# *X-RAY TOMOGRAPHY OF SAND-RUBBER MIXTURES*

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**Summary:** The behavior of sand-rubber mixtures is controlled by the mechanisms taking place at the grain scale. Here, we use a mixture of shredded tire and a silica sand with similar grain sizes to investigate granular behavior under one-dimensional compression. A mini-oedometer operating inside an X-ray scanner was used to assess the evolution of the microstructure under loading and unloading. New insights are presented on the development of the contact surfaces between sand and rubber and the evolution of the void space.

## 1. INTRODUCTION

The use of recycled tire rubber as an engineering material has major economic and environmental benefits. Sand-rubber mixtures have been reported to improve strength and deformation characteristics of the soil [1,2]. A better understanding of the mechanical behavior of sand rubber mixtures can be obtained from analysis at the micro scale. In particular, the characterization of the soft-rigid granular interactions has the potential to spur the development of more accurate modelling of these mixtures.

## 2. EXPERIMENTAL METHOD

The experiments were carried out at the Research Centre at Harwell (UK) using a Nikon XTH 225 ST scanner. A mini-oedometer with an internal diameter of 14mm was operated inside an X-ray scanner in order to obtain images of the internal microstructure of the mixtures as they deform under loading and unloading. The experimental set-up consisted of a load cell, a vertical piston, a micrometer and a small oedometer. The set-up was designed for this particular scanner and was mounted on the rotating table of the scanner.
The samples tested were composed of sub-angular Leighton Buzzard sand particles with a mean particle diameter of 0.85 mm mixed with recycled devulcanised shredded rubber particles of similar sizes. The rubber content was of 30% by mass. The size of the specimens was 14 mm in diameter and 11 mm high. The force was exerted by manually screwing the micrometer until the pre-set load was reached. A high precision micrometer with an axial loading capacity of 450 N was used. The sample container was made of Perspex with 2 mm thickness for which a value of less than 3 µm deflection under the maximum applied force was measured. The lateral friction has been minimized by considering a 1 mm gap between the container and the X-ray window. The exerted force was monitored by a low profile 'pancake type' load cell with a 500 N capacity.

A total of 3142 projections were collected per scan, with an exposure of 500ms per projection. The spatial resolution of the 3D images was 9.2µm. Slices through the 3D raw images are shown in Figs. 1(a) and 1(b). An in-house imaging processing code was developed in Matlab (Mathworks, 2018) to segment the images by separating the three phases. This includes a two-step banalization using Otsu's thresholding (Otsu, 1979), for which the sand phase was first isolated and secondly the rubber phase was separated from the void space. The key challenge of the segmentation process was to deal with the blurred boundaries of the grains due to creep [3] that caused small movement of the particles during imaging. The three phases presented in the images are shown in Figs. 1(c) and 1(d). The contacts between the sand and rubber particles were identified and their evolution under loading and unloading investigated.

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## 3. RESULTS AND DISCUSSION

This study shows that the contact area between sand and rubber particles increases with loading suggesting both the formation of new contacts and the expansion of the existing ones due to the deformation of the rubber that wraps around the sand. The interesting observation is that these large contact areas only slightly reduce upon unloading. Similar observation was made for the evolution of the pore space. This study also highlights the challenges of image-based investigation of sand-rubber mixtures, in particular, regarding the effects of creep and also the difficulties in obtaining homogeneous distribution of the rubber particles that influences the type of contacts formed and the associated grain kinematics.

## References

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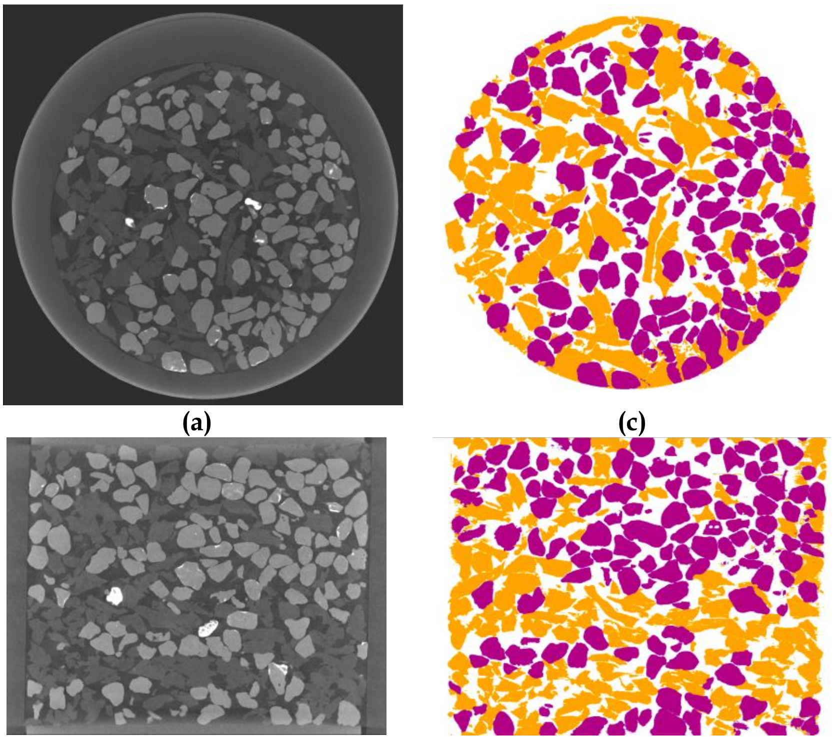

(a) (c) (b) (d)

**Figure 1:** Sections through the 3D images of a sand-rubber mixture (a) Horizontal section, grey-scale image. (b) Vertical section, grey-scale image. (c) Horizontal section, segmented image. (d) Vertical section, segmented image.