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Drainage capability of degraded ballast aggregate mixed with discarded granulated rubber particles

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ABSTRACT: The incorporation of crumb rubber (CR) among ballast aggregate is characterized as an advantageous way to considerably lessen the degradation rate of granular particles. Meanwhile, there is uncertainty about the proper drainage performance of the mixture whenever the ballast aggregate is further degraded. The present study evaluates the drainage capability of degraded ballast aggregate in which disparate percentages and sizes of discarded granulated rubber particles are incorporated. To provide degraded aggregate, the impact loading test under controlled conditions is implemented on fresh railway ballast. Afterward, the large-scale constant head permeability test is carried out on prepared mixtures of degraded aggregate and CR particles. The results confirm that the effect of CR size on the drainage potential of degraded ballast combined with discarded CR particles is more than the influence of CR percentage. Also, the nonlinear trend line observed between the applied hydraulic gradient and the water flow velocity approaches the conventional linear trend line represented by Darcy's law whenever the smaller-sized CR particles are incorporated into the most degraded ballast aggregate. As expected, a higher level of degradation of aggregate decreases the hydraulic conductivity of ballast specimens, meanwhile, the permeability is yet considerably more than the acceptable limit even for specimens subjected to the significant level of degradation combined with the smaller-sized crumb rubber particles.

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1- Introduction

Degradation of railway ballast aggregate is characterized as one of the most crucial deteriorations related to the ballasted railway tracks. Ballast aggregate subjected to the applied repeated loads experiences pulverization of particles in contact with each other as well as splitting of single particles [1, 2]. Meanwhile, the impact loads induced owing to wheel flats, rail corrugations, and transition zones further accelerate the occurrence of degradation phenomenon [3]. The ballast degradation unfavorably influences the performance of this granular course of railway track. As reported by Rohrman et al. [4], the abraded ballast demonstrated lesser particle-particle contact. Likewise, Jia et al. [5] observed weaker interlock between particles for recycled ballast which further exacerbated the settlement of the granular layer. To diminish this distress observed in the track substructure, different procedures have been developed. The utilization of rubberized materials like crumb rubber (CR) and tire-derived aggregate (TDA) is characterized as a conventional method to decelerate the process of degradation of the ballast course.

Drainage capability of the ballast course is characterized as a crucial physical property of utilized granular material. Schmidt et al. [6] utilized the constant head permeability test to figure out the detrimental efficacy of degradation on permeability. As expected, further increment of the fouling index led to lower values of hydraulic conductivity. Meanwhile, the incorporation of CR particles can decrease the permeability of perevious media like ballast material. In this relation, Masad et al. [7] observed that the addition of rubber particles to sand led to lower values of permeability coefficient. Also, Li et al. [8] observed a decrement in the permeability of sand-rubber mixtures by the further increment of rubber particles. In relation to the rubberized ballast, Koohmishi and Azarhoosh [9] assessed the drainage performance of fresh ballast aggregate combined with discarded crumb rubber particles. The results exhibited that the higher percentage of CR along with smaller-sized particles led to the reduction of the permeability of the mixture.

Generally, the results of various investigations corroborate that the CR particles can effectively lessen the level of degradation of ballast aggregate. Also, the mixture of fresh ballast and discarded crumb rubber demonstrates sufficiency in drainage level [9]. However, researches have been primarily limited to fresh ballast aggregate. As expected, the incorporation of fine-grained CR particles between coarse aggregate can adversely influence the permeability of the mixture whenever the granular material is further degraded. Therefore, detailed studies are deemed momentous to analyze

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the drainage performance of mixture of ballast and discarded rubber particles under degraded conditions which are perused herein. Indeed, the present study discerns the effect of size and percentage of CR particles on the hydraulic conductivity of degraded ballast material combined with crumb rubber particles. Conventionally, the manufactured ballast material derived from the fresh railway ballast is utilized to conduct laboratory testing [3]. Likewise, index tests like LAA are established to generate the degraded particles [10-14]. As new procedure in the present study, the large-scale impact loading test is implemented on fresh ballast aggregate in order to generate degraded material. The testing method can more effectively simulate field loading conditions.

Scope of study

The main objective of the present study is to figure out the hydraulic conductivity of degraded ballast aggregate in which crumb rubber particles have been incorporated among granular particles. Hence, degraded ballast material derived from subjecting fresh aggregate to impact loading are combined with various percentages of CR particles, and then the permeability test is conducted on prepared specimens to analyze the deleterious effect of CR on the drainage potential of the ballast course.

2- Testing procedures

2- 1- Large-scale impact loading test

To produce degraded ballast material, large-scale impact loading test was utilized. The testing apparatus was previously manufactured to simulate the degradation process of ballast aggregate subjected to impact loads as reported in Koohmishi and Palassi [15]. A cylindrical mold with a diameter of 240 mm is used to accommodate the ballast material. The hammer with the weight of 50 kg is employed to apply impact load on the tested specimen so that the falling height of drop weight is adjusted to 420 mm. The assembly is anchored to the concrete base by provided base plate (characterized as rigid subgrade). Meanwhile, to simulate the flexible subgrade condition, a sand layer of 50 mm thickness is included between the tested specimen and the base plate. 7 loading steps are established to better simulate the degradation process of ballast aggregate in which 40 blows are implemented throughout each loading stage.

2- 2- Large-scale constant head permeability test

In the present study, large-scale constant head permeability test is utilized to assess the competence of hydraulic conductivity of degraded ballast aggregate in which the CR particles are infiltrated. The two main components of the developed apparatus include the main reservoir as well as the water tank. The former is employed to accommodate the 300 mm thickness of large-sized ballast specimen by the provision of the diameter of 450 mm. The latter is used to apply a defined hydraulic head on the provided sample. Wide ranges of hydraulic heads are applied on tested specimens which consequently lead to the establishment of various levels of hydraulic gradient.

3- Results and discussions

3- 1- Experimental results

Various conditions were provided to implement large-scale constant head permeability test on degraded ballast aggregate combined with different percentages and sizes of discarded crumb rubber particles. The degraded ballast aggregate manufactured by applying 7 loading steps of drop hammer impact test on prepared samples over two distinct subgrade conditions. Fig. 1 depicts the water flow velocity with applied hydraulic gradient for established linear and power models, respectively. Generally, the variations confirm that the linear relationship described as Darcy’s law can effectively consider the water flow regime through provided media. Indeed, the degradation of aggregate along with the incorporation of crumb rubber particles leads to the suitability of the establishment of laminar flow conditions. It is evident that extremely degraded aggregate combined with fine-grained rubber particles (2-4.75 mm) clearly follows laminar flow condition.

Generally, there is a major concern about drainage potential of ballast aggregate combined with CR particles whenever the granular material tolerates further degradation under applied loads. The value of 0.01 cm/s is normally discerned as a tolerable level of permeability of ballast course [16-18]. Fig. 2 illustrates the variation of k (based on Darcy’s law) with FI for different characterized conditions to further elaborate the influence of CR size and content on the permeability of degraded ballast material combined with discarded crumb rubber particles. The given figure corroborates that the hydraulic conductivity of material is still more than the acceptable level even under extreme conditions. Meanwhile, the infiltration of external fine materials from surface can accelerate the reduction of permeability of ballast layer and inhibit drainage. Indeed, fines from abrasion of aggregate are larger-sized particles with higher weight so that the permeability of granular media is less drastically influenced. Paiva et al. [13] observed the same results by conducting hydraulic conductivity test on degraded aggregate derived from LAA test.

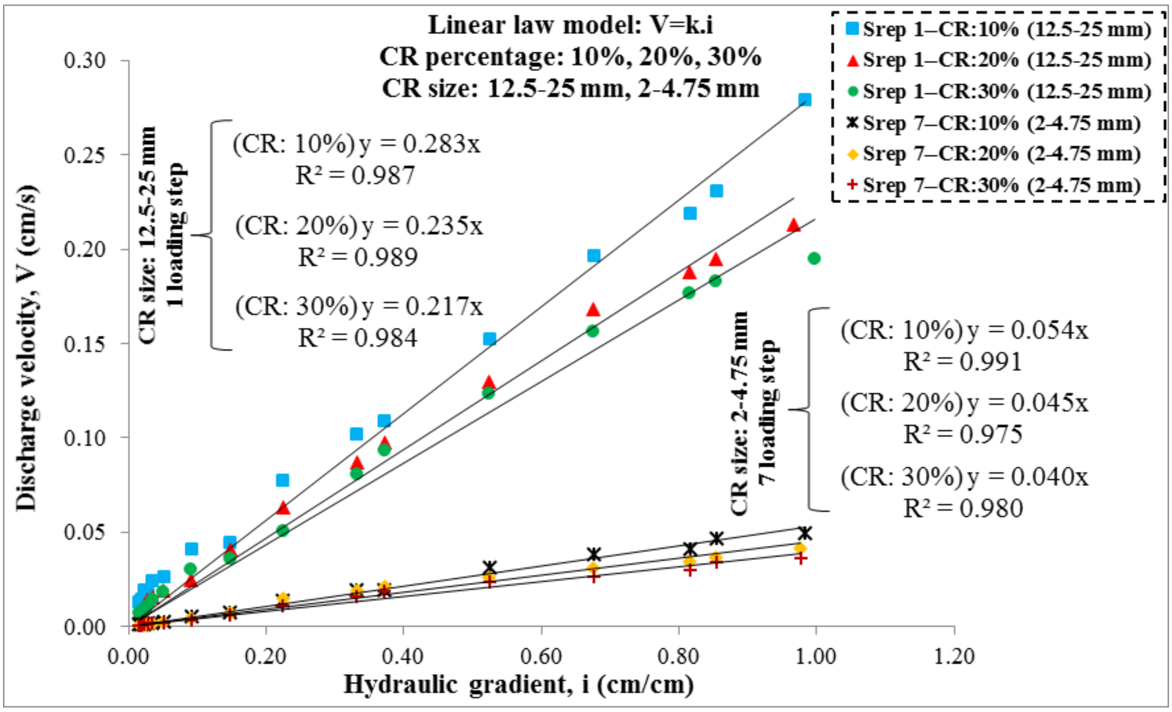
4- Conclusions

Based on the results obtained, the following conclusions are drawn:

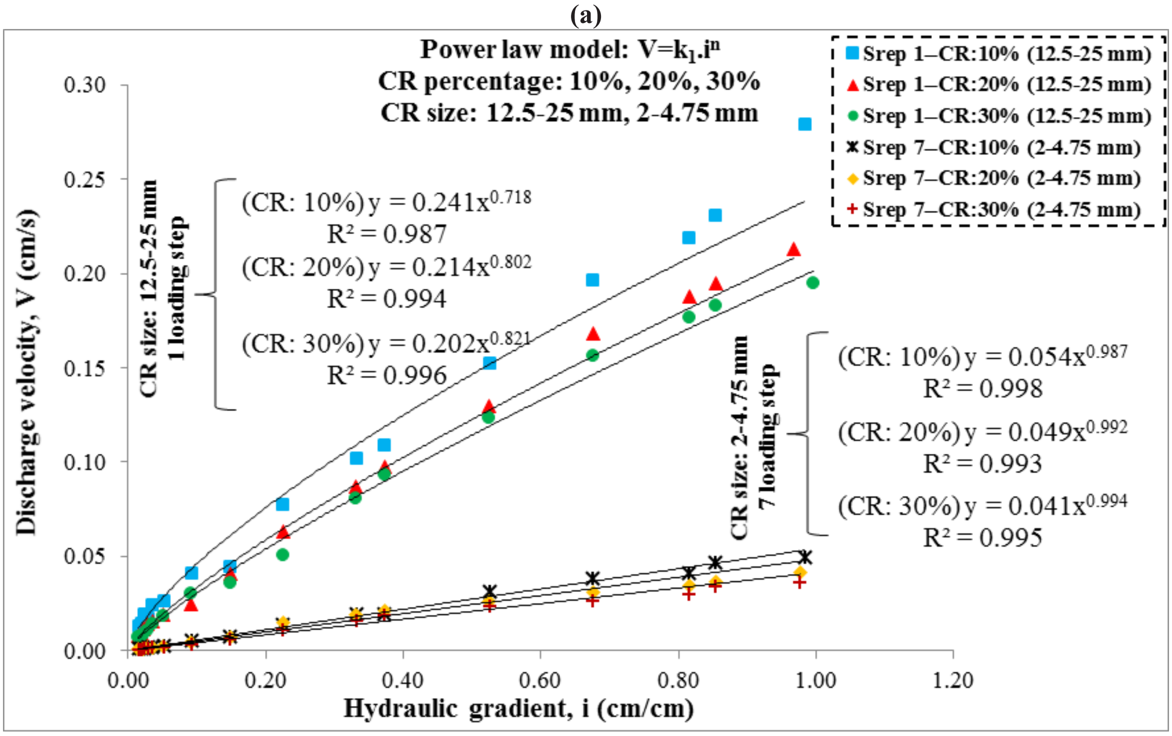
- Nonlinear trend line seems to be more appropriate in the case of less degraded ballast. Meanwhile, the establishment of the linear trend line (known as Darcy’s law) can effectively consider the water flow through provided granular media whenever the aggregate is further degraded.

- As expected, further degradation of ballast aggregate leads to the measurement of lower values of hydraulic conductivity. Increment in loading steps of impact testing as well as provision of rigid subgrade results in a higher level of degradation.

- Both utilization of smaller-sized and higher content of discarded crumb rubber particles lead to a decrease in permeability. Meanwhile, the size of CR particles is observed as a more influential parameter so the smaller-sized particles



(a)



(b)

Fig. 1. Comparison of two different trend lines applied on variation of water flow velocity with hydraulic gradient, a) Linear relationship (laminar flow regime), b) Power law relationship (non-laminar flow regime)

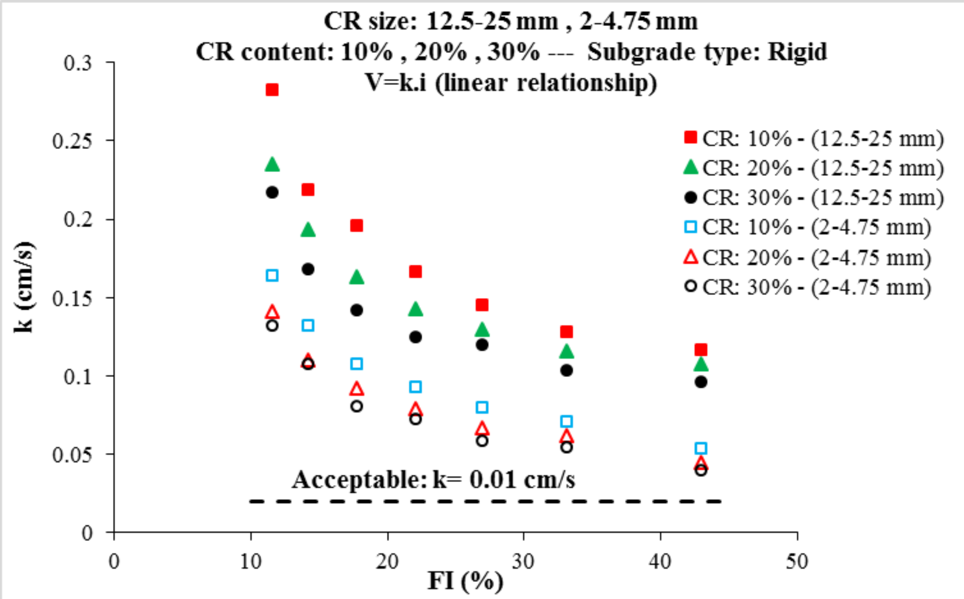


Fig. 2. Effect of fouling ratio on hydraulic conductivity of degraded ballast combined with different percentages and sizes of rubber material

considerably reduce the permeability (by 45%).

- The highly degraded ballast aggregate combined with the smaller-sized CR particles (characterized as the most severe condition) yet demonstrates an acceptable level of hydraulic conductivity.

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