Microrheology of sub-nanolitre samples: Study and characterisation of Insect adhesive secretions

Master's Thesis in view to be graded Master in Physics Engineering, by
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Summary

Insect attachment mechanisms surpass in many ways available commercial adhesives. They have faster reaction times and sustain astonishing forces when compared to the small contact areas over which they are exerted.
When pressed against a surface, both hairy and smooth pad types leave behind footprints, evidence of a liquid layer covering them.
Although the pad secretion has been discovered two centuries ago, its functional role remains unclear and the aim of this thesis is therefore to provide a rheological analysis of the sub-nanolitre volumes of insect adhesive secretions for both hairy and smooth pads insects.

The improved microrheology methods allowed measurements with samples whose volumes were in the order of magnitude of ten picolitres (10^{-11} litres).
The secretions for both smooth and hairy pads where characterised as purely viscous fluids with high dynamic viscosity coefficients: about 20 to 65 times that of water over the 17.5 to 28[°C] temperature range. The time elapsed between the sample collection and a successful measurement seemed to have little influence on the viscosity over the observed timescales.
These measurements are in good agreement with literature values.

At 17.5[°C] a sudden liquid to solid phase change in the smooth pads secretions conferred non-newtonian properties to regions of the sample, hinting a possible influence on the acclimation temperatures of insect individuals.

Established force models allowed to characterise the wet lubrication under vertical climbing and the dynamics of dry adhesion under horizontal attachment. Both mechanisms were respectively shown to require high and low viscosities. The viscosity coefficient measurements provided an order of magnitude which, considering additional insight on the pad secretions and their use, is in agreement with the force modeling.

Gas Chromatography and Mass Spectroscopy analyses allowed the main components of the smooth pad secretions to be identified. Aspects of the secretions behaviour were successively replicated with a mixture of viscous silicon oil and n-Hexadecane.
These synthetic secretions replicated the viscosity range of the insect adhesive fluids, adopted a slurry-like behaviour at 14[°C] and even hinted a possible non-newtonian response.

Keywords: Microrheology, Nanolitre, Sub-nanolitre, Rheology, Insect, Adhesive, Secretions, Adhesion, Bioengineering, Physics, Engineering.

Relevant Figures and Tables

Sample	Temperature [°C]	Elapsed Time [Days]	Rheology	η [mPas]
B1	22.5	6	Newtonian	25 ± 0.3
S1	22.5	3	Newtonian	30 ± 0.4
		13	Newtonian	40 ± 0.4
S2	24	$\frac{1}{2}$	Newtonian	34 ± 0.4
S3	17.5	3	Viscoelastic†	65 ± 0.9
	20	3	Newtonian	41 ± 0.4
	26	3	Newtonian	42 ± 0.7
	28	3	Newtonian	48 ± 0.4

Table 1: Summary table of the experimental results: temperature, elapsed time after collection, rheological behaviour and estimated dynamic viscosity coefficient η for each of the collected samples.
†As it has been previously detailed, the viscoelastic behaviour of the sample was observed only for a few probes, the average behaviour is however still considered to be Newtonian.

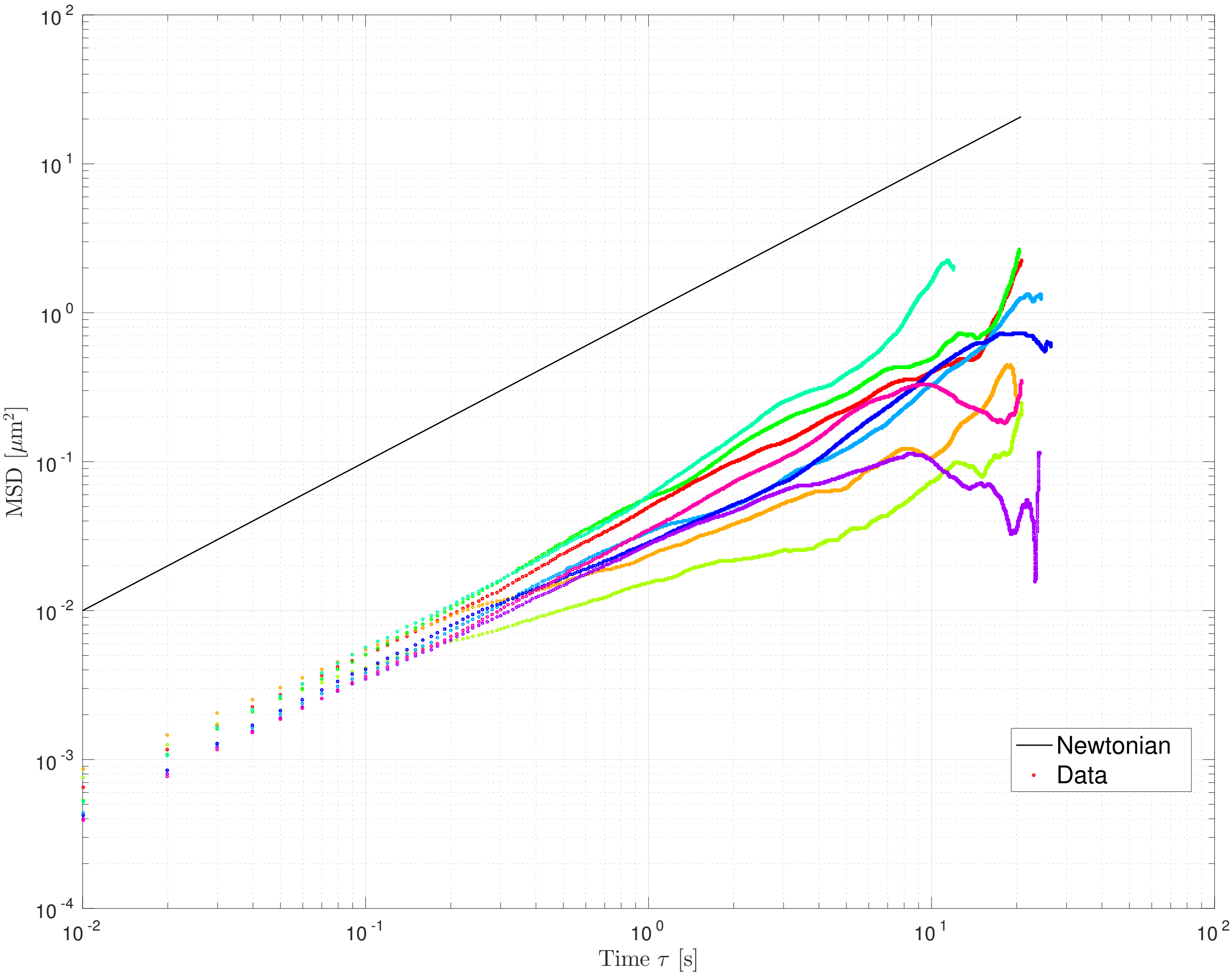

Figure 1: Mean Squared Displacement (MSD) as a function of the sampling time for $N_{\text{beads}} = 9$ micrometric probes immersed in sample S1 (*Carausius morosus*), 3 days after collection, at temperature T =17.5[°C]. Data curves in colours (each colour represents an individual bead). Newtonian behaviour represented in black.