Termite Mound - An Engineering Marvel

Nikita Zachariah
Centre for Ecological Sciences
Indian Institute of Science, Bangalore
E-mail : nikitaz@iisc.ac.in

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Walking in the wild or even in a metro city like Bengaluru it is impossible to miss giant structures made up of mud. These are termite mounds (Figure 1). Termite mounds are conspicuous features of landscapes in Asia, Africa and Australia and can be upto 10 metres tall. They are built by tiny insects called termites which are few millimeters in size. At a human scale this kind of construction would correspond to a building ten kilometers tall (taller than Mt. Everest)!! Moreover, termite mounds seem to remain unaffected by rain even though they are made up of mud. These termite mounds made with cemented soil last for several decades (Zachariah *et al.*, 2017) and their remains can last for several centuries (Erens *et al.*, 2015). Unlike bricks made by humans they are not even baked at high temperatures in a kiln. What is more interesting is that termites make these structures without an architect, without a masterplan and in fact without even seeing the structure they are making — yes termite workers do not have eyes… So how do tiny termites achieve all this? The mystery remains.

Figure 1. Mound of *Odontotermes obesus* (Zachariah *et al.* 2017)

Termites are social insects — they live in colonies with upto a million individuals. These individuals are divided into morphologically distinct castes — king and queen, workers, soldiers, nymphs (or young ones) and alates. The king and queen mate, lay eggs which form all other castes of the colony. The soldiers guard the colony against intruders like ants. The workers are involved in mound building, foraging, rearing the young ones and tending to their fungus gardens (Figure 2; Bose, 1984).

Construction of the mound, in general, can be envisioned as a three-part process involving material selection, transport and assemblage. Researchers have tried to understand these process during mound construction in the species *Odontotermes obesus* (Zachariah *et al*., 2017). They found that termites take moist soil, mix it with their secretions (which acts as an adhesive) and make tiny balls — about a millimetre in length — and carry them to the site of construction (Figure 3). These are analogous to bricks used in human construction and have been termed as boluses. Further it turns out that termite workers of *O. obesus* are of two different castes — major workers with a large body and a large, dark brown coloured head and small workers with a small body and a light brown head (Figure 2; Bose, 1984). These castes make two different types of boluses — major workers make larger boluses than minor workers (Figure 3). But how do you make a building with two different sizes of bricks? To understand this, researchers made an intentional breach at a termite mound and video recorded the process of breach repair. Upon analysing the video and marking the spatial location of the bricks deposed by major and minor workers, they found that both kinds of boluses were spatially interspersed suggesting a kind of packing (Figure 4). The larger boluses made a scaffold and the smaller boluses filled the gaps or voids between them — something similar to a glass jar filled with golf balls and marbles filling the space between them. This imparts tight packing and high strength to the mound (Figure 5; Zachariah *et al*., 2017). It also points towards a possible mechanism of coordination between termite individuals called

Figure 2. *Odontotermes obesus* workers and soldiers

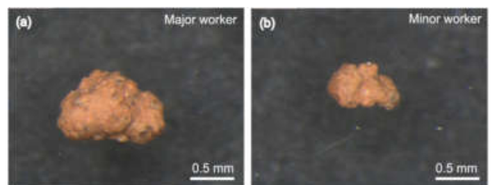

Figure 3. Boluses made by major and minor workers with soil (Zachariah *et al*. 2017)

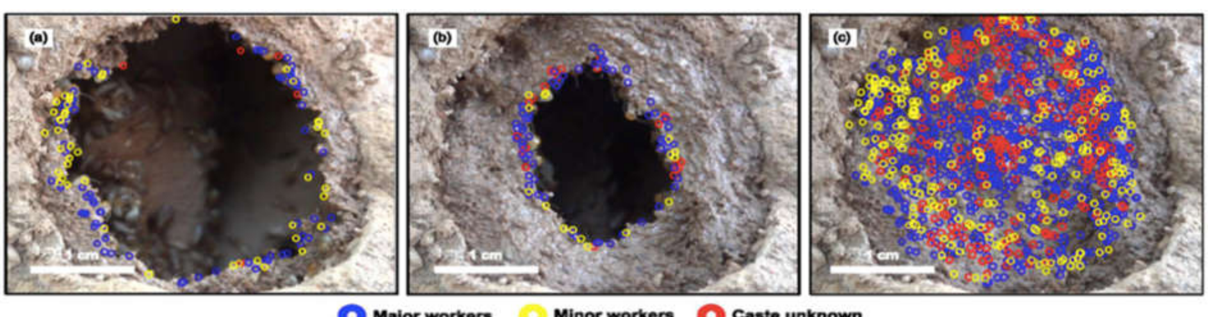

Figure 4. Placement of boluses by major and minor workers during breach repair in a termite mound as recorded by videography from a fixed location. (a) Boluses deposited during 1st minute of breach repair; (b) boluses deposited during 8th minute of breach repair; (c) boluses deposited during the entire process of breach repair; some circles indicating bolus depositions are partially overlapping and can obscure others from view. When the worker caste was not clearly visible, it is indicated as "caste unknown". Breach repair occurs in a circular manner and boluses made by major and minor workers were interspersed, leading to high packing efficiency (Zachariah et al. 2017)

stigmergy. Stigmergy is the coordination between individuals by modifying a shared environment. Researchers have tried to understand this phenomenon by building robots that carry out a task by mutual coordination simply by sensing and modifying their shared environment (Werfel *et al.*, 2014). In case of termite mounds

the presence of voids can act as a similar cue for bolus deposition helping in large scale construction (Zachariah *et al.*, 2017).

Further, researchers offered glass beads to termites instead of soil and surprisingly termites used glass beads to make boluses the way they used soil. It turned out that termites could use a wide range of materials such as metal powders, paraffin, sand grains, polymers like agar and fibrous materials like tissue paper for making boluses (Figure 6). But all of them were not equally easy to handle. The materials that were easiest to handle has certain properties common in them — they were all granular, hydrophilic, osmotically inactive, non-hygroscopic materials with surface roughness, rigidity and contained organic matter. Granular materials had the highest ease of handling followed by polymers and fibrous materials. Soil with organic material present in it had higher ease of handling than soil

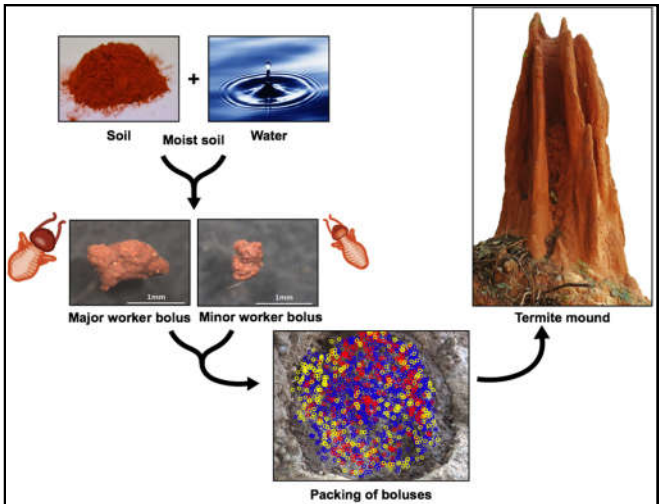

Figure 5. Phases of termite mound construction

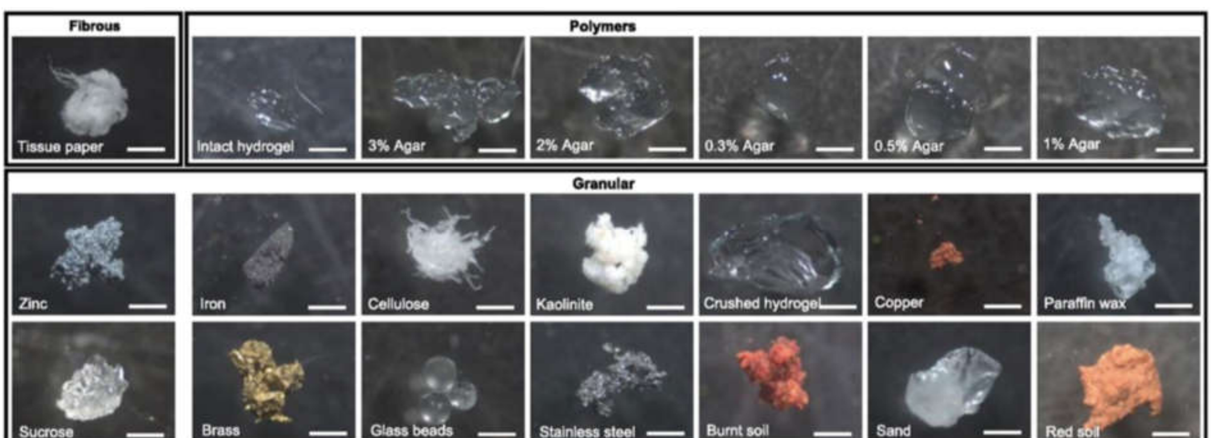

Figure 6. Boluses made with different materials. Material indicated on image. Scale bars represent 0.5mm. **(Zachariah *et al.* 2017)**

devoid of organic material suggesting that organic matter, apart from termite secretions, plays a role in cementation in termite mounds. Since termites have to moisten and adhere particles of materials with their secretions, hydrophilic materials such as glass beads and soil were easier to handle than hydrophobic materials such as paraffin. Thus material properties, in the presence of moisture and favourable climatic conditions, make a certain geographic region conducive for termite mound construction (Zachariah *et al*., 2017).

From the above description it doesn't seem obvious why granular materials should be preferred over polymers and fibrous materials. Granular materials have been regarded as the fourth state of matter by engineers; thus we have solid, liquid, gas and granular materials. Here, a single granule is a solid but as an aggregate it acts as a fluid. So you can bury your hands in sand or you can fill a bucket with sand and it takes the shape of the bucket. Granular materials can be cemented by depositing adhesive only at the junction of the particles or they can be embedded in a matrix. They can be packed tightly or loosely (Duran *et al.*, 2012; Weitz, 2004; Sowers 1979). All these can have bearing on the kind of construction termites carry out.

Surprisingly, termite mounds built with such great efforts is not the dwelling place for termites. The actual termite colony lives underground. Then why do termites make mounds? For any organism living underground, ventilation is a challenge. In case of termite colony, mounds act as an organ of ventilation — just like our lungs. They harness diurnal temperature oscillations for ventilation. Termite mound consists of a central chimney and several peripheral flutes. During the night, hot air from the colony rises in the central chimney. As the air rises up, its temperature drops and the cool air comes down through the peripheral flutes. During this time gaseous exchange take places through the porous walls of the termite mound. During the day time, the peripheral flutes get heated up due to sun's heat and the direction of flow reverses. Thus, an efficient ventilation mechanism is established where the architecture itself helps in gaseous exchange (King *et al*., 2015).

Not only do termites engineering their magnificent mounds, they also engineer entire ecosystems (Prusty, 2010). Their presence has been associated with increased soil fertility and drought resistance to climate change (Prusty, 2010; Bonachela, *et al.,* 2015). However, we are yet to get a full picture of the ecosystem services provided by termites. When it comes to understanding the construction of termite mounds, researchers have barely scratched the surface. Further studies into mound construction will inspire the construction of energy efficient buildings, biosynthesized cementing agents for construction and robots and algorithms that will self-organize and can be used for traffic regulation and construction in inaccessible places. Termites also act as farmers and grow their own food (fungus) inside their mounds. They have a highly specialised mechanism of weed control (Katariya *et al*., 2017) which is likely to inspire agriculture practices in the near future. Therefore, it is in our best interest not to disturb termite mounds in natural landscapes… we never know what treasures they are holding for us!!

References

1) Bose G (1984) Termite Fauna of Southern India. Zoological Survey of India, Calcutta.

2) Bonachela JA. et al. (2015) Termite mounds can increase the robustness of dryland ecosystems to climatic change. Science 347, 651–655.

3) Duran J (2012) Sands, Powders, and Grains: An Introduction to the Physics of Granular Materials. Springer Science & Business Media.

4) Erens H. et al. (2015) The age of large termite mounds—radiocarbon dating of *Macrotermes falciger* mounds of the Miombo woodland of Katanga, DR Congo. Palaeogeogr. Palaeoclimatol. Palaeoecol. 435, 265–271.

5) Kandasami RK, Borges RM & Murthy TG (2016) Effect of biocementation on the strength and stability of termite mounds. Environ. Geotech. 3, 99–113.

6) Katariya L, Ramesh PB, Gopalappa T, Desireddy S, Bessiere JM & Borges RM (2017) Fungus-farming termites selectively bury weedy fungi that smell different from crop fungi. J. Chem. Ecol. 43, 986–995.

7) King H, Ocko S & Mahadevan L (2015) Termite mounds harness diurnal temperature oscillations for ventilation. Proc. Natl. Acad. Sci. USA 112, 11589–11593.

8) Prusty AKB (2010) Termites as ecosystem engineers and potentials for soil restoration. Current Science, 99, 11.

9) Sowers GF & Sowers GB (1979) Introductory Soil Mechanics and Foundations. Macmillan Publishers.

10) Weitz DA. (2004) Packing in the Spheres. Science 303, 968–969.

11) Werfel J, Petersen K & Nagpal R (2014) Designing collective behavior in a termite-inspired robot construction team. Science 343, 754–758.

12) Zachariah N, Das A, Murthy TG, Borges RM (2017) Building mud castles: a perspective from brick-laying termites. Scientific Reports doi:10.1038/ s41598-017-04295-3.