SUMMARY AND CONCLUSIONS

1. PD Blend systems

A flexible cork filled microcellular foam (PD2) is found to have optimum properties for constrained damping application.

It is found that a cork filled microcellular foam produced without 1,4 butane diol as chain extender is poor in tensile properties compared to foams prepared with a chain extender. It is seen that incorporation of chain extender in PD system contributes for increasing the energy absorbing and damping property as well as the Tensile properties. PD2 foam elastomer prepared with cork filler and polymerised with chain extender is found to have good damping properties for constrained damping.

% Hysteresis shows a gradual increase against hardness up to a hardness of about 20 and thereafter rapidly rises.

Compressive modulus of cork filled and freon blown foam elastomer is the least among all the foam elastomer systems. It is also seen that compressibility modulus remains constant up to about 50% compression which is a notable characteristic phenomena.

Higher cork filler loading increases hardness owing to the filler particles, reinforcing the soft segment matrix and adding rigidity to the foam.

Unlike talc filled or silica filled system, the cork filled system does not increase compressibility modulus characteristics substantially. This is a characteristic phenomena.
Talc filled and water blown foam moulded with a low NCO index (0.40) has a nearly equal compressibility characteristics of cork filled and freon blown PD2 foam (NCO index-0.80) system possessed with highest % hysterisis. A talc filled water blown PD7 formulation prepared with lower NCO index has near equal and similar hardness and other characteristics of Freon blown cork filled soft microcellular foam (PD2) formulation. Hence NCO index has a predominant influence on the properties compared to all others.

Silica filler while adding rigidity to the foam acts as a load bearing and energy absorbing filler in the elastomer and foam. It is also found to have good damping properties.

In talc filled foam, water as a blowing agent produces higher amount of expansion compared to freon-11. Finely divided filler particles as Talc powder contributes for reducing shrinkage in foams.

It is also seen that in polyester/MDI system extended with 1,4-butane diol there is a gradual decrease of tensile strength with increasing urethane concentration.

By preparing blends of polymers with different size rigid segments, it was found that polymer compatibility depended on the relative size of the combined hard segments.
2. PE blend system

PE system gives higher free rise density and hardness of foam compared to PD system.

% Resilience increases with increasing moulded density. The damping (constrained) and cushioning property (as shown by the Resilience properties) falls down beyond a hardness of 30° Shore A. Energy absorbing capability (Hysteresis) goes through a minimum value of 40% at 20-30° Shore A in the PE system foams and thereafter increases with increasing hardness.

Talc filled PD system has a better damping and energy absorption property than talc filled PE system.

Presence of finely divided filler particles is found to provide retention of strength over an extended range of temperature understood to be due to domain structures in this segmented polyurethane.

Talc filled PD system has lower % resilience when compared to PE system and hence talc filled PD system has better damping property than talc filled PE system. This is characteristic of polyester system compared to a polyether system.

Chain extender actually makes the system more flexible and increases the tendency for shrinkage.

Water blown foam is rigid while the freon blown foam even with a higher NCO index (1.02 of PE2 compared to 0.80 of PE3 system) is semi rigid.
The compression and tensile properties of PE (Polyurethane) system indicate that water blown foam has higher strength and modulus while damping properties are good for freon blown foams.

Polyester-Polyether (PE) blend system has lower damping and energy absorbing capabilities compared to the Polyester-Polyester blend (PD) system.

Polyether-Polyester (PE) blend has good miscibility of the two polyols as seen by the loss factor characteristics.

3. HP blend systems

The foams based on blended HTPB system (HP) is distinct in that they are more flexible and possess lower hardness and lower Resilience compared to foams based on non blended systems incorporated with chain extender.

Freon was not used as blowing agent in the formulation as foaming was not consistent and product suffered large irregularities. This is believed to be due to the low reactivity of the system due to PPG and incompatibility.

Though the hydroxyl functionality is low compared to PD system, and PE system, the high reactivity of HTPB system produces more cross linking and hard segmented polyurethanes.

HTPB blended foams exhibit high % resilience and low hysterisis thereby showing their low energy absorbing capability.

Mechanical strength of HP2 foam is found to be maximum believed to be due to the effect of highest packing factor.
PVC filler in HTPB –PPG blended system gives superior mechanical strength compared to Cork filled and Talc filled systems while possessing near equivalent resilience, Hysteresis properties and damping properties.

Unfilled foam

The mechanical properties are seen to be improved in the absence of filler as the filler is believed to add more defects and voids in the foam structure.

4. Non blended systems

HTPB based systems:

Though the hydroxyl functionality is low compared to PD system, and PE system the high reactivity of HTPB system produces more cross linking and hard segmented polyurethanes.

High % resilience and low hysteresis show that energy absorbing capability of HTPB based foams are low.

It is observed that higher concentration of foam stabiliser in the formulation aids shrinkage as seen in formulation H4. Cork filler allows gas release before cure leading to shrinkage. Talc does not allow gas release thus reducing shrinkage.

The Dynamic mechanical properties show that the loss factor is least for HTPB non blended foams. Hence the damping properties are least for HTPB systems. This is understood to be due to the fact that the PU foams based on HTPB alone has low concentration of elastomeric soft segments compared to other systems responsible for viscoelastic nature.
The theory that the polymer structure and moulded density have a predominant influence in determining the mechanical strength of foams is validated in this. However the nature of filler and its quantities contributes to change in modulus characteristics of the foam.

EmpeyoI system

There is no significant change in the resilience property though it is slightly less at lower density. The hysteresis property is not affected by the change in moulded density unlike in a polymer blended system, this being a homopolymer with low cross link density though there is likelihood of some branching in the polymer chain. This system acts more like elastic spring and consequently the damping and energy absorption are not significantly altered by change in moulded densities.

5. Prepolymer based systems

The free foaming expansion actually reduces with increasing amount of blowing agent.

A characteristic feature is that resilience increases with increasing hardness in the lower ranges, reaches a maximum and then the value comes down with increasing hardness. The maximum resilience of 45% in the Adiprene based foams is found to be at a hardness of 17° Shore A. The limiting hardness value related to maximum resilience of 40% is found to be at 13° Shore A for Polyol-D prepolymers based foams. The maximum resilience value is found to be at 36% for a hardness of 12° Shore A in the case of PPG prepolymers based foam systems.

The cushioning and damping properties are found to be good both at lower and higher values of hardness. This appears to be due to attainment of
the high elastic nature of the prepolymer based urethane foam at moderate and medium densities and consequent less damping properties of the foams.

Filler does not appear to play a significant role in changing the product properties of foam in prepolymer systems. Highly elastomeric nature resulting from long chain length, lower cross linking due to lower index are believed to be the reason for this behaviour.

NCO index and the blowing agent is the primary variables which influence the properties of the foam.

6. Packing factor and moulding

Packing factor a measure of the moulding pressure very significantly influences the product properties. Higher packing factor is found to be responsible for increasing the hardness of foams. Foam shrinkage, is influenced by packing factor.

7. Constrained damping

Polyurethane flexible or semi flexible foams possessed with low resilience, high Hysteresis, high loss factor with optimum hardness (not rigid) cushioning and modulus property is most desirable qualities required for constrained damping. A cork filled freon blown microcellular foam based on a POLYOL-C-Desmophen blended system having moulded density of 0.3-0.35 gm/cc is found to possess optimum properties for constrained damping and peak damping performance at 28-33°C.

A Polyester-polyether urethane and polybutadiene-polyether urethanes behave like SEMI IPN systems.
8. Extensional (Unconstrained) damping

Polyurethane semirigid foams having high loss modulus characteristics with optimum density, hardness, loss factor and frequency response characteristics are primary characteristics to be seen for extensional damping. A blended polyol system ISRO polyol C- Polyol D blended polyol system with MEG as chain extender is found to possess best properties for extensional damping applications.

9. Energy absorbing characteristics

The moderate to large % hysteresis especially of rigid and semirigid foam structure is found to be characteristic of the high energy absorbing capability of Polyurethane foams.

The phenomenon of micro phase separation and irregular void structure seen (stereo microscope picture) in cork filled foams generate multitude of surfaces and are believed to be responsible for multiple reflections and dissipation of acoustic or vibrational energy. This explains the higher damping and energy absorption characteristics of cork filled systems.

10. Acoustic energy absorption

Sound absorption and acoustic energy absorption characteristics were determined at different densities of foams and varying different isocyanates and polyol systems. It is seen that the nature of cell size and its uniformity influences the sound absorption spectrum of the foams at various frequencies. Incorporation of fillers like cork powders, rubber, graphite and plasticizers etc., are found to improve the sound absorption capability of foams as seen in Table.3.4.8.
CONCLUSION

ISRO polyols, HTPB and their blends are a unique form of polyol systems which are studied for making polyurethane microcellular elastomers and foams having distinctive properties especially related to energy absorption and damping characteristics. The polyols or prepolymer systems and their blends were polymerised and foamed with different, isocyanates, under varying catalytic conditions. Study of various formulations, the effect of chain extension, use of different fillers and additives in the foam system under various moulding processes have revealed the exceptional properties of these polyurethane systems. These results are significantly important in the product design of a polyurethane system especially related to damping performance and energy absorption.

Effect of incorporation of different fillers and reacting with different isocyanates, NCO index, catalyst systems and blowing agents have been subjected to analysis. In order to achieve necessary hardness, density and mechanical strength of foams moulding pressure and temperature are important parameters necessary to be controlled while curing. The energy absorption and damping characteristics are significantly influenced by the raw materials its ratio and physical properties of the foams. Chain extenders, fillers, and blended systems, can significantly contribute for improving the damping and energy absorption characteristics.

Foams and elastomers having strong secondary interactions tend to suffer a general decrease in physical properties as the extent of cross linking increases, e.g. polyester based materials. Elastomeric foams which have relatively weak secondary interchain reactions, e.g. polyethers extended with diols, and polyols with pendent methyl groups, show a general increase in physical properties with increasing cross link density. Polybutadiene
containing polyurethane blends exhibit phase segregation and incompatibilities.

Polyurethane foams and IPN systems can be designed to obtain necessary energy absorption and vibration damping properties by a careful selection of raw polyols, their blends and chain extenders of desired molecular structure. Polymerisation with modified or polyisocyanates and foaming reactions with blowing agents, stabilisers and catalyst systems are to be carefully controlled. Fillers contribute for modifying the properties. NCO index play a crucial role in controlling the hard segment concentration and product properties.

The hardness of the foam depends on the crosslink density in the polymer chain and the apparent density of the foam. The crosslink density of flexible foam is lower in comparison to semirigid which is lower than rigid. It is thus possible to obtain required hardness and properties of the foam by selecting the combination of reacting systems and their polymerisation conditions. Whereas the elongation, and the compression set decrease with increasing crosslink density, the tensile strength initially increases, but later decreases. When a predominantly linear segmented polyurethane is subsequently crosslinked, physical and chemical crosslinking effects overlap.

The regression analysis and response surface methodology are found to be very useful as an important tool for analyzing the effect of complex character of polyurethane foam process and performance. These methods have been very useful for modeling the behaviour of the foams.

In polyesters some low molecular glycols used in their preparation always contain diols which contribute to the formation of hard segments. The two-phase reaction mixture encountered in the one-shot process becomes visually homogeneous in the course of the reaction but, upon the completion, noticeably returns to two phases. The capacity of the foams and
elastomers to absorb mechanical and acoustical energy is indicated by their
dynamic mechanical properties. A semi-miscible morphology in the
elastomers can give rise to a broadened glass transition temperature.

Suggestions for further study

Study of Polybutadiene-Polyester HTPB-Desmophen-2200- system
predicted rigid polyurethane system.

Investigating role of chain extender in the HTPB-PPG 3600 system –
incompatibility expected.

Study of PVC filled PD and PE blend foam systems.

Study of acoustic absorption of various other formulations of foams
particularly of low densities.