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Volume 26 No. 4

October-December, 2001



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Founded-1973

Published by:

INSTITUTION OF FIRE ENGINEERS (INDIA)

New Delhi

POLYURETHANE FOAMS—COMBUSTION AND FLAME RETARDANT STUDIES

By

HARPAL SINGH, SUVIR SINGH

Scientist, Fire Research Laboratory

&

DR. T. P. SHARMA

Dy. Director and Scientist Coordinator, Fire Research Laboratory
CENTRAL BUILDING RESEARCH INSTITUTE, ROORKEE

INTRODUCTION

Polyurethane was first time described by Prof. Otto Bayer of Germany in 1937. Besides Otto Bayer, A. Hoechtlen, P. Hoppe and E. Meinbrenner had combined the description of the polyurethanes on the scientific basis and their analysis with potential application areas and corresponding market volumes for this new material. Rinke and collaborators were successful to form a low viscosity melt which resulted in what now known as polyurethane. Rinke and associates were awarded the first US Patent on Polyurethanes in 1938.

The basic technology for the commercial production of flexible polyester foams was developed in Leverkusen (Germany) from 1952 to 1954. At that time, all commercial applications of polyurethanes were based almost exclusively on polyester polyols. Polyether polyols were first introduced in 1957. Because of technical and commercial advantages these new polyols rapidly gained the preferred role in polyurethanes. The immense variability in the preparation and structure of polyether polyols was responsible in achieving an invaluable broadening of the property spectrum of polyurethanes at considerably lower cost. From that time the gradually growing interest in polyurethanes gained ground in the world. Thus from these humble beginnings emerged the polyurethanes, one of the most versatile polymers in the modern cellular plastics industry.

BASIC CONCEPT IN POLYURETHANE FOAM CHEMISTRY

Polyurethanes are extremely large and complex molecules produced by combining a large number of simpler molecules called monomers. But actually polyurethanes are neither derived from polymerizing a urethane monomer nor they are polymers containing primarily urethane groups. The polyurethanes include those polymers containing a plurality of urethane groups in the molecular backbone regardless of the chemical composition of the rest of the chain. Thus a typical polyurethane foam structure may contain, in addition to the urethane linkages, aliphatic and

aromatic hydrocarbons, esters, ethers, amides, urea, biuret, allophanate, isocyanurate, uretidione and carbodiimide groups.

Polyurethane foams are microcellular cross-linked, thermoset duroplastic structure. The chemical formulations of polyurethane foams are based on the following ingredients.

- Polyol
- Water
- Pigment
- Isocyanate
- Blowing agent
- Additives
- Catalysts
- Surfactant

The chemistry of polyurethane makes use of the reactions of organic isocyanates with compounds containing at least two active hydrogen atoms. When polyfunctional isocyanates and intermediates containing at least two active hydrogen atoms per mole reacted at proper ratios and under certain conditions of temperatures, catalysts etc., a polymer results that can produce flexible or rigid foams. An isocyanate group reacts with the hydroxyl groups of a polyol to form the repeating urethane linkages. The isocyanate and polyol reaction is catalysed by organotin catalyst. The isocyanates also react with water to form carbamic acid which is unstable intermediates and decomposes readily to evolve carbon dioxide and an amine. This carbon dioxide acts as blowing agent during the formation of polyurethane foams. The maximum expansion of polyurethane foam i.e. 80% is controlled by the carbon dioxide itself and remaining 20% expansion is controlled by the addition of external foaming agents. This important isocyanate-water reaction is catalysed by tertiary amine compound. The amine formed during the isocyanate-water reaction, reacts with additional isocyanate to form disubstituted urea. In addition, a number of cross-linking side reactions may also take place, depending upon the reaction conditions such as temperature, the presence of catalysts, the structure of the isocyanate, polyols and amines involved. These reactions form linkages of biuret (reaction between substituted urea and isocyanate), allophanate (reaction between urethane-isocyanate). Isocyanate also undergoes self-addition reaction to form isocyanurate (trimerisation of

isocyanate groups), uretidinedione and carbodiimide (dirmerisation of isocyanate groups). Isocyanurate and carbodiimide linkages provide improved thermal stability and flammability performance to polyurethane foams to a certain extent. The important chemical reactions take places during polyurethane foam formation have been illustrated in Figure 1.

The types of polyurethane foams are classified as flexible foam, semiflexible foam, reticulated foam, microcellular foam, high resiliency foam, semi rigid foam and rigid foam. The polyurethane foams are generally manufactured in three ways i.e. slab stock foam, moulded foam and sprayed foam by using three

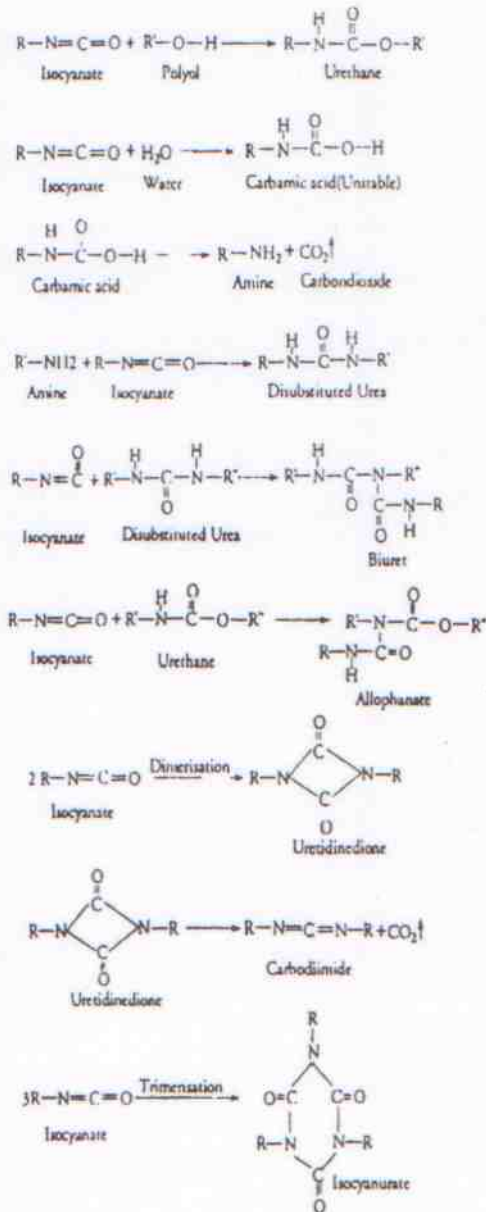


Fig. 1 Important polyurethane foam chemical reactions

basic approaches. In the one shot process, all the components are combined at one time to produce foam and the reaction is completed in one shot. In the quasi-prepolymer approach part of the polyol to be used in the formulation is pre-reacted with all of the isocyanate. The resultant product is isocyanate terminated prepolymer having free isocyanate contents between 16 and 32 percent by weight. Foams are prepared by adding rest of the foam ingredients along with remaining polyol. In the prepolymer foaming process, the hydroxyl compound is reacted with an excess of isocyanate to form an isocyanate-terminated prepolymer with free isocyanate contents of 1 to 15 percent by weight. But out of these three methods, the one shot process is most important and used maximum today because it provides the fastest, simplest and most economical manufacturing technique. These are the reasons which often favour its use in highly competitive commodity fields such as flexible foam.

POLYURETHANE MARKETS AND APPLICATIONS

The worldwide demand for polyurethane foams is estimated about 5% of total world consumption of plastics. Polyurethane foams are considered to be a special product ahead of other commodity plastics in overall volume. The polyurethane foams market is increasing at a rate of close 6% per year. Figure-2 presents the break down of polyurethane usage; as the figure indicates, the majority of polyurethanes are used in the production of flexible foam and followed by rigid foam. The maximum Consumption of polyurethane foams is in North America which is estimated around 32 percent.

The wide spectrum of properties, simple fabricating techniques and attractive cost are the important factors which have led to the manifold use of polyurethane foams. Some of the important applications of flexible polyurethane are as under.

Furniture Cushioning is one of the large outlets estimated about 40% for flexible polyurethane foam. Lighter weight, greater strength, and ease of fabrication of up holstered furniture as compared to latex foam are some of the deciding factors in its success. Seating furniture in which polyurethane flexible foam is used as the sole cushioning materials has attained increasing importance over the year. Improved molded techniques of flexible foam are responsible for its acceptance in furniture industry with unusual shapes.

Mattresses of polyurethane flexible foam are being produced in large quantities every year. Thus about 25% foam is being consumed in the form of bedding

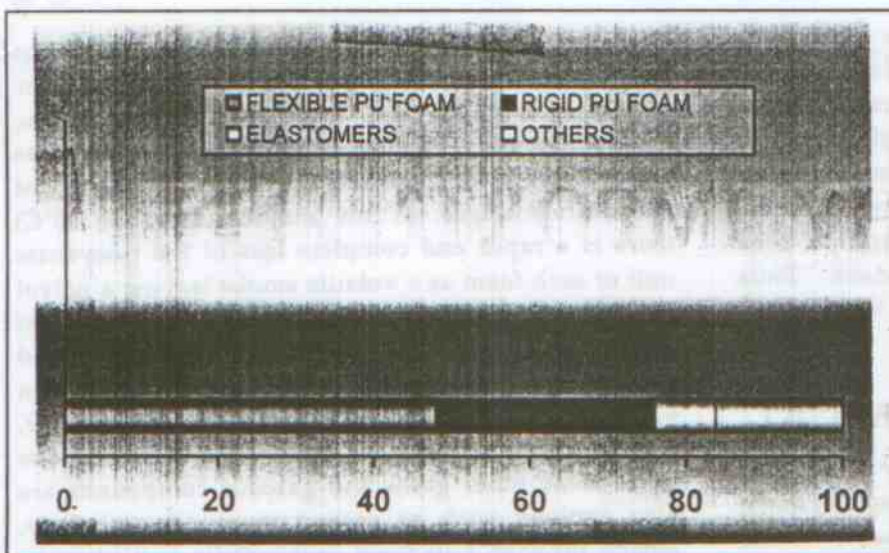


Fig. 2 Worldwide Consumption of Polyurethane Foams

and mattresses. They have found acceptance because of their high air permeability, superior durability, odourless, nonallergenic properties, ease of cleaning, resistant to dry cleaning solvents and the fact that they are only one fourth of the weight of a comparable innerspring and one half to one third the weight of latex foam.

Transportation area is the third major consumer of polyurethane flexible foam i.e. 20% of the production is being consumed due to the requirement for improved safety and increased comfort. Because vehicle seats are often occupied for hours at a time it is necessary to provide the seats for adequate air permeability and humidity. Proper contouring of the seating surface is especially important since perspiration occurs primarily on the surface touched. Thus the main use of flexible foam in the automotive industry (automobiles, airplanes and rail cars) for seat cushioning, instrument panel trim, safety pads, arm rests, floor mats, roof insulation, weather stripping and air filters etc. The low weight of foam is of special interest in equipping airplanes.

About 6% of flexible foam is used as a bonding material for fabric specially in the fabrication of apparel due to more favorable melting characteristics of foam required for flame lamination technique. Foam lining for the garments makes the fabric dimensionally stable and provide high insulating properties. Other advantages include excellent hand drape and outstanding crease and wrinkle resistance. Another important area for flexible polyurethane foams is in carpet underlay. The interior decoration of rooms in the living areas with carpeting is increasingly leading

to the use of carpet underlay where they provide cushioning, non-skiddy surface, heat and sound insulation. Flexible polyurethane foams in the form of sponges find their use in the household goods of window cleaner, pot scrubbers, cleaning brushes and are usually combined with other materials.

The second largest foam use in today is polyurethane rigid foam. The rigid foam is used as insulation and structural material and some times a combination of both. The insulating efficiency of rigid foam is unsurpassed. A mere 2.54 cm of rigid polyurethane foam is equivalent in its

insulating capacity at ambient temperature to 7.62 cm of polystyrene foam, 8.89 cm inch of mineral wool, 10.16 cm of cork, 15.24 cm of glass fibre mat, 27.94 cm of wood or 76.2 cm of cemented concrete blocks. Due to great insulation and structural capacity this foam find many applications and some of them are as under:

One of the major uses of rigid polyurethane foam is in Refrigeration Technology and Appliances such as refrigerators and freezers, commercial display cases, refrigerated trucks (milk trucks, ice-cream trucks and trailers) and container, refrigerated warehouses and walk-in-coolers and water heaters.

Potentially, the biggest market for rigid polyurethane foam is in the Building Construction and Industry in the form of insulation boards (flat roofs, ventilated roofs, pitched roofs, ventilated facades, thermowall system, interior walls, floors and ceilings), sandwich elements, specialty elements (sanitary walls, bathrooms and window sills), PU light weight concrete, wall blocks with integrated insulation, curtain wall construction, preformed rigid panels and spray-applied wall construction.

The market for these includes residential homes, commercial and industrial buildings such as large refrigerated warehouses. The other important uses of polyurethane rigid foam are technical insulation (pipe insulation and insulation of tanks), automotive industry (interior liners and cavity foaming), transportation (refrigerated vehicles, insulation for transportation of special products and caravans and mobile homes), shipbuilding (foaming of cavities, insulation of cold storage holds in fishing boats, boat building), Packaging (direct encapsulation, transportation protection in vehicles and sandwich-card board boxes), horticulture, sporting goods, furniture, solar technology and radomes.

The utility and versatility of polyurethane foams have resulted in their introduction into a wide variety of Markets, and their widespread acceptance has made them significant materials in many applications in which fire hazard is an important consideration. Because polyurethane foams, like most organic materials, tend to be combustible hence care has to be taken to render them flame retardant. Thus flammability of polyurethane foams has long been a factor limiting their greater use.

COMBUSTION OF POLYURETHANE FOAMS

Polyurethane foams have highly cellular structures, which are easily ignitable and highly flammable, flame spread is very fast on the surface of these materials and results in engulfing the entire area in a few minutes. The burning process of polyurethane foams may be considered as occurring in five stages:

Heat from external source is applied to foam progressively raising its temperature. The thermal insulation properties of foam promote a rapid temperature rise at the exposed surface because heat can not be easily transmitted to the lower layer of foam.

The polyurethane foam reaches its temperature of initial decomposition and begins to form combustible gases, non-combustible gases, entrained solid particles and carbonaceous char. The evolution of gases expand the foam structure and thus combustible and non-combustible gas both cause difficulty by disrupting the chemical and physical structure of foam, exposing new surfaces to destructive temperatures.

The resulting combustible gases ignite in the presence of sufficient oxygen and further combustion begins. The condition of ignition depends on the presence of an external source of ignition and the temperature and composition of the gas phase.

The heat of combustion raises the temperature of the gaseous products of combustion and of the noncombustible gases results increasing heat transfer by conduction.

The heat transferred from the combustion zone to adjacent foam surface produces further decomposition and ignition, resulting in flame propagation.

SMOKE AND TOXICITY OF POLYURETHANE FOAMS

The thermal decomposition products of polyurethane foams vary with polymer composition, temperature

level, rate of temperature rise, endotherms, exotherms and rate of volatile evolution. When polyurethane foams involved in fire, there is concern that the nitrogen contents of these foams may be released as toxic and deadly poisonous gases at different temperature stages. At low temperatures (200-300°C) there is a rapid and complete loss of the isocyanate unit of each foam as a volatile smoke leaving a polyol residue. The black dense smoke is stable at temperatures up to 750°C. At about 800°C the rapid decomposition of foams takes place with the evolution of hydrogen cyanide, acetonitrile, acrylonitrile, pyridine and benzonitrile. Besides these nitrogenous gases some other gases and gaseous compounds are also evolved such as carbon monoxide, ethylene, ethane, propane, butadiene, propionitrile, acetaldehyde, methylacrylonitrile, benzene, pyrrole, toluene, methyl pyridine, methyl cyanobenzene, naphthalene, quinoline, indene, carbondioxide and water vapours. At 35% weight loss of polyurethane foam, all the nitrogen-containing compounds get evaporated. At 900°C, hydrogen cyanide and benzonitrile are predominant and at 1000°C, hydrogen cyanide is virtually the only product. At 1000°C, approximately 70% of the available nitrogen of the foam has been recovered as hydrogen cyanide.

Among all the above gases evolved during thermal decomposition of polyurethane foam, carbon monoxide and hydrogen cyanide are lethal. Carbon monoxide is colourless, odourless and not detectable at all by the senses. The toxicity of carbon monoxide is mainly due to its affinity towards haemoglobin (Main structural protein of blood). Haemoglobin has 200-300 times more affinity for carbon monoxide than for oxygen. Carbon monoxide, when breathed in along with air, is absorbed by the blood depriving it of its oxygen carrying capacity. Hence, carbon monoxide readily reacts with haemoglobin to form carboxyhaemoglobin a stable compound resulting anoximia or oxygen deficiency in the body tissues causing headache, dizziness, weakness in the limbs, mental dullness, tightness in the chest and finally unconsciousness which leads to death.

Similarly, hydrogen cyanide or prussic acid is colourless, non-flammable and have the odour of bitter almonds. The inhalation of its fumes in high concentration will cause almost immediate death. Hydrogen cyanide acts by preventing the normal process of tissue oxidation and paralyzing the respiratory center in the brain, causes dizziness, headache and shortness of breath, followed by convulsions, coma and collapse.

FLAME RETARDANT TECHNIQUES FOR POLYURETHANE FOAMS

Flame retardance of polyurethane foam requires the disruption of burning process at one or more stages, so that the process is terminated within an acceptable period of time. In general, three methods have been employed to render polyurethane foams flame retardant.

Organic or inorganic based Nonreactive flame retardant additives or some times combination of both are used with the foam components by simple mechanical mixing. A wide variety of such additives are based on phosphorus, sulphur, nitrogen, halogens, antimony aluminum, arsenic, boron, and calcium. Cyanuric acid derivatives are also very good flame retardant additives. Since these flame-retardants are non-reactive additives, thus they are not permanently bound into the polymer moiety.

Reactive flame retardant additives are those compounds, which contain functional groups, particularly hydroxyl groups. When these flame retardant additives are added into the foam formulation then they immediately participate in the chemical reactions and become part of the polymer chain. This approach is much superior than the first one. Phosphorus and halogens containing polyols are reactive flame-retardants, participate in the foaming reaction and become part of the polymer and are generally liquid materials. The introduction of halogenated aromatic compounds into the polymer structure increase the temperature resistance and imparts greater dimensional stability to the resulting polyurethane foam structure.

Surface treatment of flammable foam by means of flame retardant compositions is post-manufacturing process. The flame-retardant compositions are applied on the foam surface either in the form of coatings or by adopting impregnation/injection techniques. This method is especially useful on spray-applied foams for outdoor applications where low water vapour permeability and good weather protection are desired.

SYNTHESIS AND CHARACTERIZATION OF FLAME RETARDANT COMPOUND

A flame-retardant compound based on phosphorus and nitrogen has been synthesized in the laboratory. This compound is a reaction product of phosphoralisation of highly methylolated compound. Some of the important characteristics of this compound have been shown in Table I.

TABLE 1. CHARACTERISTICS OF FLAME RETARDANT COMPOUND

PHYSICAL STATE	COLORLESS SYRUP LIQUID
SOLID CONTENTS	48.4 PERCENT
MISCIBILITY	MISCIBLE WITH WATER
FLAMMABILITY	NON-FLAMMABLE
POT LIFE	2-3 WEEKS

The synthesized compound is incorporated into the formulation to render polyurethane foam flame retardant. Treated polyurethane foam is subjected to certain thermal and fire tests to evaluate its efficacy under heat and temperature.

THERMAL ANALYSIS OF POLYURETHANE FOAM

All the polymers under go depolymerisation under certain conditions and polyurethane foams are no exception. Although polyurethane foams undergo depolymerisation when they are subjected to thermolysis, photolysis, solvolysis, pyrolysis, oxidation and microbial attack but out of these thermolysis is very important. Thermal analysis comprises a group of techniques in which a physical property of polyurethane foam is measured as a function of temperature while the foam is subjected to a controlled temperature program. When polyurethane foam is put under heat then thermal dissociation of various polyurethane linkages take place at different temperatures. The thermal dissociation temperatures of linkages found in polyurethane foam are shown in Table 2.

TABLE 2. THERMAL DISSOCIATION TEMPERATURES OF POLYURETHANE FOAMS LINKAGES

ALLOPHANATE	100-120°C
BIURET	115-125°C
Urea	160-200°C
URETHANE	180-200°C
DISUBSTITUTED UREA	235-250°C
CARBODIIMIDE	250-280°C
ISOCYANURATE	270-300°C

A complete thermal analysis of polyurethane foam measures temperature, transition energy, weight loss, dimensional changes, oscillation in the polymer chain and viscoelastic properties as under.

- ❖ Differential thermal analysis (DTA), the absorption and dissipation of heat by foam and by a thermally inert reference material are measured as a function of temperature. Any transition that the foam undergoes will result in liberation or absorption of energy by the foam. Thus it tells us whether the transition in the foam sample is endothermic or exothermic.
- ❖ Differential scanning calorimetry (DSC) measure the quantities of transition energy when foam and reference materials are subjected to a closely controlled programmed temperature variation.
- ❖ Thermogravimetric analysis (TGA) provides a quantitative of any weight changes associated with a transition.
- ❖ Thermomechanical analysis (TMA) provides measurements of penetration, expansion, contraction and extension of foam as a function of temperature.
- ❖ Dynamic mechanical analysis (DMA) detects transitions associated with movement of polymer chain.
- ❖ Gas chromatography (GC) measures different gases and their quantities evolved from the foam at different temperatures.

Scanning electron microscopy (SEM) deals with the morphological study and to observe proper distribution of additives in the foam structure if they are added.

FIRE PERFORMANCE EVALUATION OF POLYURETHANE FOAM

Both fire retardant chemically incorporated and control foams are subjected to 60 seconds exposure in horizontal condition inside a non-combustible chamber as per British Standard 4735. The heat source is a 10mm diameter burner having 38mm non-luminous flame length.

Similarly both the foam samples are also ignited in the oxygen-enriched atmosphere to observe their oxygen index as per ASTM D 2863. The results of fire retardant chemically incorporated foam and control foam both are shown in the Table 3. Some other fire properties and relationships between them are illustrated in Figures 3-8.

TABLE 3. BURNING CHARACTERISTICS OF POLYURETHANE FOAMS

PROPERTIES	CONTROL FOAM	FLAME RETARDANT FOAM
EXPOSURE TIME	60 SECONDS	60 SECONDS
IGNITABILITY	EASILY IGNITABLE	NON-IGNITABLE
FLAMMABILITY	HIGHLY FLAMMABLE	NON-FLAMMABLE
BURNING RATE	2.5 MM/SECONDS	0.1MM/SECONDS
FLAME SPREAD	VERY FAST	NO FLAME SPREAD
WEIGHT LOSS	100 PER CENT	21 PERCENT
MELTING	MELTS	NO MELTING
DRIPPING	DRIPPED	NO DRIPPING
BURN LENGTH	BURN ENTIRE LENGTH	CHARRED UP TO 7MM
OXYGEN INDEX	14.2	33.6

Some more fire tests have to be carried out to assess other fire characteristics of chemically incorporated polyurethane foam. The complete list of fire test for polyurethane foam is as under.

- ❖ Flammability (BS: 4735-1974)
- ❖ Ignitability (BS 476: Part5-1968)
- ❖ Surface spread of flame (BS 476: Part7-1987)
- ❖ Fire propagation index (BS 476: Part6-1981)
- ❖ Limiting oxygen index (ASTM D 2863-1977)
- ❖ Optical smoke density (ASTM E662-1983)

PERFORMANCE EVALUATION OF MECHANICAL CHARACTERISTICS

Market potential of polyurethane foams greatly depends on their mechanical properties. Further the mechanical properties are dependent on the density, cell structure, molecular flexibility, crystallinity, proper cross-linking and manufacturing process of polyurethane foam. Mechanical properties mainly depend upon molecular weight in case of thermoplastic polymers, while in thermoset (polyurethane foams) polymers of infinite molecular weight, they would tend to approach high level value, which would then become a function of degree of cross-linking rather than on the molecular weight itself.

This is very important that the mechanical properties of polyurethane foam should not be degraded when it is modified into flame retardant foam. Because foams with improved fire retardant properties and degraded mechanical properties has no value and are not acceptable in the competitive global market.

Flame retardant and control foams both are tested for their mechanical properties such as compressive strength, tensile strength, tensile stress, tear strength, ultimate elongation, resilience and dimensional stability. Out of these properties the compression set value of foam is of special significance.

Compression set test is applied on both flame retardant and control foams as per Indian Standard 7888-1976. Both foams put between the two plates and with the help of spacers subjected to 50 and 70 percent

deflections. The whole assembly is then stored under standard atmospheric conditions for 70 hours. After this duration, the plates are removed and the specimens are allowed to recover for 30 minutes under standard testing conditions. The decreases in the compression set values are calculated by the difference in thicknesses of foams which are in the acceptable limit as per Indian Standard 7933. The results are shown in the Figure 9.

Similarly tensile strength of flame retardant foam is also in the acceptable limit which should not be less than 1kg/cm² as per Indian Standard 7933.

Besides mechanical properties, the physical properties of foams are also very important such as density, cell size, indentation force deflection, guide factor, sag factor, initial hardness factor, indentation modulus, hysteresis and thermal conductivity. Some physical parameters such as mixing time, cream time, gel time, gas release time, rise time, tack free time, curing time and mould release time of foam should not be changed much when flame retardant additives are added in to the formulation.

RESULT AND DISCUSSION

It is evident from table 3 that the flame-retardant compound incorporated into the foam formulation is very effective in reducing the flammability and burning rate of polyurethane foam. The burning rate of flame retardant polyurethane foam is 25 times less than the burning rate of control foam. Similarly there is remarkable difference in the weight loss, which is 21 percent in flame retardant foam because during fire exposure it just charred up to 7mm only while it is 100 percent in control foam because it is fully consumed in fire under similar conditions. When both flame retardant and control foams are ignited in the oxygen enriched atmosphere, there is vast difference in their limiting oxygen index values. Approximately 2.5 times more oxygen-nitrogen mixture is required to ignite flame retardant chemically incorporated foam than the control foam. This clearly indicates the improved fire performance of polyurethane foam.

Figures 3-8 show certain effects and relationships between fire characteristics when both flame retardant compound incorporated foam and control foam are subjected to standard flammability test BS 4735. It is quite clear from figures 3-5 that burning rate, chemical retention and weight loss are inversely proportional to density, burnt extent and chemical retention respectively. Similarly figures 6-8 show that burnt extent, weight loss and burning rate are directly proportional to burning rate, burnt extent and weight loss respectively.

Figure 9 indicates the effect of flame retardant compound on the compression set value of polyurethane foam. Maximum decrease in the compression set value for flame retardant foam is 3.14 percent while it is 0.86 percent in control foam. But the decrease in the compression set value is well within the permissible limit because as per Indian Standard 7933 it should not be more than 10 percent. Thus the compression set value of flame retardant foam is not affected.

CONCLUSION

Ordinary polyurethane foams available in the markets are easily ignitable, highly flammable and on decomposition produce large quantity of black dense smoke containing deadly poisonous toxic gases. Fire retardant compound added into the polyurethane foam formulation is quite effective in enhancing the fire performance of polyurethane foam. Once the fire performance of polyurethane foam is improved, the smoke and toxicity are reduced accordingly because during fire exposure the foam charred up to certain length and remain self-extinguished. In the oxygen enriched atmosphere the flame-retardant foam is difficult to ignite. The color and texture of fire retardant foam remains unchanged, however its mechanical properties are little bit affected but are very much in the acceptable limit. Thus by the use of flame retardant polyurethane foams in the form of mattresses, furniture cushioning and in the construction of industrial and residential buildings, life and property losses could be minimised and sufficient energy saving could be achieved.

ACKNOWLEDGEMENT

The paper is sent for publication with the permission of Director, Central Building Research Institute, Roorkee. The authors will like to thank to Mr. Prakash Joshi for the assistance during the work and Mr. Sanjay Tyagi and Mr. Seva Ram for processing the manuscript.

SOURCES

1. "Handbook of polyurethane", Michael Szycher, CRC press, Washington, DC, 1999.
2. "Polyurethane Technology", Paul F. Bruins, Interscience Publishers, John Wiley & Sons, New York, 1969.
3. "Polyurethane Handbook", Gunter Oertel, Hanser Publishers, New York, 1985.
4. "The thermal decomposition products of rigid polyurethane foams under laboratory conditions", W. D. Woolley, P. J. Fardell and I. G. Buckland, Fire Research Note No. 1039, 1975.
5. "A preliminary study of the thermal decomposition of polyurethane foams by elemental ultramicroanalysis", W. D. Woolley and P. Field, Fire Research Note No. 880, 1971.

6. "The formation of nitrogen containing products from the thermal decomposition of flexible polyurethane foam", W. D. Woolley, I. Wodley and P. Field, Fire Research Note No. 881, 1971.
7. "Flammability Handbook for plastics", C. J. Hilado, Technomic Publishing Co., Connecticut, 1969.
8. "Poisons", Vincent J. Brooks and Morris B. Jacobs, D. Van Nostrand Company, Inc. Princeton, New Jersey, 1958.

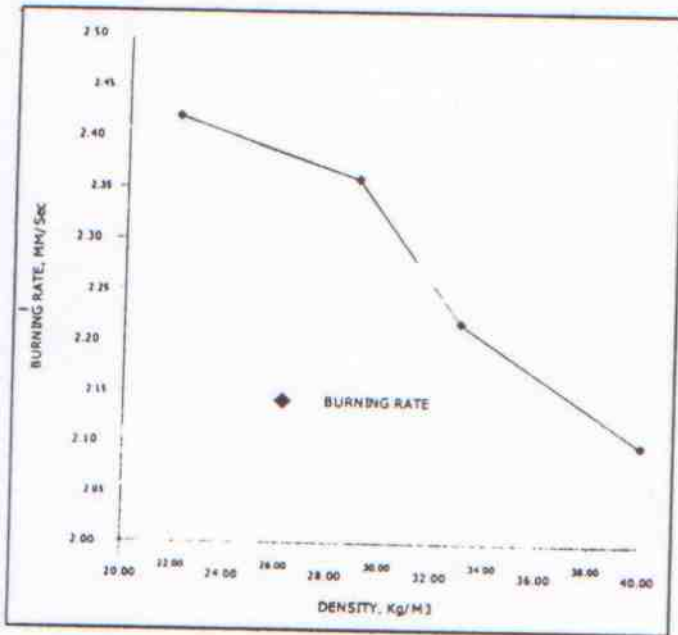


FIG. 3 EFFECT OF DENSITY ON BURNING RATE IN POLYURETHANE FOAMS

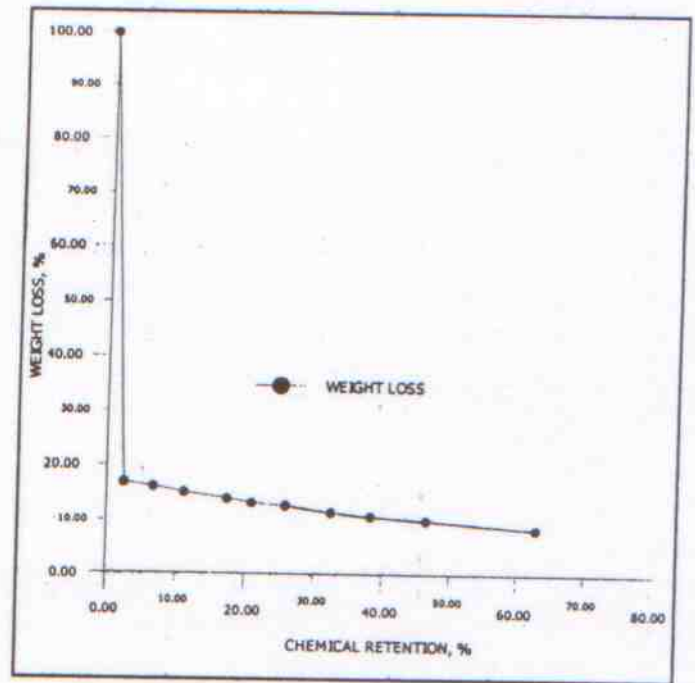


FIG. 5 EFFECT OF CHEMICAL RETENTION ON WEIGHT LOSS IN POLYURETHANE FOAMS

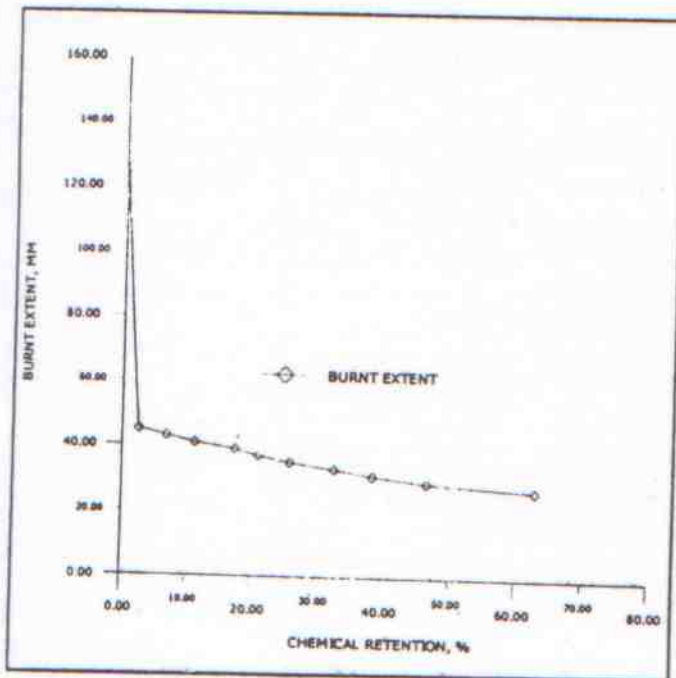


FIG. 4 EFFECT OF CHEMICAL RETENTION ON BURNT EXTENT IN POLYURETHANE FOAMS

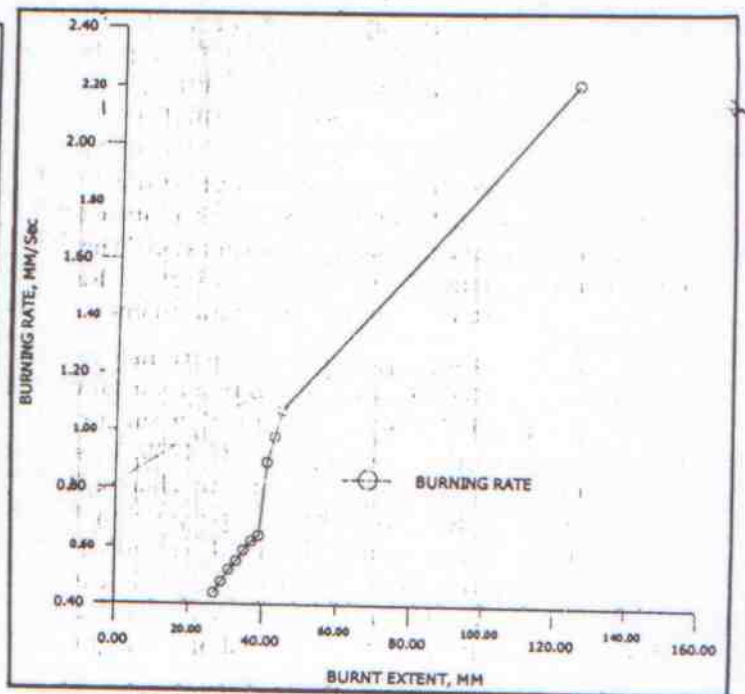


FIG. 6 RELATION BETWEEN BURNT EXTENT AND BURNING RATE IN POLYURETHANE FOAMS

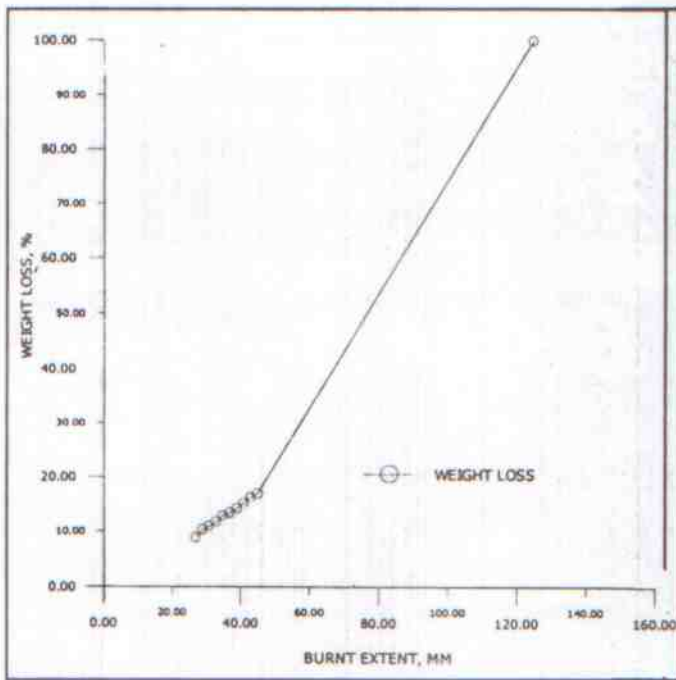


FIG. 7 RELATIONSHIP BETWEEN BURNT EXTENT AND WEIGHT LOSS IN POLYURETHANE FOAMS

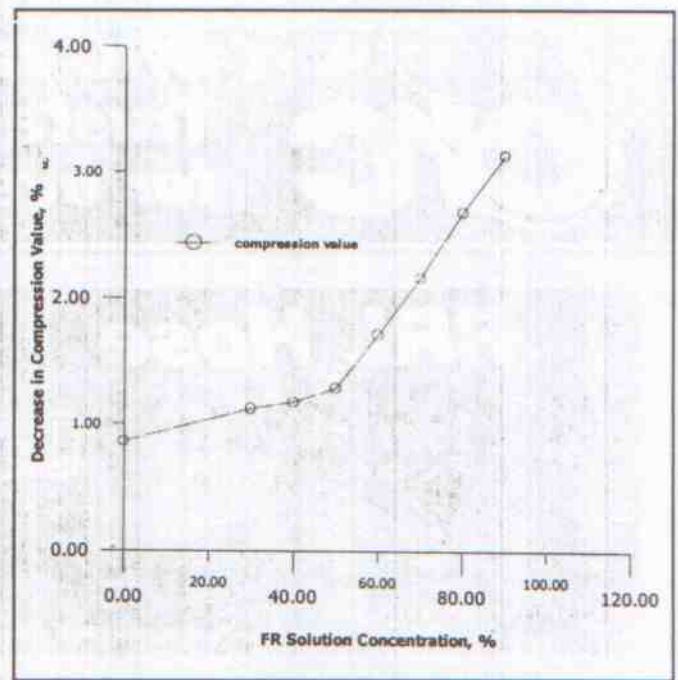


FIG. 9 COMPRESSION SET TEST OF POLYURETHANE FOAMS

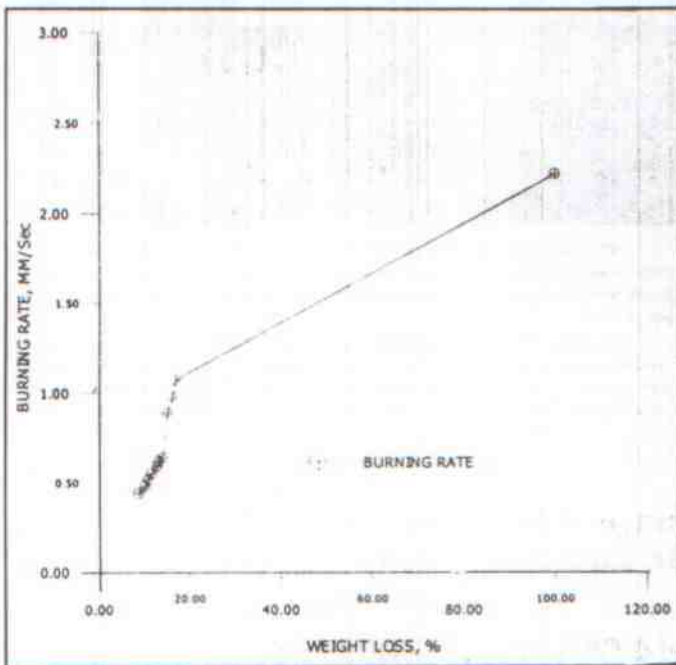


FIG. 8 RELATIONSHIP BETWEEN WEIGHT LOSS AND BURNING RATE IN POLYURETHANE FOAMS

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1. As per amendment to the rules governing the conduct of this examination in parts will have to secure 60% marks in the papers he is re-appearing.
2. The Candidates qualifying Examination by parts must pass all the papers within Five years from the date of qualifying 1st Paper/Papers. That is if a candidate has cleared 1st Paper in 2001, he must clear/pass the remaining three papers by the year 2006 failing which he will have to appear again in all Four Papers.

However, for a candidate clearing examination (All Four Papers) in one attempt the pass marks for each paper remains 40% with aggregate not less the 50%.