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Mechanical Property Evaluation of Polyurethane Foam under Quasi-static and Dynamic Strain Rates- An Experimental Study

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Abstract

Polyurethane foams are widely used as thermal insulators and also as energy absorbers in radioactive material shipping casks. In view of this, an experimental study to observe the change in impact response of rigid polyurethane foam at different strain rates was conducted. For this purpose, uni-axial compression experiments were performed at quasi-static and dynamic rates of loading. The results reveal a significant change in mechanical properties of foam under compression at different strain rates. The response of foam gets stiffer with increase in strain rate, and densification (lockup) occurs well below the strains at which lockup occurs for foam deformed at quasi-static strain rates. Consequently, the energy absorption characteristics of foam are altered with change in strain rate. It is envisioned that nuclear industries could use this information for application of polyurethane foam as an impact limiter in nuclear shipping casks, without causing un-acceptable stresses in the cask structure.

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Keywords: Polyurethane foam; Impact loading; Strain rate

1. Introduction

Radioactive material transportation packages should demonstrate compliance to regulatory tests specified by AERB-IAEA standards [1]. This necessitated development of new materials for these transportation packages which will protect the packages during the performance tests by acting as shock absorbers which take up all the impact energy during drop tests and insulate the package from the high temperature conditions of thermal tests. Polyurethane Foam (PUF) is best candidate material for this purpose. Therefore BARC has developed polyurethane foam in collaboration with M/S Pine resin, Taloja.

Various experimental studies at high strain rates have been reported in the literature on PUF using drop weight machines [2,3] and split Hopkinson pressure bars [4–7]. In this work, we performed planar compression experiments at quasi-static and dynamic strain rates on PUF to characterize its mechanical properties. Performance of foam under quasi-static tests was evaluated using UTM and Drop Weight Tower (DWT) was utilized for dynamic experiments. The investigations were carried out using cubical polyurethane foam specimens of size 50 mm X 50 mm X 50 mm.

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2. Material

Investigations were performed on a high density, closed cell, rigid polyester polyol based polyurethane foam composite material of density 288 kg m^{-3}. The foam was supplied by M/s Pine resins, Taloja, Maharashtra, India and was produced by reacting polyester polyols and isocynates with water as a blowing agent. Polyurethane foam specimens used for experiments were of nominal dimensions 50 mm X 50 mm X 50 mm (Fig. 1). In all the cases, the direction of loading is in the foam rise direction. Quasi-static tests were performed as per the ASTM D1621 [8] standard.

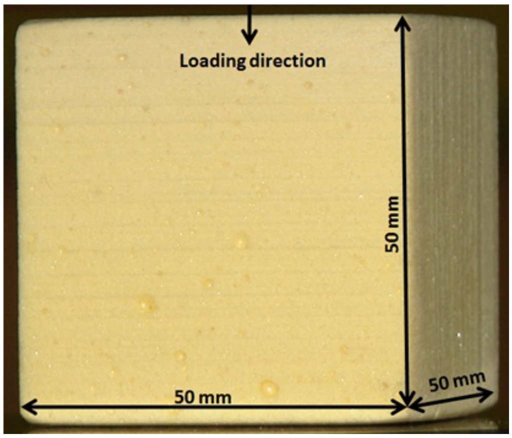

Fig. 1. Sample cube specimens of side 50 mm used in the present study.

A typical stress-strain behavior of rigid polyurethane foam subjected to compression is shown in Fig. 2. In this figure, the stress-strain curve exhibits three regions:- a linear elastic phase up to small strains (usually upto 5%-10%), plateau and densification. In the elastic regime, slope of the stress-strain curve characterizes the Young's modulus of foam. As the load increases, the cell walls begin to collapse which progresses at a roughly constant load, thus giving a stress plateau (region where stress does not increase significantly with increase in strain, characterized by a line roughly parallel to x-axis (strain axis)). A further increase in load leads to densification of collapsed cell walls, which causes the stress to increase rapidly without an appreciable increase in strain.

Energy absorbed by the foam is given by the area under the stress-strain curve. As can be seen, very little energy is absorbed in the linear elastic regime; it is the plateau region of the stress-strain curve that characterizes the maximum energy absorption of foam under compression.

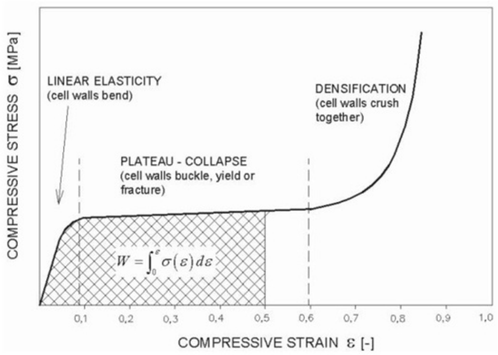

Fig. 2. Typical stress-strain curve for polyurethane foam under compression