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Wet/dry influence on behaviors of closed-cell polymeric cross-linked foams under static, dynamic and impact loads

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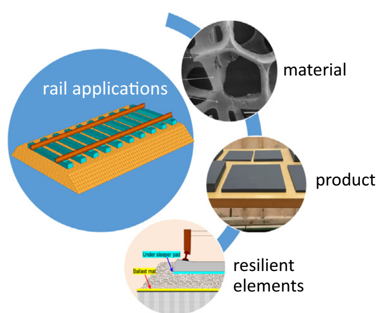
HIGHLIGHTS

- The deflections of the submerged specimens are less than those in dry condition.
- The dynamic and impact stiffness of the material in wet condition tends to be very high.
- The dynamic damping tends to be lower in dry condition.
- The closed cell polymeric foam materials can be applied as under ballast mats (UBM) in railway tracks.
- The materials fit really well as a soft to medium UBMs.

GRAPHICAL ABSTRACT



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ABSTRACT

Polymeric materials have been used as critical components in a wide range of engineering structures in built environments. The superior characteristics of polymeric materials have led to various applications such as energy absorber during shock or impact events, lightweight structures, and thermal insulation. The key benefit is derived from relatively lower weight and density in comparison with other materials. The emphasis of this study is placed on closed-cell polymeric material, which is flexible and can potentially be manufactured as a rubber mat for railway track applications. A critical literature review reveals that the dynamic behavior of closed-cell polymeric material has not been fully investigated, especially when the materials are usually exposed to water. We are the first to present the wet/dry influences on the characteristics of closed cell cross-linked polyethylene foam under static, dynamic and shock loads. In our study, the water absorption and swelling of the materials are measured after 24 h of immersion in de-ionized water. Static, dynamic, and impact loading are applied to closed-cell polymeric materials on both wet and dry states. The behaviors and responses of the materials can inform whether or not a closed-cell polymeric material can be used as under ballast mats and under sleeper pads in railway tracks under operational environments. Based on our results, it is found that this closed-cell-polymeric material is not suitable for use as under sleeper pads. However, they have reasonably strong potential for use as under ballast mats under various rail operational parameters.

1. Introduction

Nowadays, polymeric materials have been widely used in a variety of applications in diverse industries such as insulated materials, vibration reduction device, clothing, application for

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protection, construction, automobiles etc [1–4]. The superior characteristics of the polymeric materials are the ease in material processing, high ductility, lightweight, thermal insulation, elastic wave barrier, etc. Polymeric foam materials are one of the most popular types of polymers as can be seen in all fields of daily life. The polymer foams used as a replacement of natural rubber were initially made in the 1930s [5]. Polymer foams are manufactured from a synthetic mix of solid and gas phase. Polymer foams can be characterized into open- or closed-cell structures by identifying their properties such as density, chemical properties, structure, and raw materials used. Naturally, open-cell foams are flexible, while closed-cell foams are relatively more rigid. The mechanical properties of foam are dependent on the type of polymer of which the cell walls are made of and their structure [6]. Also, the volume and amount ratio of open-cell to those of closed-cell is critical to establish strength of the foam. For closed-cell foams, the cells are surrounded by completed cell walls, which are isolated separately from each other. For open-cell foams, the cells are connected with each other. Hence, the advantages of open-cell foam are the softness, lightness, and inexpensiveness, while the closed-cell foams can gain more strength and have greater resistance to the leakage of air between the cells [7].

In terms of water absorption, the literature review reveals that closed-cell foams are imperative for preventing water penetration. On the other hand, the performance of open-cell polymeric materials can be deteriorated due to the high possibility of water absorption [8–10]. When the open-cell is surrounded by moisture environment, the open-cell foams tend to absorb more water and become an ineffective. Over recent decades, the dynamic behavior of polymer material under normal condition has been studied [11–15]. Nevertheless, the previous research has not considered the dynamic behavior of the polymeric material under wet condition.

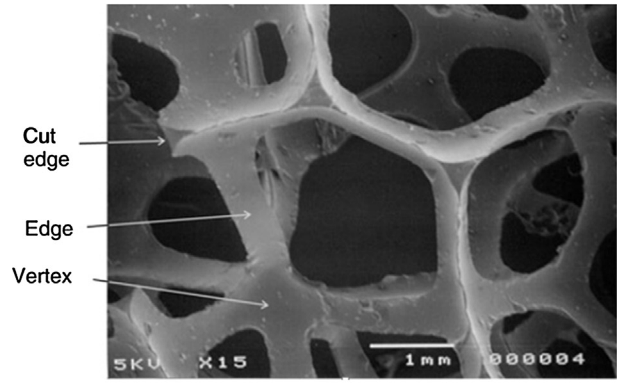
The aim of this study is to highlight the influences of water absorption on closed-cell polymeric material under dynamic and impact loading. In addition, this is thus the world first to investigate the feasibility to use the closed-cell polymeric material as an under ballast mat and under sleeper pad in railway built environments. However, the use of under sleeper pad (USP) and under ballast mat (UBM) has spread over recent years but they have been used only on a case-by-case basis [16–19]. In practice, USP has been used predominantly to mitigate ballast breakage while UBM is often used to isolate ground-borne vibration and to moderate track stiffness at bridge, tunnels and stiffness transition zone. The findings from our investigations will help improve the understanding into material behaviors of closed-cell polymeric materials for real applications in railway track systems.

2. Material and methodology

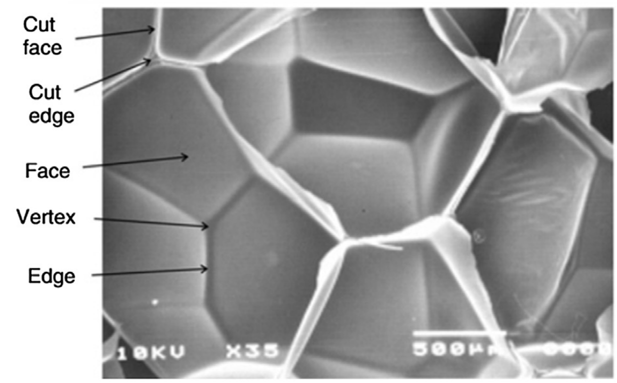
2.1. Material

Fig. 1 shows the comparison between typical microstructures of open- and closed-cell polymer foams, respectively. Complete cells can be seen in the interior of open-cell polymer foams. As can be seen from Fig. 1a, all the cell faces are open so that air can pass freely between the cells of such foams. While in a typical closed-cell foams, each cell is surrounded by connected faces. Partial cells, with cut edges and faces, are obvious on the cut surfaces (Fig. 1b), while complete cells exist in the interior of the sample. Although, the cell faces are thicker and stronger than those in closed-cell polymer foams, the cell faces can be split or otherwise damaged [7]. The polymer foams have been specially manufactured and supplied by Palziv Ltd., as part of an industry-based research project.

Polymer foam used as an elastic rubber mat is examined in this work. For a cube shape, solid mechanics' beam theorem can be



a)



b)

Fig. 1. SEM photograph of (a) PU open-cell foam of density 28 kg m^{-3} (b) closed-cell low density polyethylene (LDPE) foam of density 24 kg m^{-3} [7].

applied. Young's modulus of the closed-cell foam can be calculated as follow [20]:

$$\frac{E_f}{E_s} \approx \varphi^2 \left(\frac{\rho_f}{\rho_s}\right)^2 + (1-\varphi)\frac{\rho_f}{\rho_s} + \frac{P_0(1-2\upsilon_f)}{E_S(1-\frac{\rho_f}{\rho_s})} \quad (1)$$

where E_f is Young's modulus of foam, E_s is Young's modulus of polymer, φ is the mass fraction, ρ_f is the density of foam, ρ_s is the density of polymer, P_0 is the initial pressure of the gas contained in the foam cell, and $\upsilon_f$is Poisson ratio.

In terms of open-cell structure, for a cubic array of members, the beam theorem can also be adopted. The Young's modulus of open-cell foams become the term of relative density of the foam as follows [20]:

$$\frac{E_f}{E_s} = CR^2 \quad (2)$$

where C is a constant, ≈1, and R is a relative density, ratio of the density of foam to the density of polymer. It is important to note that the elastic modulus of the open-cell foam tends to be solid when the relative density is close to one.

The polymeric material used in this study is block foam, which is a substance produced using plate-compressing technology. The polymeric material type used is hydrophilic polyurethane foam, which has the density of 0.25 g/cm^3. This material consists linear segmented block copolymers composted of hard and soft segments. The properties of this material include elasticity, transparency, low temperature performance, high resistance to abrasion, oil and grease. It is interesting to note that hydrophilic polyurethane foam acts like a sponge and can absorb the water