Impact of organic matter on rheological behavior of fine-grained sediment

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Introduction: The presence of organic matter in fine-grained sediment usually hinders the settling of particles and eventually results in the formation of fluid mud layer, in addition to the natural wave motion or human intervention. There are two common sources of organic matter in sediment: (i) natural and (ii) anthropogenic. The natural sources include eroded terrestrial topsoils, plant litter and benthic and planktonic biomass while surface runoff and sewage effluents contribute towards the anthropogenic source of organic matter [1]. The existence of organic matter in fine-grained sediment can significantly influence the rheological and cohesive properties [2, 3].
In addition to the content of organic matter, its extent of degradation can also significantly affect the rheological properties of fine-grained sediments. The aerobic degradation (i.e., in the presence of oxygen) of organic matter usually results in the production of carbon dioxide while the anaerobic condition produces methane as well, in addition to carbon dioxide [1]. The entrapped gas bubbles can significantly decrease the strength of fine-grained. Our study is aiming to quantify the effect of organic matter on rheological behavior of fine-grained sediments and to analyze the systematic changes in rheological behavior of mud triggered by organic matter degradation.

Methods: In this study, sediment core samples were collected in the Port of Hamburg using one-meter core sampler. The samples were divided into suspended particulate matter, fluid mud, pre-consolidated sediment and consolidated sediment based on the visual differences in their consistency. The density, particle size distribution, organic matter content of sediment samples were determined in the laboratory. The samples were incubated in glass bottles under aerobic and anaerobic conditions. C release was quantified from the CO_2 and CH_4 concentrations measured in the headspace by gas chromatography and the pressure increase in the bottle head space. Aerobic and anaerobic degradation of organic matter experiments were conducted as reported in [1].
Rheological behavior of fine-grained sediment samples was analysed using HAAKE MARS I rheometer (Thermo Scientific, Germany) with Couette geometry. Different rheological experiments including stress ramp-up test, amplitude sweep test, frequency sweep test and thixotropic test were performed for fresh and degraded mud samples in order to quantify the rheological behavior of incubated sediment samples during long-term (>250 days) organic matter degradation experiments.

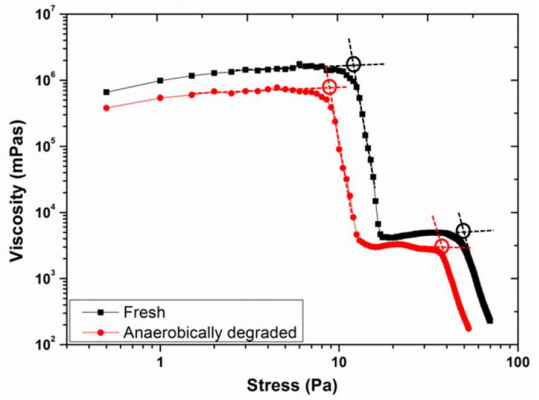

Fig. 1: Apparent viscosity as a function of shear stress for fresh and anaerobically-degraded sediment samples at the same densities. Circles represent the two yield points (i.e., static and fluidic).

Results: Our rheological analysis conducted on fine-grained sediment samples revealed the following:
1) The strength of anaerobically-degraded samples decreased systematically during organic matter degradation experiments. This decrease can be attributed to either loss of organic matter due to degradation or entrapment of gas bubbles in samples.
2) Fresh and anaerobically-degraded fine-grained sediment samples with the same densities have scientifically different rheological properties. As it is shown in Figure 1, the fluidic yield stresses (indicated in circles) were 37 Pa and 58 Pa for degraded and fresh samples, respectively.

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References: [1] Zander et al. (2020) *J Soils Sediments* **20**:2573-2587; [2] Shakeel et al. (2019) *Geo-marine Letters* **39**:427-434; [3] Wurpts and Torn (2005) *Terra et Aqua* **99**.

Impact of organic matter degradation on rheological behavior of fine-grained sediment

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Abstract

In this study, the influence of organic matter degradation on the rheological properties of mud samples, having similar densities, is examined. The mud samples were collected from four different locations of Port of Hamburg, Germany, to have varying organic matter content. The rheological analysis of fresh and degraded mud samples was performed with the help of several tests including shear stress ramp-up tests, amplitude sweep tests, frequency sweep tests, thixotropic tests and structural recovery tests.

Introduction

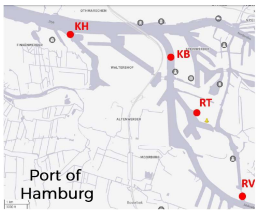
Muddy sediments usually exhibit a complex rheological fingerprint – which is a combination of yield stress, thixotropy or viscoelasticity – due to the presence of hard clay particles and organic matter (i.e., clay-organic flocs).

Marine sediment composition

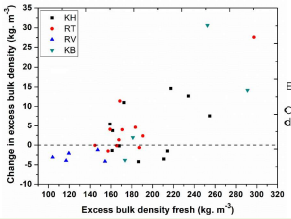
Under anaerobic conditions, the microbial degradation of organic matter typically results in the formation of carbon dioxide (CO_2) and methane (CH_4). These trapped gas bubbles in the mud sample are supposed to decrease the rheological properties and density of mud along with the delayed consolidation. As already known that the rheological properties of mud are strongly dependent on the existence of organic matter, its degradation can also significantly effect the rheological fingerprint of mud.

Methodology

The "undisturbed" mud samples were collected from four different locations of Port of Hamburg (Germany) using one meter core sampler. The bulk density of the sediments was determined by the oven drying method. For anaerobic degradation, fresh mud samples were placed into 500 ml air tight glass bottles. The headspace above mud sample was flushed with N_2 and incubated at 36°C in the absence of light to maintain anaerobic conditions for 250 days.

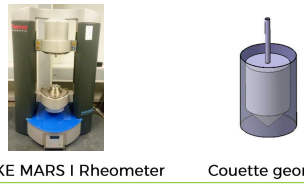


Frahmlot



Excess bulk density = $\rho - \rho_w$

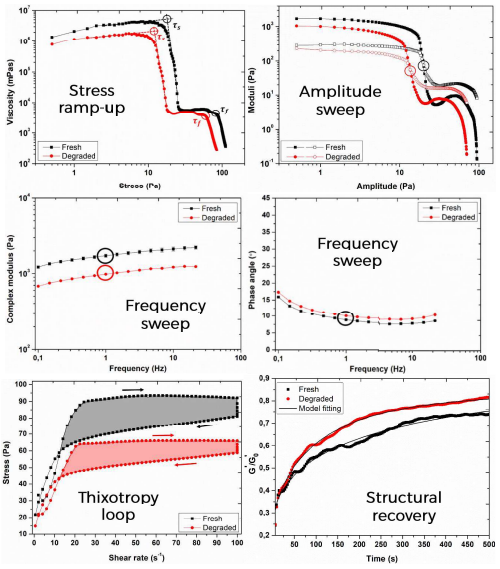
Change in properties = degraded – fresh



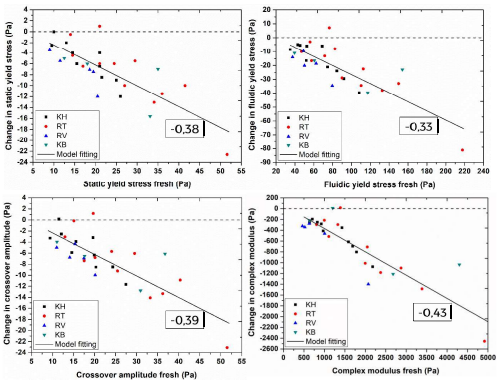
HAAKE MARS I Rheometer

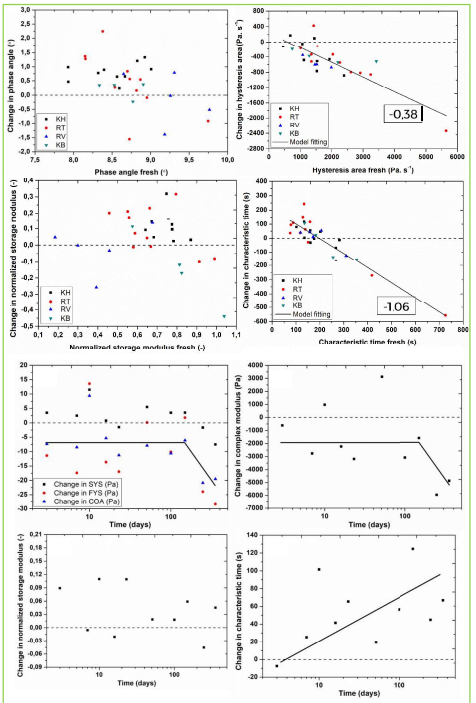
Couette geometry

Results



The results showed a significant decrease in rheological properties including yield stresses (static and fluidic), crossover amplitude, complex modulus and thixotropic hysteresis area for degraded mud samples as compared to the fresh mud samples.





Initially, after 3 days of degradation, a significant decrease in rheological properties was observed, which became more or less constant till 150 days, and after that a further decrease in rheological properties was evident.

Conclusion

The influence of organic matter degradation on the rheological properties of mud is examined. The results showed a significant decrease in rheological properties for degraded mud as compared to the fresh mud. The slope of the line, correlating the change in rheological properties as a function of the same property of fresh mud, was quite similar and varies within the range of -0.33 to -0.43. The effect of degradation time on the rheological properties of mud showed two critical time periods (3 days and 150 days) after which a significant change in rheological properties of mud was observed.

References

1. Zander, F., Heimovaara, T., & Gebert, J. (2020) Spatial variability of organic matter degradability in tidal Elbe sediments. Journal of Soils and Sediments 20, 2573-2587.
2. Shakeel, A., Kirichek, A., & Chassagne, C. (2019) Is density enough to predict the rheology of natural sediments?. Geo-Marine Letters 39, 427-434.
3. Wurpts, R., & Torn, P. (2005) 15 years experience with fluid mud: Definition of the nautical bottom with rheological parameters. Terra et Aqua 99, 22-32.

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