

Preparation of Molded Viscoelastic Polyurethane Foam for Pillow Applications

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Received: 18 May 2010, Accepted: 2 March 2011

SUMMARY

There is a growing interest in developing and commercializing viscoelastic polyurethane foam suitable for pillow and mattress applications. In the present investigation, a novel combination of polyols with different molecular weights and hydroxyl values along with other ingredients were used for the preparation of viscoelastic polyurethane foam. The optimum polyol:isocyanate ratio was found to be 100:45 to yield a good quality foam. The physico-mechanical properties of the foam were measured as per standard procedures and compared with those of a commercially available viscoelastic foam sample. It was observed that the properties of the foam from this investigation were almost similar and in some aspects better than the properties of commercially available pillow foam. The foam can be further developed to make it suitable for hospital pillows and mattress applications.

Keywords: Viscoelastic foam, physico-mechanical properties, ball rebound resilience

INTRODUCTION

Polyurethane foams find wide uses in many engineering applications because of the degree of comfort and protection which are not achievable with many

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competitor materials [1]. Viscoelastic foams are a special type of flexible polyurethane foams which exhibit low resilience (LR) and slow recovery (SR) after compression. When a weight is applied on viscoelastic foam, the foam progressively conforms to the shape of the object, and after the weight is removed, the foam slowly reassumes its initial shape. Because of this gradual recovery, viscoelastic foams are described as “SR” foams. Other characteristics include its ability to damp vibration as well as to absorb shock. In addition to these key advantages, many viscoelastic products also react to body temperature and ambient temperature, softening with heat and more easily adjusting to body contours [2]. Viscoelastic foam was first invented for NASA’s space programs in the mid 1960s, in order to reduce pressure points experienced by astronauts [3]. Pillows and mattresses made of viscoelastic foam have a unique characteristic of keeping the neck and head level with the spine and help patients who suffer from constant neck pain or headaches to get rid of the pain. Defloor et al. [4] studied the effective use of viscoelastic mattress to reduce the number of pressure ulcer lesions in different patient groups. Today, viscoelastic foams are widely used in comfort cushioning, packaging, bumper pads, sport and medical equipment, mattresses, helmet liners, pilot seats, earplugs, and for various noise and vibration dampening applications [5].

Several different chemical approaches were adopted by various researchers for the manufacture of viscoelastic foams. Kageoka et al. [6] has developed novel polyols for viscoelastic foams with reduced temperature sensitivity. The viscoelasticity of the polyurethane foams can be controlled by controlling the molecular weight distributions and functionalities of the reacting polyols and isocyanates [7]. The other routes for achieving viscoelastic polyurethane foam include use of the following, either singly or in combination: low molecular weight crosslinkers, blends of high and low molecular weight polyols, mixtures of polyols with different ethylene oxide content, use of alkoxyated alcohols, variation of the isocyanate index, introduction of plasticisers, building interpenetrating polymer networks (IPNs) and blending polyurethanes with other polymers [8]. In the present investigation, a novel mixture of low and high molecular weight polyols with different functionalities was used to achieve low resilient, slow recovering viscoelastic foam suitable for pillow applications.

EXPERIMENTAL

The materials and methods used in the present study are summarized below:

Materials

Polyols

A combination of diol and triol initiated polyether polyols with different molecular weights and OH numbers was used in the present investigation. Grafted copolymer polyol containing polystyrene and poly acrylonitrile (CS 540) supplied by Kumho Petrochemicals, Korea, was also used in the present study to impart the required hardness and load bearing properties. The polyols used in the present investigation are summarized in **Table 1**.

Table 1. Polyols used in the formulation

Polyol	Initiator	Functionality	OH Value (mg KOH/g)	Molecular weight Mw(g/mol)
Polyol -1	Glycerine	3	35	4750
Polyol -2	Glycerine, Dipropylene glycol	2.5	568	1450
Polyol -3	Dipropylene glycol	2	28	4050
Polyol -4	Dipropylene glycol	2	112	1002
CS 540	-----	-----	22.5	-----

Surfactants

Silicone surfactants are used in polyol formulations to increase the miscibility of the additives, to stabilize the foam and to control the cell morphology. The surfactant used in the present study is a mixture of L660 and L618 (Momentive Performance Materials, USA).

Catalyst Package

The catalyst package consists of DABCO 33 LV (Air Products Inc.), NIAX A-1 (Momentive Performance Materials, USA) and MP 602 (Air Products Inc.).

Crosslinker

The crosslinker used was Niox processing additive DP 1022 (GE advanced Materials, USA).

Isocyanate

Wannate 8102, a mixture of polyol-modified diphenylmethane diisocyanate and polyphenylmethane polyisocyanate supplied by Yantai Wanhua Polyurethanes

Co. Ltd., China was used in the present investigation. The NCO content of the isocyanate was 27%, hence its equivalent weight was 155 g/eq.

Blowing Procedure

Hand Mixing

The polyols, catalysts, water and other chemicals were measured into a 500 ml plastic cup and mixed at $25 \pm 1^\circ\text{C}$ using a bench mixer (Mars, USA) at 4500 rpm for 10 minutes. The required amount of isocyanate, maintained at $25 \pm 1^\circ\text{C}$, was then added to the blended polyol, and the mixture was thoroughly stirred for 5 seconds. This mixture was then immediately poured into a 2 liter plastic cup. Cream time, string-gel time, rise time and free rise density (FRD) were noted. Test blocks of dimension 375 x 375 x 100 mm were then molded using a MS mould kept at 50°C . The foam pieces were de-molded after 4 minutes of curing and were used for testing of various physico-mechanical properties of the foam.

Machine Mixing

The polyol blend was prepared in a 100 kg drum by adding the required quantity of polyols and other ingredients. The blend was mixed thoroughly for 60 minutes using a heavy-duty stirrer (RQ 134 S/D, Remi Motors) with a speed of 4000 rpm. The polyol and the isocyanate were then loaded into a high-pressure foaming machine (A 20, Cannon, Italy). The foam was poured using a 2000-3500 psi injection pressure at a throughput of 200–300 g/s into an aluminum pillow mold (80 x 41 x 17 cm) heated at 50°C . The pillow was demolded after 5 minutes and kept at 22°C for cooling.

Mechanical Property Measurement

The physico-mechanical properties of the foam such as density, indentation force deflection (IFD) behavior, tensile strength, tear resistance and resilience (ball rebound) were measured as per the methods described in ASTM D 3574 – 05. These properties were compared with the properties of commercially available viscoelastic pillow foam sample Blissco™ [supplied by Sreeram Foams Ltd., Chennai, India].

RESULTS AND DISCUSSION

Optimization of the Polyol Formulation

Various trial and error based experiments were carried out in order to optimize the formulation of the polyol system, which can produce a low resilient, slow recovery viscoelastic foam. The optimized formulation is given in **Table 2**. Patent application is currently in progress [9]. The amount of isocyanate required to react with the polyol and any other reactive additives in the formulation, plays an important role in deciding the viscoelasticity of the resulting foam. In the present investigation, the parts by weight (pbw) of the isocyanate required for 100 pbw of polyol mixture was calculated using the following equation:

$$\text{Pbw of MDI required} = \left(\frac{\text{pbwpolyolA}}{\text{eq.wt.polyolA}} + \frac{\text{pbwpolyolB}}{\text{eq.wt.polyolB}} + \dots + \frac{\text{pbwpolyolN}}{\text{eq.wt.polyolN}} + \frac{\text{pbwH}_2\text{O}}{\text{eq.wt.H}_2\text{O}} \right) (\text{MDIeq.wt}) \quad (1)$$

The pbw of isocyanate required as per the above equation was 89 and was taken as 100 index. The reactivity profile of the polyol at 100 index was determined using the cup test and it was observed that the reaction was very fast with cream time of 3 seconds and free rise density (FRD) of 120 Kg/m³. In order to slow down the reaction and to reduce the FRD, the index was varied from 50 to 100 and the bench properties of the polyol at these indices were determined and summarized in **Table 3**. As expected, the

Table 2. Optimized formulation of polyol blend

Ingredients	Parts by weight (pbw)
Polyol -1	10-30
Polyol -2	20-40
Polyol -3	10-20
Polyol -4	20-40
CS 540	5-15
Surfactants	1.0-2.5
Catalyst Package	1.5-3.0
Crosslinker	1.0-3.0
Water	1.0-3.0

reaction time was found to increase and FRD was found to decrease with decrease in isocyanate index. The variation of various bench properties with isocyanate index is graphically shown in **Figure 1** and **Figure 2**. It was found that 50 index, or in other words, a polyol:isocyanate ratio of 100:45 gave an optimum set of bench properties and a foam with very good viscoelastic characteristics.

Table 3. Reactivity profile (bench properties) of the polyol system

Bench Properties	50 Index (100:45*)	60 Index (100:54*)	100 Index (100:89*)
Cream time (seconds)	8	6	3
Gel time (seconds)	62	45	32
Rise time (seconds)	70	50	41
Free rise density (Kg/m ³)	65	98	120
*(Polyol:Isocyanate)			

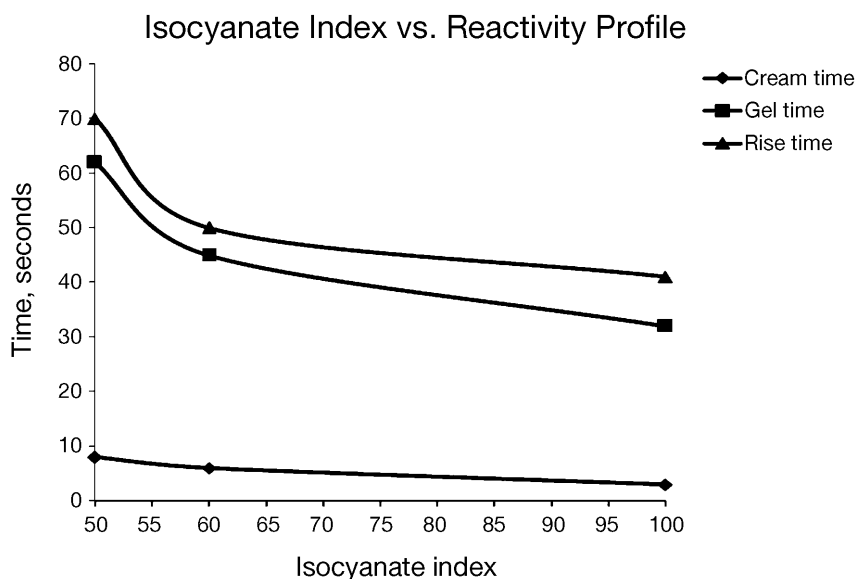


Figure 1. Effect of isocyanate index on reactivity profile of polyol

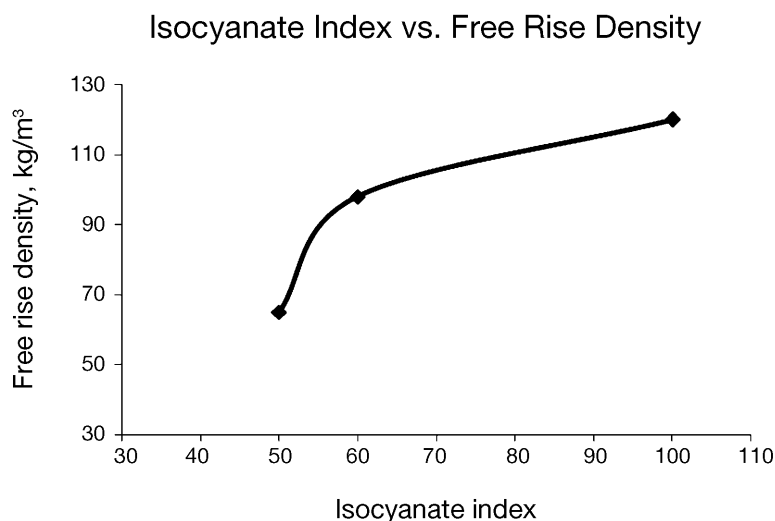


Figure 2. Variation of free rise density with isocyanate index

Mechanical Properties

The density of the molded foam was varied from 65 kg/m³ to 70 kg/m³. Viscoelastic foam mattresses and pillows are usually denser than other types of flexible foam available in the market. This makes it more supportive to the body contours, especially neck and shoulders. The density and other mechanical properties of commercially available viscoelastic foam pillow sample were measured and compared with the foam in the present investigation. The results are summarized in **Table 4**. Tensile strength, tear strength and elongation values were almost similar for both foams. Firmness or the comfort of the memory foam is measured by IFD rating. The cushioning quality is determined by measuring the sag factor (ratio of 65% IFD to 25% IFD). A value more than 2 indicates resistance to bottoming out. The degree of viscoelasticity and the energy dissipation characteristics are estimated by the ball rebound (BR) resilience values. The lower the BR value, the higher the degree of viscoelasticity in the foam [10]. The foam samples from the present investigation showed a rebound resilience value of 3%, whereas the value for the commercially available sample was 5%. The time taken by the foam to return to 95% of its original height after being compressed for one minute to 25% of its initial height was used to indicate the memory character of the specimens [11]. In this aspect also the foam developed in the present study was found to be better than its commercially available counterpart.

Table 4. Physico-mechanical properties of the viscoelastic foam

Properties	Samples from the present study	Samples from Blissco™
Density (Kg/m ³)	65-70	65
Tensile strength (Kg/cm ²)	1.13	1.20
Elongation (%)	124	128
Tear Strength (Kg/cm ²)	0.68	0.62
IFD at 25% (Kgf)	3.25	3.42
IFD at 40% (Kgf)	4.51	4.62
IFD at 65% (Kgf)	8.73	8.68
Sag Factor	2.69	2.54
Rebound resilience (%)	3	5
Time to return 95% height	14	10

CONCLUSIONS

A novel viscoelastic polyol blend consisting of different types of polyols and other additives was developed.

The optimum polyol:isocyanate ratio was found to be 100:45 to get a low resilient and slow recovery viscoelastic foams suitable for pillow applications. Foams were prepared both by hand mixing and by using a high-pressure PU dispensing machine.

The physico-mechanical properties of the foam were measured as per ASTM standards and compared with a commercially available viscoelastic pillow sample. Rebound resilience and time to return 95% of original height values were found to be better for the foam developed in the present investigation while all other properties were almost similar.

The foam can be developed further for applications such as hospital pillows and mattresses.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the management of Manali Petrochemical Ltd., Chennai, India, for their support for the successful completion of this investigation. The authors would also like to thank Mr. M Sivaswamy, Consultant (R&D) and Mr. R Meenakshisundaram, Head (AT/QA), Manali Petrochemical Ltd., for their valuable suggestions during the course of this investigation.

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