methods that the user can adopt when he purchases foams for his upholstery shop. We will now discuss this in more scientific terms. Through the diagrams, drawings and data at the end of this section, you can see that the measurement of the characteristics of foams require a considerable amount of apparatus and technique, but this is not the user's business to provide. In normal practice, this is done by (a) the local bureau of standards, (b) the foam manufacturer himself, and (c) the supplier of the raw materials - provided that the foamer sticks to the original formulations used by the raw material manufacturer.

What constitutes a good foam? This is the question that many a furniture manufacturer puts to himself when it comes for him to purchase his padding material. There are no hard and fast and absolute rules to go by, but with time, some code of practice has been established, and more than anything "experience" is more the guideline, and reliability of the foam manufacturer, and the trust that the user puts in him, plays a big role in the choice of the user. The code of practice varies from country to country, and many a time within the same country.

But a consensus has been established, and presently the following is more or less current practice:

Standard polyurethane foams for seating, 23-30 kgs/m$^3$ density, for backs, 18-23 kgs/m$^3$ density and for mattresses, 20-25 kgs/m$^3$ density.

As we have seen in 3.1 above, density does not mean much if not coupled with other parameters, so the table hereunder has been compiled to give a better understanding of the product offered.

| | | | |
|---|---|---|---|
| Foam density in kgs/m$^3$ | 23- 30 | 28- 23 | 20- 25 |
| Air permeability ++ | 115-125 | 115-125 | 115-125 |
| Tensile strength (kPa) | 100-110 | 75- 90 | 80-100 |
| Elongation at break (%) | 175-200 | 160-180 | 140-160 |
| Compression hardness (kPa) | 4- 5 | 1.5-3.8 | 3.5-4.5 |

---

++ 100 = completely open cells to 350 = completely closed cells.

Foams having characteristics varying between the values mentioned above have been found to give good performance for the respective uses mentioned.

The properties of cold cure and self-skinning foams vary considerably from those of standard foams, and these foams are tailored to their intended specific end-use, so standards for these goods are not established, but are normally set out by the user, and the required raw material supplied by the manufacturers to produce the characteristics set out at time of the purchase.

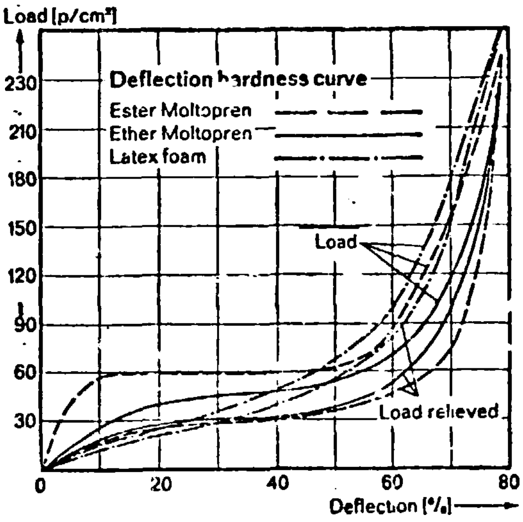


Fig. 1: Deflection hardness curve

Before looking in detail at foam characteristics, we will cast a glance at Fig. 1. We see from there that the deflection hardness curve for Latex foam forms a very smooth curve from low loading to high loading, whereas the curves for the other foams which are of synthetic origin show bumps in their curves, which indicates that their ability to take loads are not even throughout their performance under load. This is what has made the biggest difference between latex foams and their synthetic substitutes. We must note however that the curves for cold cure and self-skinning foams nearly equal the curve for latex foams.

## Characterization of properties of flexible foams

### 1. Density and apparent density

Density is a property which is particularly suitable for the characterization of a material, because it is dependent neither on the geometry of the test specimen nor on the test method used. Moreover, many technological properties of expanded polyurethane materials in particular are very much dependent on their apparent density. It is therefore essential to state the apparent density values whenever discussing the other properties of foams. With expanded materials, the term "apparent density" refers to the fact that the entire volume of the test specimen is taken into account, and not just the much smaller volume actually taken up by the mass of the polymer (for example, with a foam having a apparent density of 24 kgs/m$^3$, the polymer itself accounts for only approximately 2 percent of the total volume of the sample on which the calculation is based).

With semi-flexible and rigid PUR foams, the apparent density is more or less constant throughout the entire article. Special systems, such as integral skin foams, are produced using formulations and processing methods which result in great differences in apparent density between the skin zone and the core. The determination of density is described in ISO R 1183, and that of the apparent density of foams is described in ISO 845. (Full numbers and titles of all ISO, DIN, BS and other standards are referred to in annex I).

### 2. Mechanical properties

As in the case with all highly polymeric organic materials, the properties of polyurethanes are also dependent on the temperature at the time of measurement, and the duration of the load or rate of deformation during the test.

Thus mechanical tests can be divided up according to the type of load and the conditions under which it is applied: tensile, compressing and flexion tests, as well as those for hardness, are tests of short duration with low rates of deformation. Impact and shock tests are of short duration with a high rate of deformation. Long term tests using a static load (creep tests) and a vibrating load (dynamic fatigue test) complete the spectrum of properties as regards long term performance. The torsion pendulum test, whereby the shear modulus and mechanical damping are determined as a function of temperature, is used principally to obtain information on changes of state, and thus to gain an insight into the structure of the macromolecules and their arrangement.

## 3. Tensile tests

PUR materials are subjected to tensile stresses during production, fabrication and in actual service. Tensile tests (see Fig. 2) are therefore standard for most polyurethane types. Using a predominantly uniaxial load, and a constant rate of deformation, the relationship between force and deformation is determined until failure occurs. The force - deformation diagram obtained is converted into a stress-strain diagram (see Fig. 3), in order to be able to

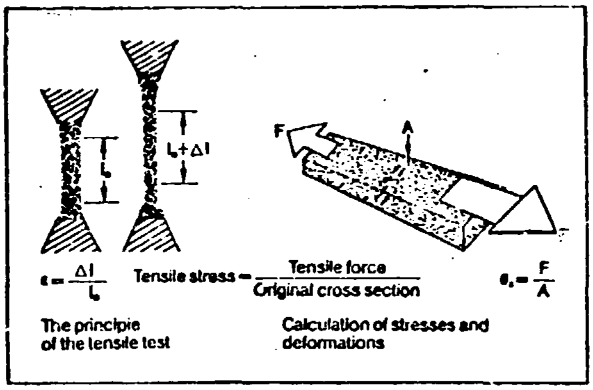


Fig. 2: Tensile test

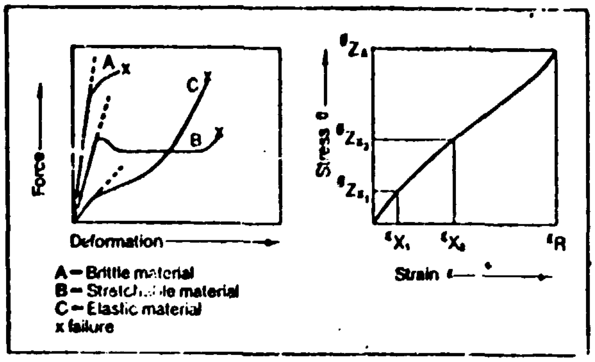


Fig. 3: Force-deformation diagrams

make comparisons between test specimens of different cross sections. In each case, the tensile force is related to the initial cross section of the sepcimen, in order to obtain the tensile stresses. The elongation is obtained from the change in length in relation to the original length.

The rupture stress and associated elongation at break are derived as characteristic values from the stress-strain diagrams. Occasionally, the stress at a particular elongation, eg. 100 percent, is referred to as a characteristic.

## 4. Tear resistance

In addition to the tensile test, flexible PUR materials are also subjected to a test which determines the resistance to tear propagation of a cut specimen; specially shaped test specimens are used here.

## 5. Compression test

In compression tests, a test specimen is held between two parallel plates and the force necessary to compress it at a constant deformation rate is determined. From the resultant compressive stress-compression diagrams, the stresses for rigid foams are given as follows: at 10 percent compression for very rigid systems, and at the initial breakdown of the cellular for brittle, hard systems (see Fig. 4).

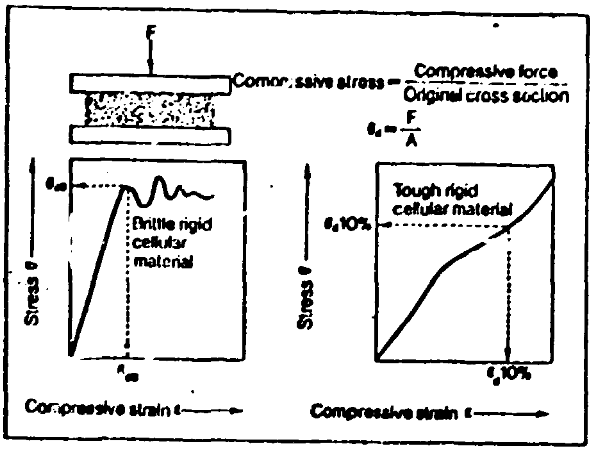


Fig. 4: Stress Compressive Strain Diagrams

The characteristic values and functions obtained from the results of compressive stresses are those most frequently used for classification, particularly in the case of PUR foams. With flexible and semi-flexible systems, they provide reliable information on the behaviour of the foam during load application and removal (in the form of compression hardness curves), and enable a very clear distinction to be made between the various types (see Fig. 5).

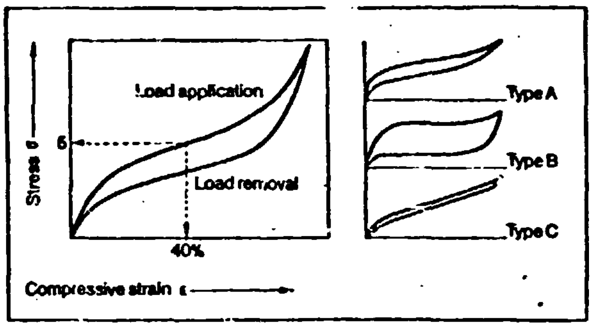


Fig. 5: Compression Hardness Curves

Differences in hardness are evident in the different gradients of the load application and removal curves. Differences in flexibility are indicated by the areas enclosed by the load application and removal curve. Particularly flexible foams give diagrams of type C as shown in Fig. 5. The compressive stresses at 40 percent deformation (compression hardness) are often taken as characteristic values.

## 6. Indentation hardness tests/hardness determination

In the case of flexible PUR foams in particular, the results of compressive tests are often confused with the data obtained from indentation hardness tests. The indentation hardness test is quite different from the compression test, because the test specimen is compressed by a plunger only over a portion of its surface (see Fig. 6).

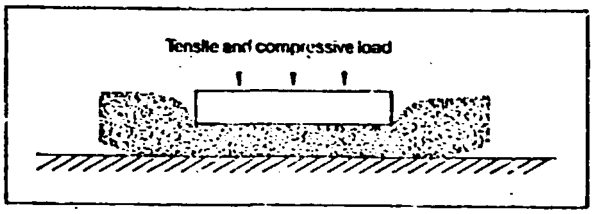


Fig. 6: Principle of the indentation hardness test

The forces necessary to produce indentations to certain distances are represented by force-deformation diagrams, and from these the indentation forces leading to a particular degree of deformation (25%, 40%, 65%) are taken as characteristic values.

Since this method is particularly suitable for the non-destructive testing of mouldings, results obtained on differently shaped test specimens and mouldings are sometimes mistakenly compared. In order to characterize the hardness (shore hardness) of elastomers, a special indentation hardness test is used in which a small, cone-shaped, spring loaded, pin is pressed into the test specimen. The indentation depth is an indication of the hardness of the elastomeric material. These shore hardness data, which are obtained with small, easy to handle instruments, are typical single reference values, and should only be referred to in connection with other technological parameters.

## 7. Bending tests

Bending loads are often encountered in actual service conditions, and are therefore important, particularly in rigid PUR foams and rigid integral skin PUR foam systems. The bending test laid down for these products in ISO 1209, in which the force necessary to deflect a test specimen under three-point loading is determined (see Fig. 7), is used exclusively for the purpose of comparative tests and quality control.

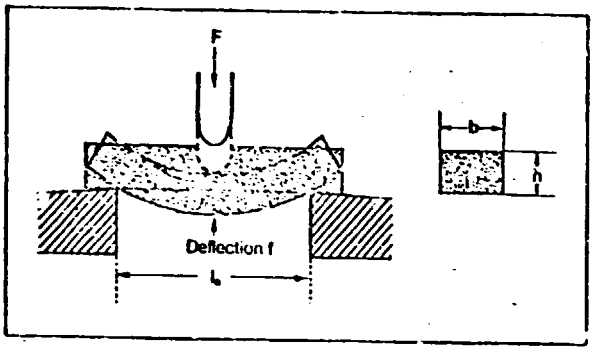


Fig. 7: Bending Test

The data obtained cannot be used for design engineering purposes, because the three-point loading which is a feature of this test prevents pure bending loads from being brought to bear on the test specimen.

8. Shearing tests

The material to be tested is glued between two parallell metal plates which then move in opposite directions (see Fig. 8). The force required to produce failure of the test specimen is converted into shear stresses to give shear strength; the stress-strain curves initially displays an almost linear profile i.e. stress and deformation are proportional to each other. The quotient of a stress and the elongation caused within this linear range is known as the modulus of elasticity.

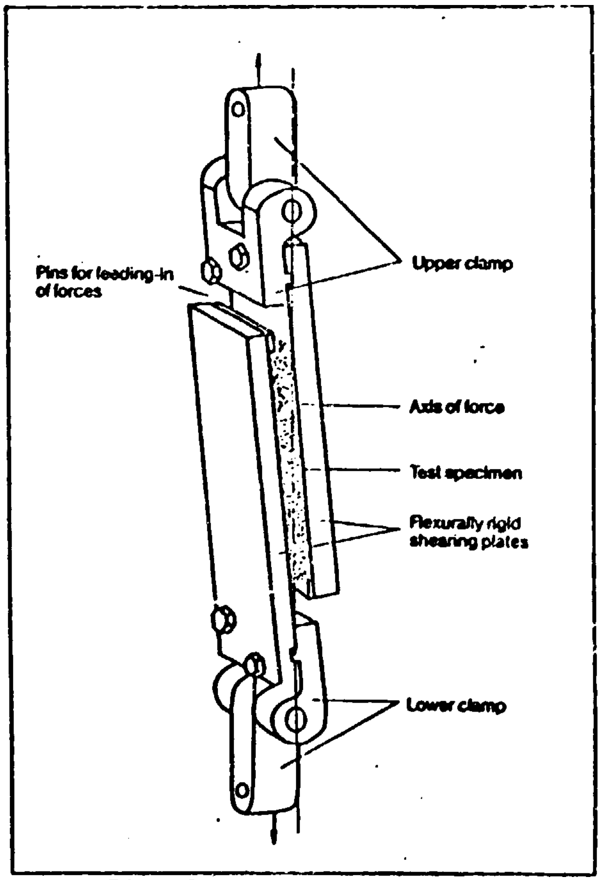


Fig. 8: Shearing test

## 9. Modulus of elasticity

Each of the stress-strain curves obtained in the above mentioned tests initially displays an almost linear profile, i.e. stress and deformation are proportional to each other. Within this range, all deformation produced by loads of short duration is reversible, i.e. the test specimen reverts to its original shape after removal of the load. The quotient of a stress and the accompanying elongation within this linear range is known as the modulus of elasticity. It is a characteristic parameter of materials, which is used in design engineering whenever the deformation is relatively small and the duration of the forces applied is short. Shear modulus and elasticity modulus are connected by a mathematical equation which contains the transverse contraction ratio.

## 10. Impact and shock tests

It is often interesting, particularly with regard to PUR foam materials having a relatively high modulus of elasticity, to know about behaviour under load at high rates of deformation. The most important characteristic value in all impact tests is the impact energy which is necessary to deform a test specimen under flexion or tension load until failure occurs. These data make it possible to list the products under test in order to toughness; no conclusions can be drawn from this, however, with regard to the behaviour of mouldings under impact load during service.

In the puncture test, which is chiefly used for thin sheet and film, the energy absorbed by the test specimen during puncture is determined, and the maximum impact force is calculated from the maximum deceleration of the drop hammer which deforms the test specimen.

In cases where PUR foams and expanded PUR elastomers are used for reducing shocks (in the packaging sector, for impact buffers and for bumpers and all-foam seats in automobiles), their shock absorbing and damping properties are of interest.

The determination of impact resilience in accordance with ISO/DIS 2650, in which the ratio of the rebound of a pendulum to its drop height provides a measure for the energy absorbed for the polymer, is a relatively simple process. There are, however, considerable reservations with regard to the use of this method with foams, since the data obtained with one product are even more dependent on the geometry of the test specimens and the method used than is the case with elastomers. This method should only be used as a check on the uniformity of production.

When designing shock absorbers, relatively complex test methods are essential in order to determine the cushioning factors and the specific energy absorption from the maximum impact of deceleration of various drop weights falling from different heights onto the test specimens. In many cases however, it is impossible to compile the results in the form of characteristic data. So the design engineer has to resort to diagrams showing the dependence of the maximum deceleration on the given parameters for test specimens of various thicknesses.

In order to demonstrate the outstanding adaptability of flexible PUR foams with regard to the requirements of all-foam seats in automobiles, tests on the finished articles are absolutely essential.

## 11. Tests of long duration

### 11.1 Creep tests

Because of the dependence of the properties of high polymers on time, PUR materials must also be subjected to creep tests. The deformation of test specimens under constant load and at constant atmospheric conditions (in particular constant temperature) are taken as a function of time, with either tensile, compressive or flexural loads. In this way time-strain curves for various stresses are produced over a period of years, and from these it is possible to read off the time at which a given stress produces a certain strain. From these time-strain curves (see Fig. 9) it is possible, with the aid of the given stresses, to calculate the isochronic stress-strain lines in the range of small deformations for any length of time (eg. 10, 100 or 1000 hours); time dependent moduli (creep moduli) can be taken from the initial linear profile of these stress-strain curves. These moduli of creep are lower than the moduli of elasticity determined in the short duration test. They enable the design engineer to calculate the dimensions of an article in such a way that no inadmissibly great deformation will occur on exposure to loads of long duration.

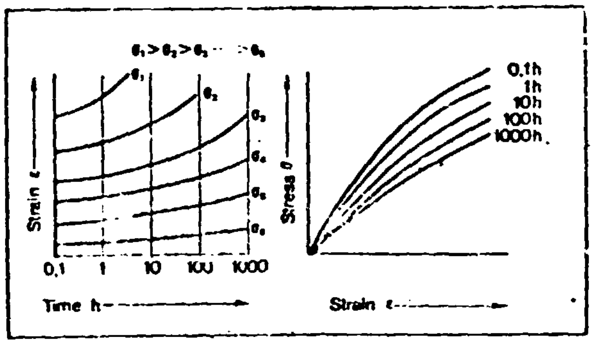


Fig. 9: Illustration of Time-Strain Curves
and Isochronic Stress-Strain Lines

## 11.2 Compression set

With flexible PUR foams and PUR elastomers, the permanent deformation after constant deformation (see Fig. 10) at a constant temperature is determined as a compression set. This test is a highly abbreviated creep test under constant deformation, in which the time and temperature parameters are also set at fixed values (single point measurement). The conclusiveness of this test for practical applications is frequently overvalued.

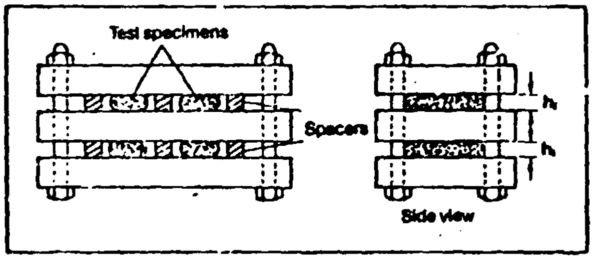


Fig. 10: Principle of Determination of Compression Set.

## 11.3 Long-term tests with alternating stress

PUR materials in service are exposed not only to constant loads, but also to alternating loads over long periods of time. This type of load on eg. cushioning materials is reproduced in the dynamic fatigue test in accordance with DIN 53574 (see Fig. 11).

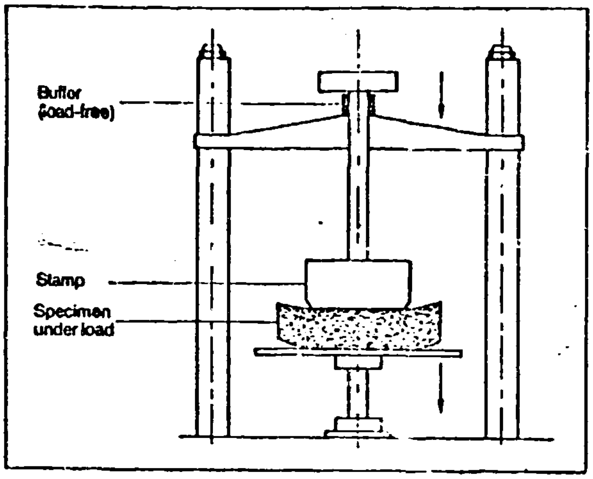


Fig. 11: Principle of Dynamic Fatigue Test

In this test a mass of 75 kgs is periodically applied to and removed from the test specimens usually used for the determination of indentation hardness. The test is interrupted after 80.000 load reversals and the change in hardness is determined using the indentation hardness test method. Results obtained in this way show good correlation with changes in hardness which occur during actual service. Dynamic fatigue tests are carried out on PUR elastomers and semi-flexible PUR integral skin foams, mostly under flexural (bending) laod. In an intensified form of this test, the section of the specimen in which the greatest deformation occurs is punctured using a small needle. After a prescribed number of load cycles, the cut growth - i.e. enlargement (normally a tear in one or more directions from the centre) of the original hole made by the needle - of this hole is measured.

## 11.4 Abrasion and wear tests

Abrasion tests are intended to assess the wear to be expected on PUR elastomers and shoe sole materials based on semi-flexible PUR integral skin foam systems, by determining the loss in volume of a test specimen on rubbing with an abrasive of a specified degree of hardness. These tests are suitable for quality control testing, to ensure that specifications are being maintained; the results have only a limited value, however, as regards the prediction of abrasion behaviour in actual service.

## 11.5 Ageing tests

All irreversible chemical and physical changes which take place in a material in the course of time are ageing processes. The changes effected by repeated mechanical loading have already been dealt with. There is, in addition, a number of other causes of ageing. Thus, for example, exposure to light (particularly the UV portion of the spectrum) may result in photo-oxidation, or splitting of the chemical bonds. This usually leads to a reduction in strength values. Discolouration cracking and blooming may also be observed. Exposure tests are intended to reproduce this type of phenomena as encountered in service. In the Xenon- and Weather-mometer tests, the effect of rain, as well as that of exposure of light can be simulated. By intensifying these influencing parameters, an attempt is made to accelerate ageing. One must however be careful not to over-estimate the value of artificial exposure tests of this type. There have been numerous cases in which the order of merit of products according to artificial ageing has been very different from that obtained in actual outdoor use.

Of particular importance wiht regard to testing of PUR materials is the determination of resistance to water and water vapour at elevated temperatures. To this end tests are carried out, chiefly steam rooms, in which the materials are stored in climatic test cabinets, preserving jars and (at temperature in excess of 100°C) in steam autoclaves. It should be pointed out here that attempts to accelerate the test by increasing the temperature can give rise to decomposition processes in the PUR material of a sort which would not occur in practice (in many cases increasing the temperature causes more than just a thermodynamically calculatable increase in the speed of the reaction.)

Since PUR materials have such a broad property spectrum these remarks can only touch on a few important test methods.

## 11.6 Determination of the dependence of materials characteristics on temperature

Tensile, compression and flexural tests can be carried out in temperature controlled cabinets in order to obtain stress-strain curves over a wide range of temperature. In addition to the strength properties, which are greatly influenced by temperature, and the type of failure, the elasticity moduli determined fromthe curve at different temperatures are of particular interest; in the form of elasticity modulus-temperature curves they make an important contribution to the characterization of polymeric materials.

## 11.7 The torsion pendulum test

Modulus-temperature curves are easier to determine by the torsion pendulum test. The test specimen taken from the material under investigation is used as a torsion spring; it bears a mass in the form of a disk and can be stimulated to produce free vibrations. The shear modulus is calculated from the dimensions and the frequency of vibration. From the reduction in vibration amplitude one obtains the damping factor "d" (also characterized as tan $\delta$ ), which is a measure of the work done by deformation, which is converted into heat within the test specimen. When carried out at set temperature intervals, the test gives the profiles for modulus and mechanical damping as a function of the temperature, from which relationship between the microstructure of the material and the macroscopic properties can be illustrated.

In the glassy state, i.e. when the test specimen attains the temperature at which damping is found, polymers have a high modulus (see fig. 12), while damping is low.

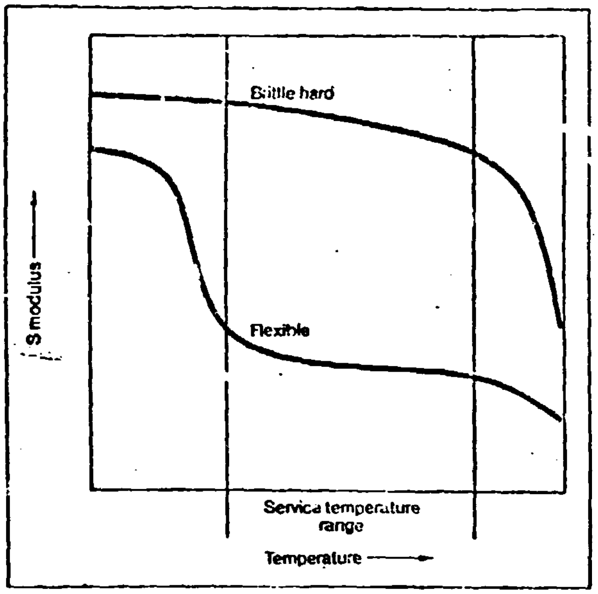


Fig. 12: Shear Modulus Curves

The linear deformation range is small, and sizeable deformation lead to stretching at ordinary temperatures and failure. On account of the high modulus, polymeric materials are often deliberately developed in such a way that they are in a glassy state within the service temperature range.

In the transitional range, the modulus falls by several powers of ten, during which the damping factor passes through a maximum. The onset of softening is usually marked by an intersection, and the associated temperature is termed the second order-transition temperature. The temperature at which maximum damping is found is usually known as the glass transition temperature. As the temperature continues to increase, a plateau occurs in the modulus profile of many polymers. Within this temperature range the material behaves practically like rubber. It is softer than in the glassy state, and can withstand great reversible (elastic) deformation. PUR elastomers and flexible PUR foams exhibit this behaviour over the entire service temperature range. Many manerials only exhibit rubber elastic-behaviour over a narrow range of temperature. When the glass transition temperature is exceeded, they are transformed into melts, in other words they become thermoplastic. In between these two extremes, there are numerous transitional stages, such as that of thermoformable PUR elastomers.

## 12. Determination of cell structure

The apparatus described in Fig. 13 below permits a determination of the percentages of open and closed cells in foams. The measuring principle is based on the Boyle-Mariotte law. The cell volume is determined from the change in pressure resulting from a predetermined change in volume.

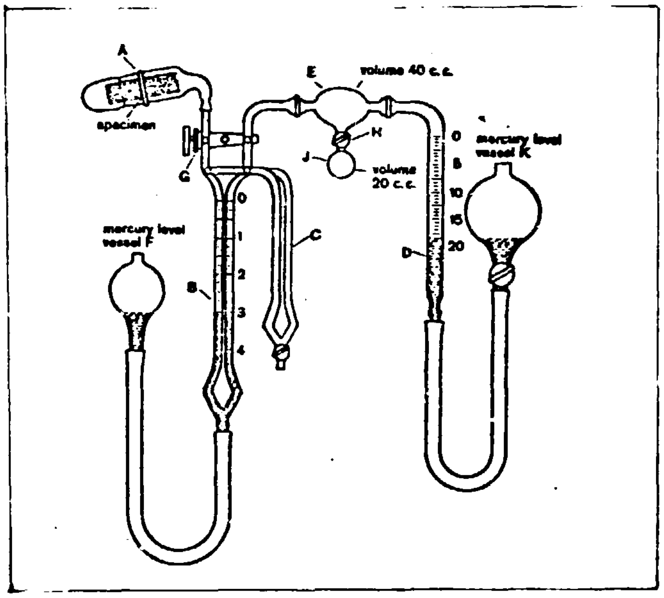


Fig. 13: Equipment to determine cell structure

The apparatus shown in the figure above consists essentially of the specimen chamber A which is connected with the reference chamber E by two paralell pressure gauges B and C. Pressure gauge B is provided with a mercury level vessel F, while pressure gauge C, as a precision instrument, is filled with dibutyl phtalate or another liquid of low density and low vapour pressure. The reference chamber E is connected with a burette D and a mercury level vessel K. The apparatus is divided into two systems by the pressure gauge liquids.

The sample container system includes the sample chamber A, the left half of the mercury pressure gauge B and the left half of the auxilliary pressure gauge C. The reference container system consists of the flask E, the auxilliary flask J, the right halves of the mercury pressure guage B and the auxilliary pressure gauge C and the burette D.

The air volume displaced by the foam specimen consists of the space taken up by the closed cells and the cell walls. The test procedure consists essentially of a comparison of the volumes of both systems with and without specimens. The air volume displaced by the foam specimen in the left half is reproduced by removing a corresponding volume in the right part of the apparatus (compensation principle). Agreement between the left and the right volume is determined by pressure comparison of the air located in the two volumes following an equal change in volume.

## 13. Fastening properties

We have analysed the characteristics required in a good foam, now we will see that the properties we want are not only for good resilience and durability, but are also required for another purpose, namely fastening.

Foams can be tacked on, stapled, welded, stitched and also glued.

### Tacks

Except on the smallest of jobs tacks are rarely used nowadays as they are too time consuming and tedious to lay and fix.

### Staples

Instead, staples are used, as they are easier to fix, kinder to the foam through their larger bearing surface, and also all in all they are cheaper in the short run, whether laid by hand pressure or by air or electric action. They also reach in the confined spaces, where hand and tack cannot be used. They do not cause split lines in the frames or bases as closely spaced tacks would do. Add, when time comes for repair they are easily removed and replaced. As wide a crown as possible should be used to minimize tear in the foam.

### Welding

Foams are successfully welded by high frequency welders, but this is only feasible if fairly large quantities of one item are required, as the electrodes should be set according to the exact pattern to be welded, so a different set of electrodes and subsequent adjustment to the machine are required each time the pattern is changed.

## Stitching

Foams, at least in thin sheet form can be easily stitched. The method used is (a) a low pressure on the claw foot, (b) wide stitches and (c) a strip of paper is inserted between the machine bed and the foam, and another between the foot and the foam. Where foams are to be used in highly stressed areas, stitching is not recommended.

## Glueing

By far the most widely used fastening method used for fixing plastic foams is by glueing. With modern glues, the method is foolproof if properly carried out. The best adhesives are neoprene based contact adhesives, and they give an even and smooth continuous line of fixing. These glues can be spread by a spatula, by a dispenser or by a spray gun if a sprayable grade is prescribed at the time of the pruchase. The adhesive should be spread evenly in a thin coat on both surfaces to be glued and allowed to stand a few minutes to reach "tacky" point, when both surfaces are brought together and pressed firmly together. By this method foams can be glued to wood, metal, particle board, plywood, and even to glass. These contact adhesives are very inflammable in nature and care should be taken in their use. Well ventilated premises and firm closure of containers after use will greatly minimize the risk of fire and the inhalation of solvents which may be injurious to the health of the operators.

Some grades of PVA glues have been recommended for the glueing of foams, but on trial these have been found to have a very long drying time and to leave a hard glue-line which tends to show under the upholstery material.

## ANNEX I

### STANDARDS FOR FOAMS USED IN UPHOLSTERY

| | |
|---|---|
| ASTN-D 1692 | Flammability of plastic sheeting and cellular plastics. |
| ISO R 3795 | Road Vehicles - Determination of burning behaviour of interior materials for motor vehicles. |
| DIN 53572 | Compression set in polyurethane foams. Tests at various percentages of compression. |
| DIN 53577 | Compression hardness in polyurethane foams at 40% compression. |
| DIN 53574 | Polyurethane cellular materials: Fatigue tests with constant load amplitude. |
| ASTM 1564-755 | Indentation hardness tests on cellular materials. |
| DIN 53420 | Density determination tests on flexible polyurethane foams. |
| DIN 53571 | Tests for tensile strength in polyurethane cellular materials. |
| DIN 53575 | Tear resistance tests in flexible urethane foams. |