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Effect of silica nanoparticles on tensile strength of flexible polyurethane foam

D. Ebrahimzadeh[1], GH. Zohuri[1*], M. Nourmohammadi [2]

[1]Department of Chemistry, Faculty of Science, Ferdowsi University of Mashhad, Mashhad, Iran
[2]Department of Research and Devlopment Center, Ayegh Khodro Toos (AKT) Co. of Part Lastic Industrial Group, P.O. Box 91851-77209, Mashhad, Iran.
Email: zohuri@um.ac.ir*

Abstract
In order to investigate the effect of silica nanoparticles (0.0, 0.2, 0.4, 0.6 and 0.8 w%) in flexible polyurethane foams, properties such as tensile strength and elongation of nanocomposite foams were studied. Investigations showed that with increasing percentage of the silica nanoparticles (from 0 to 0.6 w%) leads to an increase in the rate of nucleation and, as a result, decreases the size and thickness of the cell walls. The tensile strength of nanocomposite foams has increased from 0.077 to 0.146 MPa, and the elongation percentage has decreased from 118% to 72%, and it was found that the use of 0.6 w% of the nano-silica is the optimal amount. Also, FT-IR analysis confirmed the polyurethane structure of the foams by showing index peaks in 2272 cm^{-1} (NCO), 3345 cm^{-1} (N-H), 1600-1800 cm^{-1} (C=O), 1600 cm^{-1} (CN) and 2850-2950 cm^{-1} (CH).

Keywords: flexible, tensile strength, polyurethane foam, FT-IR, silica nanoparticles.

Introduction
Polymeric foams are multiphase materials consisting of a polymeric matrix that contains a large number of cells and are known as porous polymers [1]. They are lightweight, versatile materials with good insulation properties. Polyurethane (PU) foams are type of polymeric foam with a wide range of applications. They can be rigid or flexible and are made from polyols and isocyanates with various additives. Flexible foams are used for packaging, cushioning, transportation material, sound insulation, sports protective equipment and many other applications [2]. Polymers have low mechanical and thermal properties due to their inherent softness. Fillers like silica nanoparticles are often used in the production of composites. By adding silica nanoparticles to the matrix of these polymers, the mechanical properties of these nanocomposites are improved and their performance in various fields isincreased [3].

Experimental
Material
Polypropylene glycol with an average molecular weight of 2000 g/mol (PPG, Isfahan Copolymer Co, Iran) and toluene diisocyanate (TDI, Yantai Wanhua Polyurethanes Co, China) are as the two main components in producing foam. Other additives like crosslinker (Glycerin, Wanhua Co, China), dibutyltin dilaurate (DBTL), 1,4-diazabicyclo[2.2.2]octane (DABCO 33-LV) as catalysts and silicon surfactant (TEGOSTAB) were attained from Evonik Co, Germany. Carbon black (CB, Doodeh Sanati Pars Co, Iran) as pigment and deionized water as blowing agent, silica nanoparticles (Aerosil200, Evonik Co, Germany) are used to made PU foam.

Preparation of flexible polyurethane foams (FPUFs)
PPG (90.7 w%) stirred with surfactant (3.6 w%), crosslinker (2.1 w%), DBTL (0.25 w%) and DABCO 33-LV (0.8 w%), CB (0.3 w%) and deionized water (3.25 w%) are mixed and stirred (5 min at 1500 rpm) using a mechanical stirrer. This solution is obtained as component A and then the silica nanoparticles (0.2, 0.4, 0.6 and 0.8 w%) are added to it, and sonicated to dispersed the nanoparticles of the solution. Subsequently, TDI (51.8 w%) as componet B was added to the component A to make FPUF.

Results & Discussion
FT-IR study was used to confirm the polyurethane foam chemical structure (Fig. 1). The band in the 3200–3450 cm^{-1} region is attributed to the symmetric and asymmetric stretching vibrations of the N-H of the urethane and of urea groups. The strong peak at about 1080 cm^{-1} and the weak peak at about 810 cm^{-1} are assigned to the asymmetric and symmetric bending of the Si-O-Si bonds and the C=O region is 1600–1800 cm^{-1}.Also, the peak of CN group has appeared at 1600 cm^{-1} .The band at 2272 cm^{-1} shows free NCO stretching of polyurethane and the bands between 2950 and 2850 cm^{-1} correspond to the asymmetric and symmetric C-H stretching vibrations.

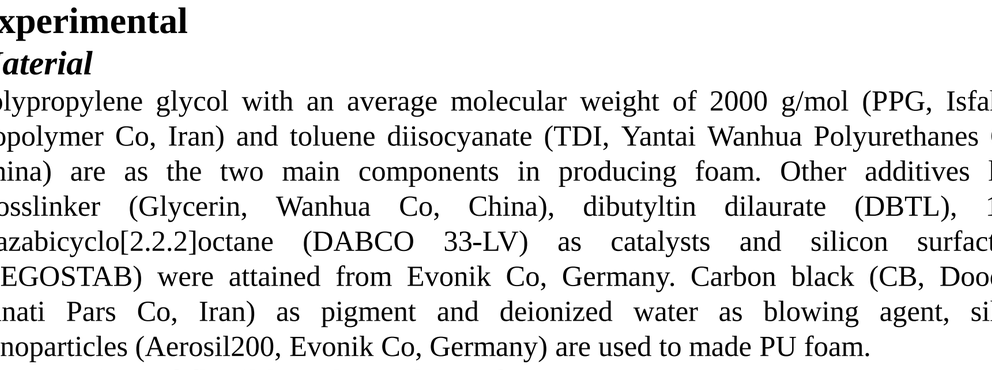

Figure 1. FT-IR spectra of the flexible polyurethane foam containing nano-silica (0.6 w%).

Effect of the silica nanoparticles on tensile strength of the flexible polyurethane foams was investigated (Figure 2). It was observed that by increasing the percentage of silica nanoparticles (up to 0.6 w%) in the formulation, the tensile strength of the foams has increased (from 0.077 to 0.146 MPa). This improvement is attributed to structural changes in the foam cells. The silica nanoparticles act as nucleating agents, promoting nucleation in the polymer matrix. Consequently, increasing the percentage of the nanoparticle increases the nucleation rate and the density of the foams. A higher nucleation rate results in a higher number of cells per unit volume in the product foam. As a result, the tensile strength and resistance of the cell walls against stress increases, and thereby the elongation at break of FPUFs decreases (from 118% to 72%) when using nanoparticles (0-0.6 w%).

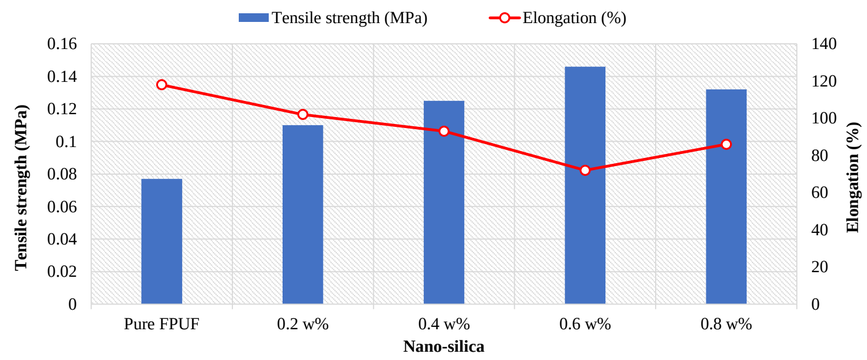

Figure 2. Tensile strength of flexible polyurethane foams containing the nano-silica with different w%.

Conclusion
With the increase in percentage of the nano-silica (0 to 0.6 w%) in the structure of foams, tensile strength has increased (0.077 to 0.146 MPa), which is in line with the expectation, because the nano-silica in the foam formulation leads to an increase in the rate of nucleation, an increase in the number of cells and cell wall resistance against to stress and as a result, using the optimal percentage of the nano-silica (0.6 w%), improved the tensile strength and the elongation decreased (from 118% to 72%). Also, the chemical structure of polyurethane foams was investigated and confirmed via FT-IR analysis.

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