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Fracture toughness estimation of ballast stone used in Iranian railway

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ABSTRACT

Ballast is a layer composed of crushed stone basically with diameters of 20–60 mm, on which sleepers and rails are set. Ballast is used to withstand vertical, horizontal and lateral forces applied on sleepers and to hold the line in operative conditions. Ballast deterioration induced by crashed stones is a major issue of track instability as the ballast layer quality depending on the materials used and their densities should be focused on. Therefore, ballast should be resistant against loads applied, and the fracture toughness of ballast stone is of great importance. For this purpose, the fracture toughness of two kinds of ballast stones used in Iranian railway, i.e. Gaduk (limestone) and Anjylavnd (andesite), is investigated experimentally in this paper. The quality of ballast stone is evaluated in different weather conditions. Numerical results shown that the Anjylavnd stone is more appropriate for rainy and cold weather when there is a probability of fracturing due to frozen water captured in ballast.

1. Introduction

Ballast is composed of uniform gradation broken stones, a layer embedded between rail and sub-ballast. Since ballast usually bears heavy loads, its mechanical behavior is critically important as the axle load on each wheel and rail reaches almost 25 tons at operation. Therefore, the ballast should have the capacity to resist weathering, breakage and creation of the fines as well as the loads imposed. In other words, if the ballast is gradually crushed and the fines are generated, stone permeability and drainage property will be changed, which will result in instability in the long run. In this sense, the replacement of the damaged ballast stone is usually of high costs. As for the stone fracture toughness, a number of studies have been conducted. Gogotsi (2013) proposed various models in order to study the fracture toughness of ceramics and other brittle materials. Cicero et al. (2014) studied the fracture toughness of notched granite and limestone. Xiao et al. (2014a, b) performed a series of large-scale triaxial compression tests on Tacheng rockfill material (TRM) in order to understand the influence of density, pressure and particle breakage on the strength and deformation behaviors. Also, Xiao et al. (2016) investigated the effect of intermediate principal stress ratio on the particle breakage of rockfill material (RFM). Furthermore, Aliha and Ayatollahi (2011) obtained fracture toughness of Iranian Harsin marble in mixed mode using laboratory and analytical techniques to conduct tests on semi-circular bending (SCB) specimen. Lim et al. (1994a, b) used SCB specimens to calculate the fracture toughness. The SCB specimen was originally used to study the mode I fracture toughness, and recently it is used to review mode II and mixed-mode fracture toughness (Azar et al., 2015).

To investigate crack propagation, Lancaster et al. (2013) developed an extended finite element method (XFEM) to model crack propagation in SCB asphalt sample. Zhou and Shou (2017) proposed a new method to model the initiation, growth, and coalescence process of cracks in rock materials under compressive loads. Xie et al. (2017) investigated the crack growth trajectory of SCB specimen using the XFEM.

In this paper, the fracture toughness of two kinds of ballast stones used in Iranian railway, i.e. Gaduk (limestone) and Anjylavnd (andesite), was studied experimentally. Fracture in common engineering problems may be in mixed-mode. However, most works, especially in the field of stone fracture mechanics, are based on the analyses of mode I fracture because stone and concrete are weak in tension and will fail in most cases when tensile loads are applied, or in opening mode. Besides, cracks under loading applied are of mode I in many practical situations. Therefore, all tests are conducted in mode I to obtain fracture toughness in this context.

Since railway line is used in all seasons including rainy conditions, ballast materials must have sufficient strength to maintain high performances during different seasons. For this purpose, the

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stress of frozen water accumulated in cracks is calculated using weight function method.

2. Specimen preparation

As the existing joints and impurities of ballast stone can result in errors, stones free of defects should be used as possible. In this study, tests were performed on SCB specimens of two kinds of stones, i.e. Gaduk Mine ballast stone composed of limestone and dominant calcite, and Anjylavnd Mine ballast stone which is andesite with respect to plagioclase and amphibolite. The SCB specimens were selected for simplicity of geometry, ease of loading, and possibility of applying compressive stress rather than tensile stress to the specimens. The mechanical parameters, mineralogical properties, and description of each specimen are shown in Table 1.

Stone blocks were cored for specimen preparation. For this purpose, cores with a diameter of 70 mm were obtained firstly using core machine (see Fig. 1). Specimens were cut then by stone cutter into circular disks with a thickness of 30 mm. Next, the specimens were split using the same cutter, and half-disk specimens were sampled from each circular disk specimen (Fig. 2a). For straight crack, a notch was produced in the specimens. However, most of rock specimens were resistant to fatigue and pre-cracking was not possible at low loading levels. Thus suitable measurement tools were required for precise control of load and displacement to prevent undesired development of any additional cracks. For this purpose, many researchers used another simple method in which the notch is sharpened using a very thin blade after a notch is made in specimen. A thin hand saw was used to sharpen the tip of crack, and the end notch was also sharpened (Fig. 2b).

In this study, a total of 12 SCB specimens were prepared with a diameter of 70 mm, 6 specimens of andesite and 6 specimens of Gaduk stone. The a/R ratios of 0.14 and 0.43 are used for the samples, where a is the crack length and R is the radius of specimen, so that the effect of crack length on the fracture toughness can be identified. In each sample group, 3 specimens had a/R ratio of 0.14 and the remaining of 0.43. According to the suggestion of Lim et al. (1994a), a constant thickness of 30 mm was selected for specimens with a diameter of 75 mm. Using this thickness, the specimen will be fractured in plane strain condition and the stress intensity factor (SIF) can be achieved. The $\overline{R} = 0.5$ ratio $S/R = 0.5$ was used for all tests, where S is the half-distance between two bottom supports. Specimen loading was achieved by displacement control apparatus. According to Fig. 3, the loading rate was determined as 0.2 mm/min (Lim et al., 1994a).

Table 1
Mechanical and mineralogical properties and appearance of tested stone specimens.

Stone type	Appearance	Mineralogical properties	σ_c (MPa)	E (GPa)	ν
Gaduk (limestone)	Dark grey, massive and dense with delicate veins of calcite	Tiny particles of calcium carbonate with small amounts of clay minerals	123.8	44.17	0.24
Anjylavnd (andesite)	Red, dense and massive	Porphyry texture. The dominant minerals of plagioclase and amphibolite are trapped within the context of minerals	134.6	48.02	0.28

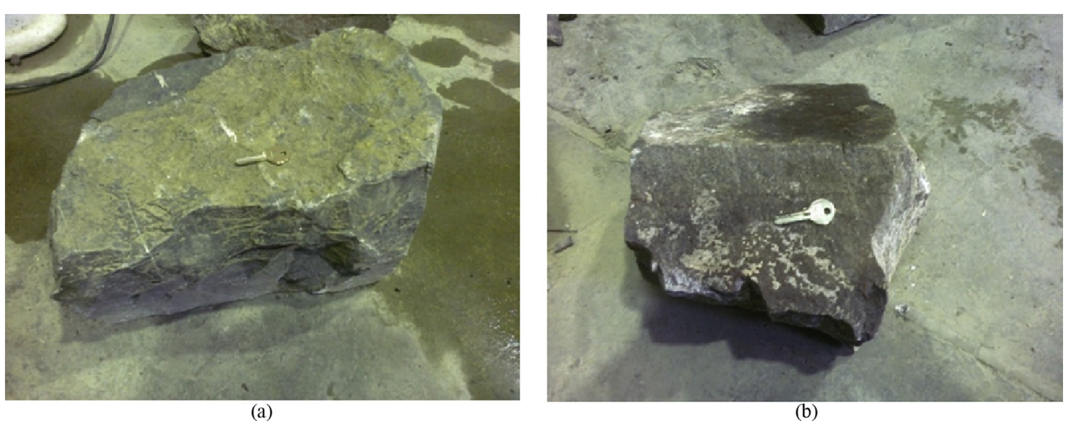

Fig. 1. Tested stone specimens: (a) Gaduk Mine stone, and (b) Anjylavnd Mine stone.

Fig. 2. Half-disks (a) without and (b) with edge crack.