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ANTI-THIXOTROPIC NON-NEWTONIAN FLUID IN COMPLEX CONDUCT: GLUING PROCESS SIMULATION OF RAILWAY BALLAST

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ABSTRACT:
An elasto-visco-plastic model of the Cauchy stress is proposed for gluing solution of railway ballast, with an asymptotic time-dependent viscosity accounting for the anti-thixotropic and shear-thickening features. Flow characteristics and time-dependent solidification of the gluing solution in the multiconnected conducts spanned by the gravels, accomplished by the algorithm in generating a ballast consisting of convex octahedral grains, are simulated by using the ANSYS© package. While different vertical penetrations of the gluing solution can be achieved by using different characteristic times scales of the asymptotic time-dependent viscosity, the lateral extension is rather limited and local. Pouring gluing solution into ballast tends to create more concrete adhesion between the gravels vertically, while concrete lateral adhesion can be obtained by spreading gluing solution onto ballast. The present study provides an integrated method for the estimation of the gluing solution distribution in a ballast, and for optimal layout of the gluing solution arrangement a priori gluing practice.

KEY WORDS:
anti-thixotropic fluid, ballast, gluing process, non-Newtonian fluid

1 INTRODUCTION

Ballast is a large amount of discrete gravels with prescribed distributions of size and shape, in which the interstitial space is filled by air generally. It is the key part of the railway track system with four intentions: (i) it supports the sleepers or bearers both vertically and laterally; (ii) it spreads the loading from the sleepers or bearers onto the formation; (iii) it provides a drainage path for precipitation; and (iv) it facilitates adjustment of the track geometry [1–4]. Ballast is in fact a kind of dry granular mixture in the research field of granular matter [5, 6]. In static circumstances, strong and weak force chains induced by gravity spread out the ballast through the long-term enduring frictional contact and sliding among the gravels to support and transfer the loading laterally and vertically onto the formation. On the other hand, short-term instantaneous inelastic collision between the gravels appears when mechanical vibration enters the ballast via the sleepers or bearers [2, 7–10]. The mechanical energy is transformed into noise via the short- and long-term gravel-gravel interactions, and is eventually dissipated into the thermal energy at the molecular level [11]. Thus, a ballast is a highly dissipative material of the turbulent kinetic energy of the gravels [12, 13].

A practically capable ballast should be one with the features that (i) the gravels assume the correct size and shape, (ii) the gravels are sufficiently hard to resist crushing and abrasion, (iii) the gravels are resistant to water, indicated by the wet attrition value, and (iv) the gravels are angular to interlock into one another to form a stable matrix to support the track but allow free drainage [1–3, 14]. However, due to destructive gravel-gravel interaction (e.g. crushing or abrasion) and environmental influence, a ballast degrades or fails in the presence of fines, ingress of fines from above, or ingress of material from the formation. The situation becomes more serious when water is present, e.g. attrition, ingress of vegetable matter, wet beds, slurry rising up through the ballast [15]. These affect the track geometry (track quality) significantly.

Practical techniques have been developed for ballast maintaince [4, 16–23], in which the gluing process is noticed [24–26]. A gluing material, usually a two-component polymeric solution in liquid form, is poured into or spread out the pre-cleaned ballast to create likely pointwise adhesion between the gravels for the benefits of (i) protection from ballast flight by solidification on the ballast building surface, (ii) stabilization of the ballast bed at railroad crossing and with switches, (iii)

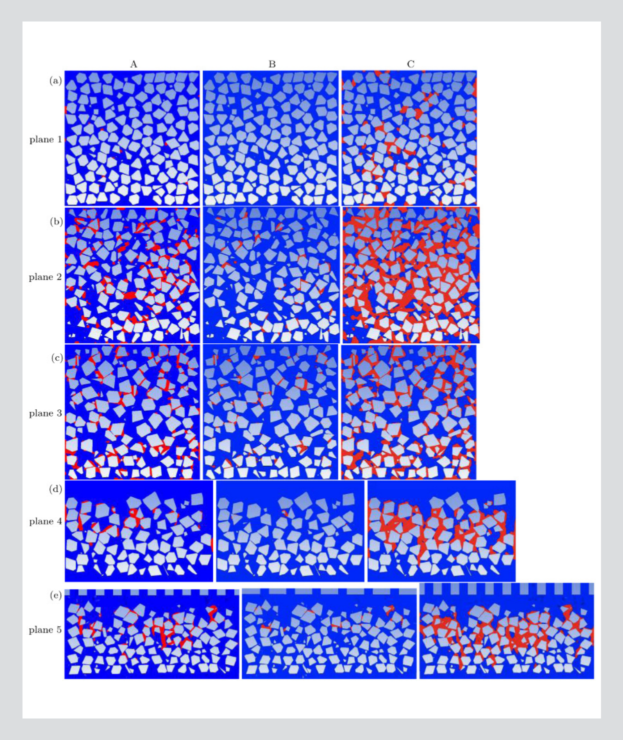

Figure 6: Gluing solution distributions at the final stage of the solidification for variations in the matrix arrangement (A: a matrix of 100 units, B: a matrix of 36 units, C: a matrix of 100 units with a double solution amount in each unit): (a) Distributions on the plane 1, (b) Distributions on the plane 2, (c) Distributions on the plane 3, (d) Distributions on the plane 4, and (e) Distributions on the plane 5.

stress and viscosity models and the octahedral ballast were incorporated into the ANSYS© to solve the resulting BVP to simulate the time-dependent solidification of the gluing solution in a railway ballast.

While the vertical penetration of the gluing solution depends on the solidification speed, characterized by the characteristic time scale of the phenomenological viscosity, the lateral extension is rather limited and local, maximum to a width of the initial span of the gluing solution unit. The lateral extension can be improved by increasing the gluing solution amount or by arranging the gluing solution into a matrix distribution. While pouring the gluing solution into the ballast tends to create a concrete adhesion between the gravels vertically, a laterally concrete adhesion is achieved by spreading the gluing solution onto the ballast. Laterally and vertically concrete adhesions can be achieved by using a matrix arrangement of the gluing solution with controlled unit-spacing and solution amount in each unit. The proposed stress and viscosity models, the algorithm for ballast generation and the ANSYS© package provide an integrated method for the estimation of the gluing solution distribution at the final stage of the solidification, and for the optimal arrangement of the gluing solution a priori the gluing practice.

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