On the Possible Role of *Opuntia ficus-indica* Mucilage in Lime Mortar Performance in the Protection of Historical Buildings

A. Cárdenas, W. M. Arguelles, and F. M. Goycoolea
Centro de Investigación en Alimentación y Desarrollo, A. C.
P.O. Box 1735
Hermosillo, Sonora
C.P. 83000 México

ABSTRACT

In Mexico, the preparation of lime mortar may include the addition of nopal juice. The lime mortar prepared in this way has been used for centuries for restoring and protecting historical buildings because of an improved performance against water penetration and cracking. To date, no scientific explanation has been offered to explain the use of cactus juice in lime mortar. The objective of this study was to provide a preliminary experimental account of the use of nopal juice as an impermeabilization agent. Calcium hydroxide and commercial slaked-lime pastes were prepared and mixed with varying concentrations of nopal juice at ratios of 0.65%, 1% and 1.95% of cactus juice to $Ca(OH)_2$ or commercial slaked lime. The dry pastes thus obtained were evaluated by a penetration-breaking test with a TA-XT2 texture analyzer. Increasing amounts of cactus juice in the formulation resulted in a drastic reduction of the maximum stress and deformation values of the pastes as compared to those of the control sample. In the control sample, a more mechanically homogeneous $Ca(OH)_2$ structure was formed. In the sample with the lower cactus juice ratio, the mucilage had a reduction effect upon the continuity of the network. The amorphous soft filler, forming a discontinuous phase, makes the hydroxide network weaker. As the ratio increased, mechanical properties also increased due to the formation of a homogeneous network of nopal mucilage interpenetrated into the hydroxide base. Results indicate the formation of an interpenetrated network of nopal mucilage with no structural modification involved.

INTRODUCTION

It is known that the use of cement in the restoration of historical buildings has detrimental effects because it is too hard and incompatible with adobe. Also, it restricts transpiration, increasing the risk of damage caused by humidity.

Consequently, mortars for use in historical buildings or monuments are usually derived from slaked lime putty, alkalies, copper salt, and sand, and incorporate pozzolanic and particulate materials. These mortars have a high mechanical resistance, increased waterproof protection, and antifungal properties (Gomez del Campillo and Dorrego, 1995).

Interest in the development of different such formulations of lime mortars is growing, especially in Europe. Lime mortars in Mexican historical buildings commonly incorporate cactus juice extracted directly from the cooked pads of *Opuntia* spp., a centuries old practice. The nopal juice is added as an organic adhesive that prevents the mortar from drying too quickly and helps retain the necessary moisture that the mixture needs to set correctly, transporting CO_2 from the atmosphere that combines with the slaked lime to form an artificial limestone. This formulation is known mainly in America but there is increasing interest in Europe to explore and develop it. (Fontana, personal communications).

To prepare the mortar, the thicker pads of the plant are boiled whole so that the juice is not diluted. Typically, "Castilla" cactus is the most commonly used because it does not have large thorns. The boiled pads are then pressed to obtain a thick juice that is added to the liquid content of the mortar (20%).

No sound scientific explanation for the use of cactus juice in lime mortar is available. Nevertheless, cactus juice is known to be rich in insoluble fibers as well as water-soluble mucilage (Granados and Castañeda, 1991). This polysaccharide mucilage has a chemical composition similar to that of pectins, and it generally contains varying proportions of L-arabinose, D-galactose, L-rhamnose, and D-xylose as the major neutral sugar units as well as D-galacturonic acid. Different species of nopal contain different percentages of mucilage, for instance in *Opuntia ficus-indica* the total pectin content is 1.9% and for *Opuntia robusta* is 3.3% (wet-weight basis). This mucilage displays a great tendency to aggregate in salt solutions, as we have previously demonstrated (Cárdenas *et al*. 1997). Cactus mucilage can be dispersed in a salt solution at concentrations of up to 5% and it does not form a gel system but a high-viscosity solution. Even at this concentration level, the mucilage has a mechanical spectra characteristic of an entangled network of disordered polymer coils (Cárdenas, 1997). Claims of the advantages of admixing cactus juice in lime mortar include increased impermeability and prolonged duration of the wall coating, thus effectively preserving the original stones and bricks of ancient monuments.

Although we are aware that the phenomena involved in the development of the internal physical microstructure of mortar and concrete, are very complex, the aim of this paper was to give a preliminary account of the effect of incorporating increasing amounts of cactus mucilage in solution in lime-mortar pastes, and of the mechanical properties of the dry solid pastes thus obtained.

Our working hypothesis was that cactus mucilage polysaccharide in the presence of $Ca(OH)_2$ could suffer structural modification, resulting in the ability of the polymer to form a gel network, hence promoting a better binding of stucco solid microstructure. The mechanical properties (strength and toughness) of dried mixtures of lime mortar with cactus mucilage should reflect these phenomena.

MATERIALS AND METHODS

Materials

A batch of cactus pads of *Opuntia ficus indica* was kindly donated by Mr. Vicente Santos, a commercial farm operator in San Pedro, Hermosillo, Sonora. Commercial slaked-lime powder was purchased from a retail shop in Hermosillo. Calcium hydroxide from "Productos Monterrey" was used.

Mucilage Extraction

The pads were cleaned, cut into small pieces (about 3 cm^2 each), then cooked in a steam bath without adding extra water. The sample was then placed in a cutter to reduce the size of the pieces in order to promote mucilage extraction. This material was centrifuged at 1040 rpm, to extract the mucilage. The extract thus obtained was freeze-dried. The yield of dry mucilage recovered was approximately 0.88% dry weight.

Lime Mortar Pastes Formulation

The dry pastes were prepared with different concentrations of mucilage solution (1%, 2%, and 3%) while the amount of calcium hydroxide or slaked lime was kept constant to give a final ratio (c) of mucilage to lime of 0.65%, 1%, and 1.95%, respectively. The control sample was prepared with water (c=0%). The ratio of cactus polysaccharide to $Ca(OH)_2$ (dry-weight basis) can be expressed as:

$$c\ (\%) = \text{weight mucilage}/\text{weight of } Ca(OH)_2 \times 100$$

The pastes were placed in a Perspex plate with cylindrically shaped molds of 1.1 cm height by 1.3 cm diameter, in which they were dried for 4 hours at 60°C in a convection oven.

Mechanical Tests

The dry paste cylinders were subjected to plunge-probe penetration-breaking tests with a TA-XT2 Texture Analyzer. The height of each cylinder was registered before the test. The plunge dimensions were 3.7 cm high and 1 mm diameter. The plunge was placed just above the surface of the cylinder and the probe was moved at a constant velocity of 0.1 mm/s until the sample broke.
Return

RESULTS

The approach adopted in this study to investigate the possible role of cactus polysaccharide in the performance of lime mortar during wall coating was to mix isolated cactus mucilage dissolved in water at several concentrations into pastes of slaked lime or pure low-moisture $Ca(OH)_2$, which should have a major effect on the mechanical properties of the dry mixtures subjected to compression tests. This should help gain preliminary understanding of the fundamental aspects involved in the physical nature of the intrinsic structure of the material.

Initially, the effect of adding proportionally increasing amounts of cactus polysaccharide to pure $Ca(OH)_2$ pastes was assessed. From Figure 1, it follows that even at the lowest c ratio (c=0.65) there is a significant reduction in the maximum amount of stress that can be supported by the formed network before it collapses and fractures with respect to the control sample of $Ca(OH)_2$ alone (c=0). This also reflects the formation of a more brittle structure with e_{max} = 0.06. Both pastes (c=0 and c=0.65) seem to exhibit a small yield peak at exactly the same stress. As the c value increased, the weakening effect was even more accentuated. At c=1 the weakest and more brittle pastes were formed, with slightly stronger ones at 1.95. These results suggest that our initial hypothesis, arguing in favor of a structural modification in cactus polysaccharide, which would lead to promote the formation of a gel network, cannot be sustained. Indeed, some preliminary tests in excess of water mixing $Ca(OH)_2$ in a concentrated mucilage solution, showed no evidence of gel formation, neither at room temperature nor after heating and cooling the solution. Instead, a phase separation process was observed in this solution.

Figure 2 presents the results for mixtures of commercial slaked lime and *Opuntia* mucilage at similar c ratios as for the $Ca(OH)_2$ mixtures. The overall effect observed on the admixing of cactus mucilage into slaked lime is similar to the one on $Ca(OH)_2$ dry pastes. The weakest pastes were obtained at c=1, as in the case of $Ca(OH)_2$. The stress response curve of paste with c= 0.65 follows the same trace as the one of pure slaked lime (c=0), whereas at greater values of c, the networks show significant weakening. In all cases, the addition of cactus mucilage to slaked lime results in the formation of noticeably more brittle structures. The slaked-lime-paste curve (c=0) seems to reflect the existence of a yield point, which is lost when cactus mucilage is added. In general, addition of cactus mucilage to $Ca(OH)_2$ or commercial slaked lime pastes results in a ‘shortening’ effect of the structure, qualitatively similar to that obtained by the addition of fat to flour during the baking of cookies.

Figure 3 shows the overall observed behavior of the mixtures with $Ca(OH)_2$. The individual curves on each graph represent replicates of various pressed cylinders. It is worth pointing out that for $Ca(OH)_2$ alone (c=0), there is very good reproducibility between individual curves. However, at c=0.65 and c=1 the error between replicates is increased greatly. At c=1.95 homogeneous behavior is observed again.

Insets on each family of curves in Figure 3 at the various c ratios tested include our present interpretation of the behavior of $Ca(OH)_2$ pastes as a model for lime mortar in the presence of cactus polysaccharide mucilage. At c=0 a uniform homogeneous crystalline structure is formed basically by the most efficient packing of $Ca(OH)_2$ particles as drying takes place. This structure is expected to behave like an isotropic solid as the probe penetrates its structure up to the point where the stress cannot relax any longer the applied strain, so it breaks. Upon the addition of small quantities of cactus mucilage (c=0.65), the polymer in the paste has a net effect of decreasing the overall degree of connectivity, in the mechanical sense. Therefore, although the continuous strong network is still formed by crystalline $Ca(OH)_2$, the inclusion of mucilage as a soft amorphous filler results in the overall weakening of its structure. This type of effect can be interpreted in terms of the blending laws of Takayanagi proposed to describe the mechanical properties of mixed polymers in plastic composites (Lewis and Ward, 1980). The composite consists of "droplets" of one semisolid phase acting as filler particles contained within a second continuous solid phase (Kasapis, 1995). In this case, the mixtures at c=0.65 and c=1 would form rather heterogeneous anisotropic mixtures, which could explain the low reproducibility observed between individual curves. The weakening of the $Ca(OH)_2$ network can also be explained in terms of this model. At c=1.95% however, there is a clear increase in the strength of the mixtures and the curves tend to be more reproducible. This latter effect is explained as the result of the formation of an interpenetrated network of cactus polysaccharide and $Ca(OH)_2$. Such physical arrangement is formed when each polysaccharide component gels independently, resulting in the formation of two independent networks spanning the entire sample and interpenetrating through each other, thus effectively increasing the overall mechanical connectivity of the network (Morris, 1995).

The observed effects in mechanical properties of slaked lime and $Ca(OH)_2$, rule out the possibility that a change in the structure of cactus mucilage polysaccharide results in the formation of mortar pastes with increased mechanical strength. On the contrary, the evidence presented here shows that the overall effect of mixing cactus mucilage with slaked lime in dry pastes is to weaken and shorten its texture.

This is only a preliminary account of a use of cactus in mortar formulation, for which hardly any scientific studies have been documented. At this stage only mixtures of $Ca(OH)_2$ and commercial slaked lime have been tested as models of lime mortar. However, the observed phenomena in mechanical behavior may not bear a significance in the reduction of capillary transportation of water and increased permeability of the mortars prepared incorporating cactus juice.

REFERENCES

Cárdenas, A. Higuera-Ciapara and Goycoolea F. M. 1997. J. of The Professional Association for Cactus Development. 2:152-159.
Cárdenas A. (1997) Reología y asociación molecular en solución de poliuronatos de origen diverso. Tesis de Maestría. CIAD, A. C. Hermosillo, Sonora.
Gomez del Campillo L. and Dorrego M.P., 1995 Patente ES-94-855.
Granados, D. and Castañeda, A.D. 1991. El Nopal. Historia, Fisiología, Genética e Importancia Frutícula. Trillas. México.
Kasapis S. 1995. Phase Separation in Hydrocolloid gels. In: Bipolymer Mixtures. Harding, S.E., Hill, S.E. and Mitchell, J.R. (eds) Nottingham University Press p. 193.
Morris V.J. 1995. Synergistic Interactions with Galactomannans and Glucomannans. In: Bipolymer Mixtures. Harding, S.E., Hill, S.E. and Mitchell, J.R. (eds) Nottingham University Press. p.290.
Lewis E.V.L. and Ward I.M. 1980, J. Mater. Sci. 15:2354.

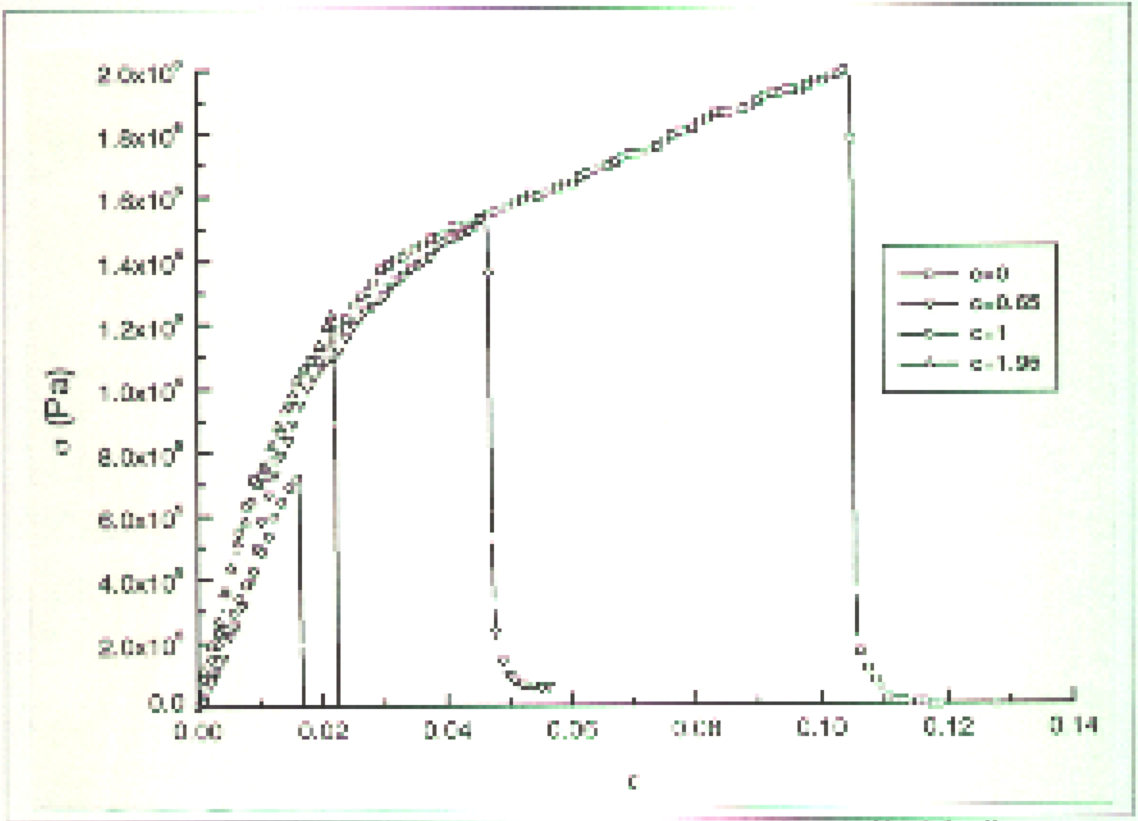

Figure 1. Stress (σ) - Strain (ε) Curves for *Opuntia ficus-indica* Mucilage with the Ratio (c) of Mucilage to $Ca(OH)_2$

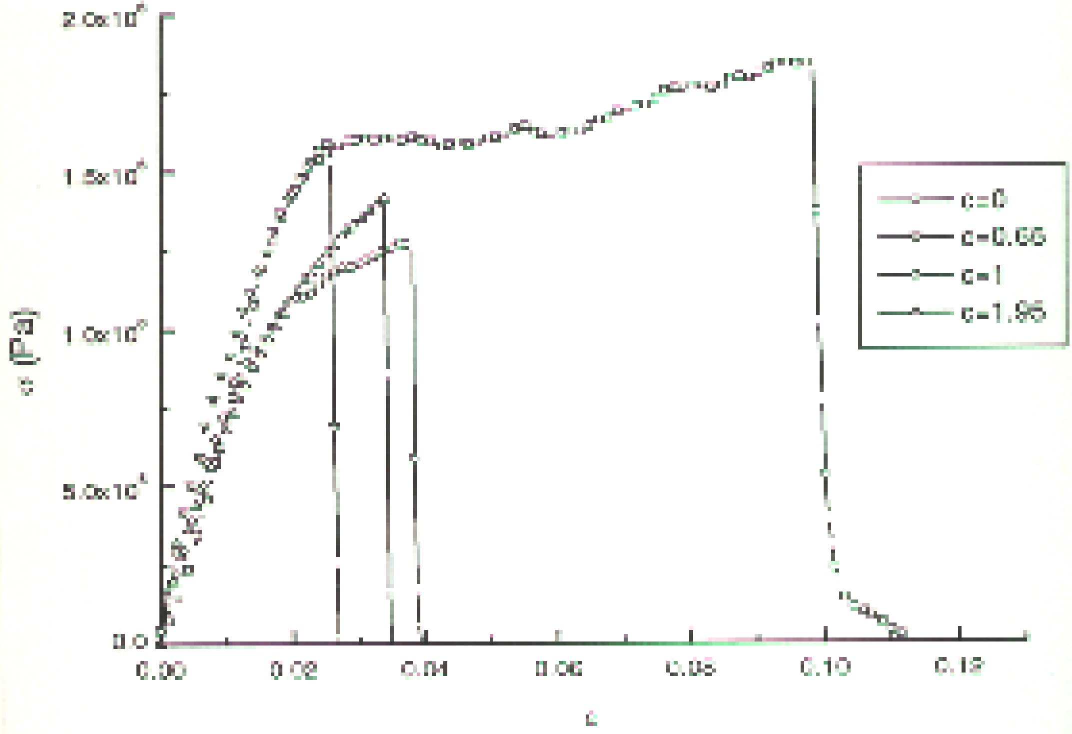

Figure 2. Stress (σ) - Strain (ε) Curves for *Opuntia ficus-indica* Mucilage with the Ratio (c) of Mucilage to Commercial Slaked Lime

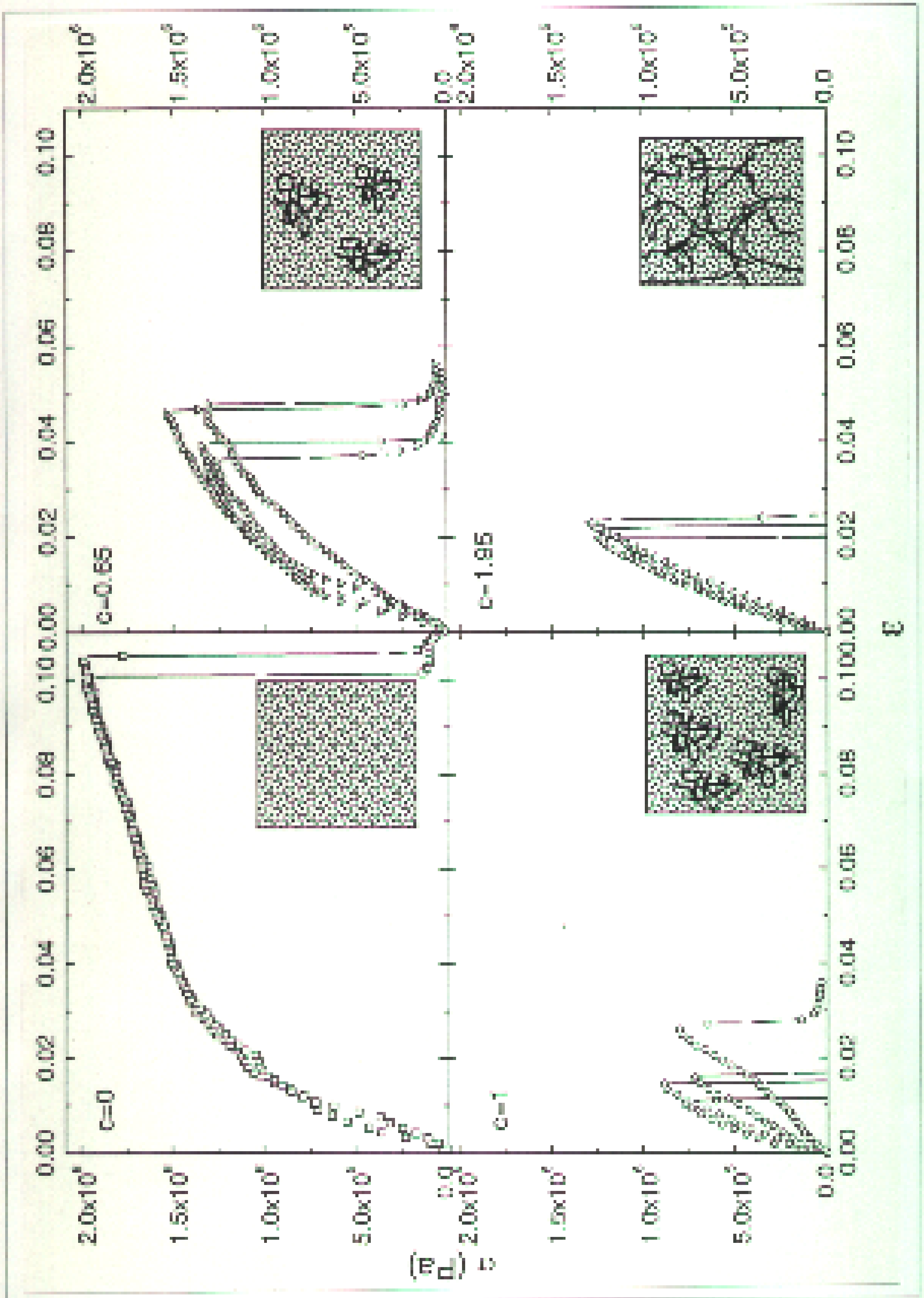

Figure 3. Stress (σ) - Strain (ε) Curves for *Opuntia ficus-indica* Mucilage with the Ratio (c) of Mucilage to $Ca(OH)_2$. Different curves in the same graph represent replicates. Inserts in each graph represent models for fisical behavior observed.