Properties of rigid polyurethane foams prepared with synthesized PIPA polyol

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Citation

Abstract
Polyisocyanate polyaddition (PIPA) polyol was synthesized in laboratory. Fourier transform infrared spectrometry (FTIR) and gel permeation chromatography (GPC) were employed to characterize the PIPA polyol and the best synthetical formula was found. The rigid polyurethane foams blown by water were made from the mixture of PIPA polyol and low hydroxyl number polyol. How the controlling variables such as the ratio of two kinds of polyols, surfactant, chain growth and cross linking, and isocyanate index affected the properties of the foams were studied with the scanning electron microscopy (SEM), mechanical testing and rheological testing. When the amounts of surfactant, 1, 4-butanediol, trimethylol propane and TMN-3050 polyol were respectively 1.0 php, 1.0 php, 1.0 php, and 15 php, and the isocyanate index was 1.15, the cells were well-proportioned and close, the cell size and foaming time were moderate, and the foams performed the best strength and toughness.

1. Introduction

Rigid polyurethane foams (RPUFs) can be defined as a kind of polyurethane foams which have no remarkable deformation under a certain load but cannot return to the original shape after large deformation under an overload. RPUFs have excellent mechanical, acoustic, electrical and chemical resistant properties, and they are the most ideal thermal insulating materials, for they have the prominent feature of especially low coefficient of thermal conductivity. RPUFs can be synthesized from monomers to polymers in one step. Moreover, by changing the chemical structure, quality, category, etc. of raw materials, RPUFs can be manufactured as different final products widely applied in thermal insulation, packaging, shipbuilding industries, etc. [1-6]

Polyols are one of the two main parts to prepare polyurethane foams, and presently polyether and polyester polyols are widely used[7]. There is a modified polyether polyol called Polyisocyanate polyaddition (PIPA) polyol, which is a new filling polyether polyol came after POP. PIPA polyol is the product of an addition reaction which occurs between Polyisocyanate and low molecular weight compound with multiple hydroxyl, primary amine Tertiary amino group in polyol with high molecular weight, especially Polyether polyol. The primary reaction is the interaction among Alcoholamine and
multiple functional groups of Isocyanates, and the products are Polyurea or Polyurethane particles, i.e., PIPA particles, while polyol acts as sufficient inert carrier of PIPA particles. PIPA polyol is the dispersoid of polymer particles (PIPA particles) well dispersed in the continuous phase of polyol. It is prepared by additional reaction of isocyanate with alcohol amine in polyether polyol, and the carbamate is considered as dispersant. With strong steric hindrance effect of aryl, the molecular chains are difficult to get close to each other and arrange regularly, which results in the difficulty of crystallization. Therefore, PIPA polyol can be used to manufacture polyurethane products with eminent mechanical property and flexibility at low temperature, and can enhance the rigidity, elasticity and open ratio of soft foam, rigid foam and semi-rigid foam. As long as PIPA polyol is commercially available, it is widely used to produce bulk foam plastic or molded soft foam, hard foam and semi-half foam, and the bearing capacity of the foam is significantly improved compared with those congenic products.

Owning to the outstanding water-splitting proof property, thermal expansion coefficient and better energy absorption capability of the foam made from PIPA polyol, it can be used in shipbuilding industry, the weight reduction of heavy-duty military equipment such as tank to expand the horizon of further research. PIPA polyol is easy to synthesize in laboratory generally through batch process and continuous process by far, and the products by continuous process have a steady system and the viscosity \( \eta \) is easier to be controlled. The convenient process and low price of PIPA polyol make it wider used in coating and adhesive fields. In this study, how to prepare qualified PIPA polyol in lab and how the components affect the properties of the foams prepared with PIPA polyol were investigated.

2. Experiments

2.1. Materials

The isocyanates used in this study were polyaryl polyisocyanate (PAPI, commonly called Polyurea polyphenylene isocyanate, PM-200) and toluene diisocyanate (TDI-80) supplied by Yantai Wanhua PU Co., Ltd. And the polyether polyols were TMD-450 (OH value: 450 mgKOH/g) and TMD-3050 (OH value: 56 mgKOH/g) supplied by Tianjin third petrochemical factory. B8433 from Evonik Degussa Co. was used as surfactant here. 1, 4-butanediol (BDO, CR) and trimethylolpropane (TMP, CR) were from Sinopharm chemical reagent Co., Ltd. Triethylenediamine (A-33) and Dibutyltin dilaurate (T-12) were used as a catalyst that accelerated the polymerization. Triethanolamine (TEA) was used as a material to prepare PIPA polyol. Distilled water was used as the blowing agent.

2.2. Preparation of PIPA Polyol and RPUFs

TEA and microcontent T-12 were mixed into TMD-450 with an electric stirrer at 200 rpm for 30 s. The mixture was added rapidly with TDI and stirred for 60 s at the same speed. Then bubbles in mixture were cleared in vacuum to obtain PIPA polyol. Here TEA/TDI = 10/9, and TMD-450/TEA (w/w) was 110/0, 110/5, 110/10, 110/15, 110/20, respectively. The properties of samples with different TMD-450/TEA were tested and found the best ratio to synthesize PIPA polyol.

Table 1. Foaming formulation of rigid polyurethane foams.

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Dosage/php</th>
<th>( \text{g} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-side material</td>
<td>PAPI</td>
<td>90–110</td>
</tr>
<tr>
<td></td>
<td>TDI</td>
<td>10</td>
</tr>
<tr>
<td>B-side materials</td>
<td>PIPA</td>
<td>70–100</td>
</tr>
<tr>
<td></td>
<td>TMD-3050</td>
<td>0–30</td>
</tr>
<tr>
<td></td>
<td>A-33 and T-12</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Distilled Water</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>B8433</td>
<td>0.5–2.5</td>
</tr>
<tr>
<td></td>
<td>BDO</td>
<td>0.5–1.5</td>
</tr>
<tr>
<td></td>
<td>TMP</td>
<td>0–2.0</td>
</tr>
</tbody>
</table>

[1] The dosages of all ingredients are expressed in parts per hundred parts of polyol, which conventionally dictates that the sum of all polyols adds up to 100 parts.

PIPA (A-side material) and B-side materials shown in table 1 were prepared separately by stirring for 30 s at 200 rpm. Thereafter PAPI was added into B-side materials and mixed for 10 s at the same speed. The reacting mixture was then poured quickly into an uncovered mold to foam freely, and the creaming time, rising time and gelling time were recorded. When cured completely, the foam materials were cut and made into standard samples for each property test. The performances of different formulas were studied, and the mechanisms of how they affect the properties of foams were also analyzed.

2.3. Characterization

The characteristic functional groups in PIPA polyol were determined by a Fourier transform infrared spectrometer (FTIR, Nexus 670, Nicolet Co., USA). The average molecular weight of PIPA polyol was determined by gel permeation chromatograph (GPC, Waters Co., USA) with polystyrene standards. The samples were dissolved in tetrahydrofuran (1% w/v solutions) which was also used as carrier solvent at a rate of 1 mL/min. The \( \eta \) of PIPA polyol was measured at 20 °C by a Brookfield viscometer model DV-11 (Brookfield Engineering Laboratories, Inc, USA). The measurements were performed at 3 rpm with the spindle 52.

The compressive strength was measured by Lloyd universal testing machine (LR30K, Ametek Co., Ltd, Britain) according to the standard GB 8813-88 at a speed of 5 mm/min, and the dimensions of the samples were 50 × 50 × 50 mm. Flexural strength was measured by the same machine according to the standard GB 8812-88 at a speed of 10 mm/min, but the dimensions of the samples were...
20×25×20 mm. Impact strength was measured by Resil Impactor (Ceast Co., Ltd, Italy) according to the standard GB/T 13525-92 with the dimensions of the samples being 120×15×10 mm. The foam morphology was observed by a scanning electronic microscope (SEM, S250, Hitachi Co., Japan). Samples were freeze-fractured in liquid nitrogen and the fracture surface was sputter-coated with gold before observation. The samples were observed with an accelerating voltage of 19 kV. The dynamic frequency sweeps with torsion mode were performed on ARES rheometer (TA Instruments Co., USA) in N₂ at 50°C to get dynamic rheological properties of the samples with dimensions of 45×12.7×6 mm. The strain was 5% and the sweep frequency was 0.1-100 rad/s.

3. Results and Discussion

3.1. Characterization of PIPA Polyol

As shown in Scheme 1, the reactions of isocyanate with TEA and polyol were the two major reactions in the system. The former generated carbamate, which act as the organic filler in PIPA polyol was to improve the properties of following products, and the latter was a cross linking reaction which could increase the viscosity of the system.

Scheme 1 Reactions of isocyanate with TEA and polyol

The reaction of isocyanate with TEA occurred firstly[5]. But along with the active groups of TEA being consumed, the rest groups were annihilated due to steric hindrance effect and barely reacted. Then the reaction of isocyanate with polyol started to become the major reaction, which made η of the mixture increase rapidly.

The solid content is an important parameter to measure the quality of PIPA polyol, which can be defined as the weight percent of generated PIPA granules in the system, and namely the weight percent of alcohol amine and isocyanate in the mixture. In general, the higher solid content brings the better load capacity and modulus of the foams, but the higher η of the foaming system is unfavorable. Therefore the solid content ought to be moderate. Here solid content changes with different ratios of TMN-450/TEA, and the best one need to be found.

The products are analysed by FTIR and the obtained spectra are shown in Fig. 1. The overlapped peak of N-H and O-H is observed between 3600 cm⁻¹ and 3200 cm⁻¹. The peaks of nonsymmetrical and symmetrical methyl and methylene appear between 2970 cm⁻¹ and 2850 cm⁻¹, and so does the peaks of symmetrical deformation vibrations of methyl and methylene at 1370 cm⁻¹ and 1450 cm⁻¹. There are no peak between 2270 cm⁻¹ and 2100 cm⁻¹ which is the characteristic absorbing range of N=C=O, which indicates that isocyanate groups are totally reacted. The nonsymmetrical peak of C-O-C in aliphatic polyether appears between 1130 cm⁻¹ and 1080 cm⁻¹, overlap with the peak of C-O at 1100 cm⁻¹. The above spectrums indicate that there is polyol in the product. There are several peaks at 1730 cm⁻¹, 1604 cm⁻¹, 1538 cm⁻¹, and between 1250 cm⁻¹ and 1230 cm⁻¹ in all samples except sample 1(namely TMN-450), and they strengthen with the increase of TEA in the samples, especially in sample 3, 4 and 5. Thereinto, the peak of C=O is at 1730 cm⁻¹; the characteristic peaks of amide II bond are at 1604 cm⁻¹ and 1538 cm⁻¹; the peak of C-N in secondary amine is between 1250 cm⁻¹ and 1230 cm⁻¹; the peak of N-H bending vibrations in secondary amine is at 1450 cm⁻¹. All of these demonstrat that the carbamates has been synthesized and the PIPA polyol has been prepared successfully in all the samples except 1.

Table 2 shows weight-average molecular weight ($M_w$) and polydispersity ($α$) of PIPA polyols with different ratios of TMN-450/TEA. It can be observed that the weight-average molecular weight of products gradually increased with the ratio of TMN-450/TEA. Larger solid content means more reactants which would lead to longer molecular chains and higher η of products. And the $α$ also increased gradually, which means a wider distribution of molecular weight, and a gradual diversification of the molecular structure of the products from isocyanate-TEA and isocyanate-polyol reactions.

![FTIR spectra of PIPA polyols with different ratios of TMN-450/TEA.](image)

**Fig 1.** FTIR spectra of PIPA polyols with different ratios of TMN-450/TEA. (1) 110/0; (2) 110/5; (3) 110/10; (4) 110/15; (5) 110/20.

<table>
<thead>
<tr>
<th>TMN-450/TEA(w/w)</th>
<th>110/0</th>
<th>110/5</th>
<th>110/10</th>
<th>110/15</th>
<th>110/20</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_w$</td>
<td>524</td>
<td>596</td>
<td>628</td>
<td>619</td>
<td>614</td>
</tr>
<tr>
<td>$α$ ($M_w/M_n$)</td>
<td>1.289</td>
<td>1.380</td>
<td>1.331</td>
<td>1.439</td>
<td>1.424</td>
</tr>
</tbody>
</table>

Except for solid content, viscosity η is another important parameter to measure the quality of PIPA polyol, which has a close relationship with solid content. The overhigh η goes against the well mix of the materials and leads to bad fluidity in foaming procedure, which would reduce the quality of the product. The η of PIPA polyol is mainly related...
to the degree of cross-linking reaction of isocyanate with polyol and the molecular weight of product. It can be observed in Fig. 2 that the $\eta$ of the products increases with the solid content in exponential relationship, which means the increasing speed grow faster at high solid content. This phenomenon mainly results from four reasons. [5] First, the polyols used here have higher activity, which is very easy to react with isocyanate and bring about cross linkage. Second, polyether polyol are the solvent of both TEA and isocyanate, so the reaction in solution has a faster cross linking speed. Third, larger solid content means more isocyanate groups, so the degree of cross linking reaction is deepen. Fourth, TEA can be a catalyst of cross linking reaction and also a cross linker because of its high functionality. More TEA could speed up the cross linking.

Fig. 2. Viscosity and log $\eta$ of PIPA polyols with different ratios of TMN-450/TEA.

Considering the above investigation on the products, the formula of TMN-450/TEA=110/10 was optimum. The PIPA polyols synthesized with this formula can be used as a material to prepare RPUFs in the following research, for the solid content was about 15%, the $\eta$ was about 3400mPa•s, and the molecular weight was moderate.

3.2. Surfactant

Surfactant is not only vital to the forming and stabilization of cells, but also important to the regulation of cell size in polyurethane foams. Organosilicone is the most widely used surfactant presently, and is often synthesized via hydrosilation of polyhydrosiloxane and allyl-terminated polyether using platinum as a catalyst. [13] Most surfactants for the rigid foams are non-hydrolyzed (Si-C). In parts of them one end of the polyether is unsaturated double bond (C=C) while the other one is hydroxyl group terminated, but not alkyl. This kind of surfactant has outstanding emulsification on the components in the mixture, therefore the capability is stronger to control the cell size.

3.2.1. Foaming Time

When the amount of the gas from the foaming reaction increases and surpasses the equilibrium critical density, it starts to form micro cells. This is nucleation phase, and the time required is called creaming time. Rising time is the time in which foams get maximal volume. After formation, the foams are harder, dryer, and no longer sticky. This time is called gelling time. Surfactant mainly affects the nucleation phase in foaming reaction.

<table>
<thead>
<tr>
<th>B8433/php</th>
<th>0.5</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
<th>2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>creaming time /s</td>
<td>35</td>
<td>38</td>
<td>40</td>
<td>41</td>
<td>45</td>
</tr>
<tr>
<td>rising time /s</td>
<td>81</td>
<td>86</td>
<td>88</td>
<td>90</td>
<td>93</td>
</tr>
<tr>
<td>gelling time /s</td>
<td>119</td>
<td>120</td>
<td>119</td>
<td>121</td>
<td>122</td>
</tr>
</tbody>
</table>

It can be observed in Table 3 that the creaming and rising time increase slightly with the dosage of B8433, whereas the gelling time change a little. B8433 possesses very strong emulsification to foaming system, and it can lower the $\eta$ in nucleation phase and make the surface nature of everywhere in the mixture as identical as possible. So it need longer time to attain total emulsification. This makes the foaming system to maintain well fluidity in a longer time, which is very propitious to mould foaming and filling foaming. At the same time, B8433 makes cell size well-distributed and the volume increase smoothly, and as the consequence the rising time is a little longer.

3.2.2. Structures of the Cells

SEM micrographs of RPUFs with different dosages of B8433 are shown in Fig. 3. It can be observed that the average cell size of samples firstly decreased and then increased with the increasing dosage of B8433, which were about 2.4mm, 2.0mm, 2.5mm, 2.7mm and 3.0mm, respectively. The insufficient B8433 has weakly emulsifying capacity, so the high viscosity makes it harder to form micro cells; whereas excessive B8433 would sharply decrease the viscosity and the micro cells are easier to get together, which results in larger cell size and uneven distribution of cells’ diameters. Over 2.0php, the cell walls had not enough strength to maintain the shape and intactness of the cells in foaming procedure.

Fig. 3. SEM micrographs of RPUFs with different dosages of B8433. (a) 0.5php; (b) 1.0php; (c) 1.5php; (d) 2.0php; (e) 2.5php.
3.2.3. Mechanical Properties

Owing to excellent mechanical properties with a low density, RPUFs can be used as structural materials. Whatever they've been used as, the relationship between microstructure and mechanical properties should be understood. The mechanical properties of polymer foams mainly depend on the intrinsic property of the polymer matrix, the density of foams and the geometric feature of the cells. And the architecture is determined by the thickness of the cell walls, the distribution of the cell size and the shape of the cells.\[14\]

Fig. 4 shows mechanical strengths of RPUFs with different B8433 dosages.

![Fig. 4. Compressive, flexural and impact strengths of RPUFs with different B8433 dosages.](image1)

Properties: ■-compression, ▼-bend, ●-impact

Fig. 4. Compressive, flexural and impact strengths of RPUFs with different B8433 dosages.

Fig. 5. Compressive, flexural and impact strengths of RPUFs with different dosages of chain extenders and cross linkers. (1) 0.5php BDO+1.0php TMP; (2) 1.0php BDO; (3) 1.0php BDO+1.0php TMP; (4) 1.0php BDO+2.0php TMP; (5) 1.5php BDO+1.0php TMP.

The product from reaction with 1.0 php BDO and 1.0 php TMP show the best mechanical properties in the five samples. More chain extenders brought about longer molecular chains and make molecular segments move more easily to absorb more energy under external load. This could improve the elasticity and toughness of foams, but reduce the rigidity. More cross linkers increased the density of cross linking, which could hinder molecular segments to move. This brings about better ability to keep the structure and strength, but worse flexibility of materials. However, because of some hydrogen bonds in the foams, the increasing of cross-linking density would lead to stronger effect of chains separation, and the non-covalent bonds between molecules may be destroyed by more chemical cross linkages. Besides, the cross linkages may destroy the regularity of molecular chains, which can reduce the ability of crystallization of soft segments in RPUFs. All of the above changes may reduce the strength of foams, so excessive cross linkers are unexpected. The foams with excellent comprehensive performance can be prepared via using appropriate chain extenders associated with cross linkers.

There must be some relationship between the mechanical properties and dynamic storage modulus of polymers, for both of which have a close relationship with molecular chain

3.3. Chain Extender and Cross Linker

The network structure of typical polyurethane foam can be made by both chemical and physical cross linkage. The chemical cross linkage arises from the use of hydroxyl polyols with more than two functional groups, while the physical cross linkage arises from the phase separation of hard segments (the isocyanate segments).\[15\] The chemical cross linkage of RPUFs is obtained mainly by generating covalent bonds. Active isocyanate groups could react with a variety of functional groups. In general, the small molecules with two functional groups are called chain extenders, whereas the ones with more than two functional groups are called cross linkers. As the former are used to lengthen the main molecular chains, and the latter are used to make the molecular chains form network structure, using chain extenders associated with cross linkers could accelerate the solubility process of foams, increase the degree of cross linking, and make cross linking points well-distributed, all of which result in the foams with high density and small cells and thus improving the mechanical properties.

In this research, BDO was used as the chain extender with two functional groups, and TMP as the cross linker with three functional groups. The mechanical properties of RPUFs with different dosages of chain extenders and cross linkers are shown in Fig. 5.
structure. For instance, the chain extenders can change the procedure of foams’ micro phase separation and improve the compatibility of soft and hard phases, as a result, the beginning of micro phase separation is delayed and the storage modulus comparatively decrease. [16] But the improvement of the compatibility between soft and hard phases can increase the crystallization, and make the storage modulus and mechanical strength both increase. [17] The increase of cross linkers makes the cross-linking density increase, which also makes the mechanical strength and storage modulus increase at the same time. In a word, the microscopic changes of phase separation, crystallization and cross-linking all have an effect on the macroscopic mechanical strength and storage modulus. It can be observed in Fig. 6 that the changes of dynamic storage modulus and mechanical strength with different ratios of chain extenders and cross linkers generally have the same trend. So by measuring the dynamic rheological properties, the mechanical properties of the materials can be predicted.

3.4. Polyols with Low Hydroxyl Number

The main molecular chain of polyurethane is composed of soft and hard segments. The former generally derive from polyols, whereas the isocyanate groups transform into urethane linkages and form hard segments. Phase separation happens when the soft and hard segments separately gather together, so they are respectively called soft and hard phases. [18] Therefore, the higher the polyols molecular weight is, the more soft segments there are in the polyurethanes. TMN-3050 has low hydroxyl number, high molecular weight and long molecular chains. The product from isocyanate and TMN-3050 reaction has a larger molecular weight of the chain between the cross-linking points, which is a soft segment. These segments get together and form soft phases in the polyurethane.

Fig. 7 shows the mechanical properties of RPUFs with different TMN-3050 dosages. It can be observed that the mechanical strengths of samples decreased with the increasing of TMN-3050 dosages between 10 php and 30 php, and reach the peak at about 15 php. The proportion of soft segments in the product of TMN-3050 and isocyanate reaction was larger due to its low hydroxyl number compared with TMN-450, so the molecular chains were easier to rearrange in time to absorb external force, which improved the elasticity of the foams. At the same time, appropriate increase of soft segments was beneficial to improve the regularity of molecular chains and the degree of phase separation, which may bring higher crystallinity and more hydrogen bonds. And all of these can strengthen the foams and make them display good macro mechanical properties. However, excessive soft segments may make the molecular chains too flexible, and the density of cross-linking points decrease at the same time. The polymer may be hard to maintain the cross-linking network, and the properties of foams may also fall down.

**Fig 6.** Plots of dynamic storage modulus ($G'$) with frequency ($\omega$) for rheological behavior of RPUFs with different ratios of chain extenders and cross linkers. (Formulation: ■-0.5php BDO+1.0php TMP, ●-1.0php BDO, ▲-1.0php BDO+1.0php TMP, ▼-1.0php BDO+2.0php TMP, ◆-1.5php BDO+1.0php TMP)

**Fig 7.** Compressive, flexural and impact strengths of RPUFs with different TMN-3050 dosages.

**Fig 8.** Plots of dynamic storage modulus ($G'$) to frequency ($\omega$) for rheological behavior of RPUFs with different TMN-3050 dosages (Formulation: ■-0php TMN-3050, ●-10php TMN-3050, ▲-15php TMN-3050, ▼-20php TMN-3050, ◆-30php TMN-3050)
There is a close relationship between the polyurethane phase separation and storage modulus. The storage modulus starts to increase at the beginning of phase separation of hard segments. This increase results from the growth of the physical network of hydrogen bonds in the carbamate. The separation of hard segments brings physical cross-linking, and the hard phases act as physical cross-linkages and reinforcing fillers, both of which can improve storage modulus and mechanical strengths at the same time.\[19\] It can be observed in Fig. 8 that the testing results of rheological and mechanical properties are approximately identical, just except the sample without TMN-3050. But because the viscosity of TMN-3050 is far less than that of PIPA polyol, polyols mixed with TMN-3050 have a lower viscosity and make the cells formed easily. Compared with the sample without TMN-3050, the mechanical properties of the sample with 15php TMN-3050 are better, so 15 php TMN-3050 is considered as the best solution.

3.5. Isocyanate Index

Isocyanate index is the mol ratio of isocyanate groups to hydroxyl groups in the reactants mixture, namely n(NCO)/n(OH). In order to make the polymerization react completely, the isocyanate groups and the hydroxyl groups ought to be equal in mol theoretically, which means n(NCO)/n(OH)=1. But water can react with isocyanate groups when it is used as blowing agent, and so does the chain extender. In addition, the formation of polyurethane foams is accompanied with many side effects, such as reactions of forming urea and biuret. All of these will consume some isocyanate groups. Consequently, isocyanate index ought to be greater than 1 in the practical foaming system.

Fig. 9 and Fig. 10 separately show the mechanical properties and the relationship of dynamic storage modulus to frequency of RPUFs with different isocyanate indexes. It can be observed that the flexural and impact strengths decrease with the increase of isocyanate index, and the peak is at 1.15, whereas the compressive strength and dynamic storage modulus increase continually. The more free isocyanate groups can accelerate the initial polymerization reaction rate. As a result, the polymers become more highly cross-linked, the foams have a better dimensional stability and mechanical strengths. However, an over high isocyanate index will lead to excessive cross-linkages, and result in the decrease the fire resistance and the mechanical properties of the foams.\[20\]

4. Conclusions

In this article, the PIPA polyol was synthesized and the rigid polyurethane foams were obtained from the reaction of PIPA polyol and polyols with low hydroxyl number. The controlling variables such as the ratio of two polyols, surfactant, chain extender and cross linker, isocyanate index were discussed. The product with well-proportioned cells and good mechanical properties can be obtained from this system.

Acknowledgement

The authors thank the National Science and Technology Support Program and the National Natural Science Foundation for financial support.

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