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Viscoelastic behavior of clay and slip used in ceramic

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Abstract

In this article we studied the effect of time and mass concentration on the viscoelastic behavior of a clay and slip used in the manufacture of ceramics from CERAMIR Algeria. The generalized model of Kelvin-Voigt is successfully applied to fit the creep and recovery data and to analyse the viscoelastic properties of clay and slip. The increase of time of creep-recovery shows a slow increase in Newtonian viscosity corresponding to the steady-state and instantaneous and delayed elastic compliance. On the other hand, the increase in the mass concentration of clay causes a rapid increase in the Newtonian viscosity corresponding to the steady-state and a decrease in instantaneous and delayed elastic compliance.

Keywords: clay, slip, ceramic, viscoelastic behavior
Kulcsszavak: agyag, agyagmassza kerámia, viszkoelasztikus viselkedés

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1. Introduction

Clays are used in different branches of industry, such as in drilling fluids in order to control the viscosity and the yield stress of drilling muds [1-3], in ceramic industry [4], in the treatment of polluted water, for example in the adsorption of toxic organic compounds [5-6] and pharmaceutical application [7-9]. The clays are also employed as a thickener in stabilizing the oil-water emulsions [10-12]. Knowledge of rheological properties of clays plays a fundamental role in industrial application such as in a ceramic construction plant in order to determine good operating conditions of the pumps during ceramic manufacturing operations. Numerous researches have been devoted to the study of the rheological properties of suspensions of clays used in ceramics [13-14].The effect of a number of additives on rheological properties of slip of ceramic has been widely studied and it was the subject of many previous works [15] for example the sodium tripolyphosphate and sodium hexameto-phosphate [16], polyelectrolyt [17] and the non-traditional biopolymeric [18].

The main objective of this study is to achieve a fine characterization of the rheological properties of clay and slip used by the New Company of ceramic tiles of Remchi, Algeria in order to define a good condition of use of these clays for the operation of the pumps during the ceramic manufacturing operation in this factory.

2. Materials and methods

2.1 Materials and sample preparation

The Nedroma clay and slip were, recovered from the New Company of Ceramic tiles of Remchi, Algeria in powder form. The Nedroma clay as a powder was brought to the oven for 24 hours at 40 °C for dehydration then crushed and passed away a sieve of 80 µm to perform a size sorting compatible with cone and plate geometry used for rheological measurements. Then the clay powder was dispersed in the required amount of distilled water by continuous magnetic stirring at room temperature during 24 hours in order to ensure their homogenization. Note that the slip is mixed in distilled water without sieving. The *Table 1* shows the composition of slip used in this study.

Nedroma Clay	Yellow Clay	Blue Clay	Feld-spars	Sand	Lime-stone	Fire-clay
20%	20%	21%	21%	6%	7%	5%

Table 1 The composition of slip
1. táblázat Az agyagmassza összetétele

2.2 Experimental set up

The rheological measurements was performed by using a torque controlled rheometer (RS600 from Thermo-Fischer) connected to a temperature controlled water bath and equipped with a plate-cone geometry (diameter: 60 mm; angle: 2 degree; gap: 105 µm). A solvent trap was placed around the measuring device in order to minimize solvent evaporation.

3. Results and discussion

3.1 Effect of time on creep and recovery

The study was carried out on a mass concentration of 50% in slip and 55% in Nedroma clay with the following protocol: after a pre-shear at 100 s^{-1} for 60 s following a rest of 120 s after rest time we applied a constant stress of 10 Pa, in the field of linear viscoelasticity, for different durations (50 s, 150 s, 300 s and 700 s) while recording the evolution over time of the elastic complacency during the creep phase during each duration. At the end of each phase of the creep, the stress is instantly brought back to zero and the elastic compliance is measured during the recovery phase for different durations. *Fig. 1* and *2* show the evolution of the elastic compliance of the slip and Nedroma clay as a function of time.

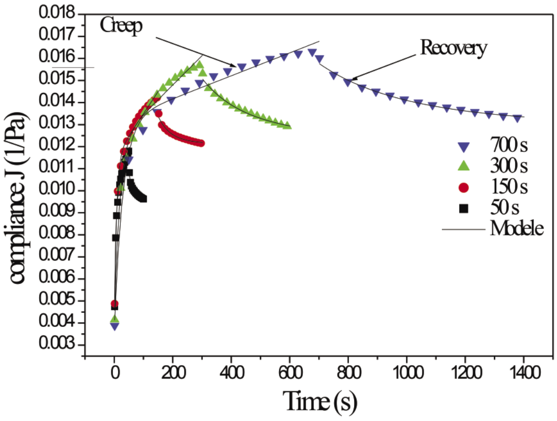

Fig. 1 Evolution of the elastic compliance of the slip as a function of time for different time applied
1. ábra Az agyagmassza rugalmassági tulajdonságának alakulása az idő függvényében

The viscoelastic behaviour were defined by correlating the results with the well-known viscoelastic models of Burger model or Generalized Kelvin–Voigt model, comprising the association in series of the Maxwell model and the Kelvin–Voigt

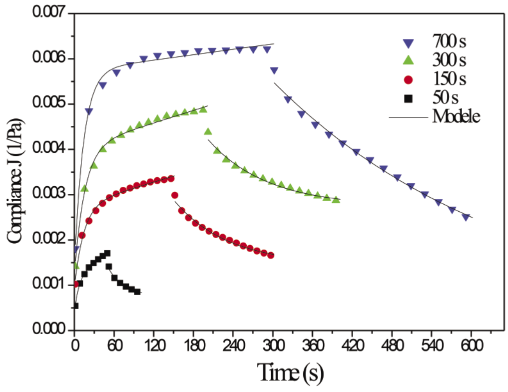

Fig. 2 Evolution of the elastic compliance of the Nedroma clay as a function of time for different time applied
2. ábra Nedroma agyag rugalmassági tulajdonságának alakulása az idő függvényében

The function of creep of this model is than written:

$$J_F = J_0 + \frac{t}{\mu_0} + \sum_{i=1}^{N} J_i \left[\;\; - \exp\left(-\frac{t}{\theta_i}\right)\right] \tag{1}$$

$$\theta_i = \frac{J_i}{\eta_i} \tag{2}$$

Whereas the recovery strain is given by:

$$J_R = \frac{t_1}{\mu_0} + \sum_{i=1}^{N} J_i \left[\exp\left(\frac{t_1}{\theta_i}\right) - \;\;\right] \exp\left(-\frac{t}{\theta_i}\right) \tag{3}$$

where J_0 is the purely elastic contribution (or the instantaneous elastic compliance), η_0 is the purely viscous contribution, represented by the dashpot of the Maxwell model, i.e., the uncoupled or residual steady-state viscosity obtained from the creep curve at long times when the compliance curve is linear, J_i is the contribution to retarded elastic compliance, θ_i is the retarded time, η_i is the retarded viscosity and t_1 is the time where the stress is applied for $t \leq t_1$ and removed at $t = t_1$.

Fig. 3 and *4* show the evolution of the creep and recovery parameters as a function of applied time. The figures show an increase in instantaneous and delayed elastic compliance as well as Newtonian viscosity with increasing time [19]. The increase in instantaneous delayed elastic compliance and the Newtonian viscosity of the slip and the Nedroma clay with time indicating the transition from a viscoelastic regime to a viscous regime.

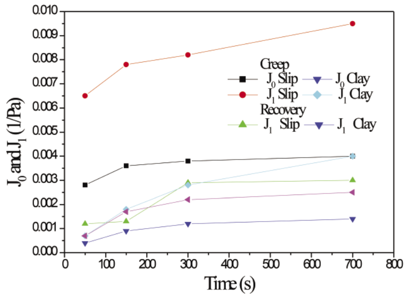

Fig. 3 Variation of the instantaneous elastic compliance J_0 and delayed J_1 of the Nedroma clay and slip of ceramic as a function of applied time
3. ábra A Nedroma agyag és agyagmassza J_0 és késleltetett J_1 pillanatnyi rugalmassági tulajdonságának változása az idő függvényében

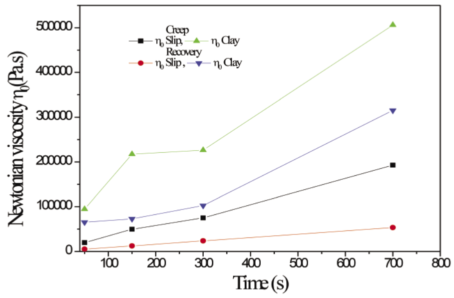

Fig. 4 Variation of Newtonian viscosity of the slip and the Nedroma clay as a function of applied time
4. ábra A Nedroma agyag és agyagmassza newtoni viszkozitásának változása az idő függvényében

3.2 Effect of mass concentration on creep and recovery of clay

The effect of mass concentration was performed only Nedroma clay for different concentration (40%, 45%, 50%, 55% and 60%). After a pre-shear at 100 s, for 60 s following a rest time of 120 s, we applied a constant stress of 2 Pa during 180 s and recording the evolution of elastic compliance during the creep phase. After 180 s the stress is instantly reduced to zero and the elastic compliance is measured during the recovery phase for a time of 180s. *Fig. 5* and *6* show the evolution of elastic compliance as a function of time for different concentration of clay.

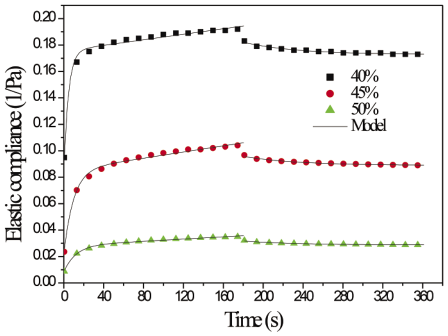

Fig. 5 Variation of elastic compliance of clay as a function of time (concentration: 40%, 45% and 50%)

5. ábra Agyag rugalmassági tulajdonságában változása az idő függvényében (40%, 45% és 50%-os kocentráció esetén)

We observed in *Fig. 5* and *6* for weak concentrations of clay the deformation the clay during the creep phase is much greater and the system quickly relaxes during the recovery phase, we can explain this phenomena by weak liaisons of the internal structure of the clay on the other hand for high mass concentrations of clay the deformation during the creep phase becomes weak and the system slowly relaxes in this case the liaisons of the internal structure of the clay becomes rigid.

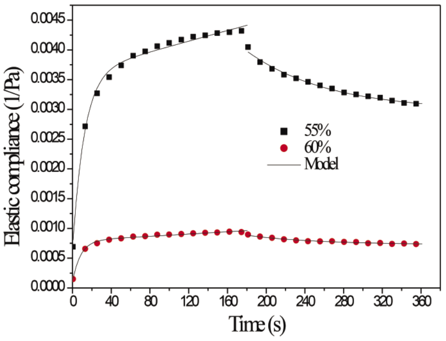

Fig. 6 Variation of elastic compliance of clay as a function of time (concentration : 55% and 60%)

6. ábra Agyag rugalmassági tulajdonságában változása az idő függvényében (55% és 60%-os kocentráció esetén)

The evolution of elastic compliance as a function of time for different mass concentrations of clay was correlated using the generalized Kelvin-Voigt model (*Eqs. 1* and *3*). *Fig. 7* shows a decrease in instantaneous elastic complianceJ_0 and retarded elastic compliance J_1 of Nedroma clay with mass concentration. On the other hand, *Fig. 8* shows an increase in Newtonian viscosity with the mass concentration of clay. Although these suspensions are initially formed from viscoelastic networks, they quickly disintegrate with concentration. A strong increase in Newtonian viscosity is observed for strong concentrations. In this case, the shear stress of 2 Pa is not sufficient to break weak particle-to-particle bonds of the clay and the suspension does not flow.

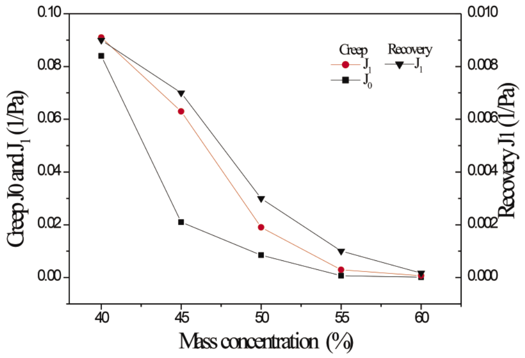

Fig. 7 Variation of instantaneous elastic compliance J_0 and retarded elastic compliance J_1 of Nedroma clay as a function of mass concentration

7. ábra Nedroma agyag J_0 pillanatnyi rugalmas összeférhetőségének és J_1 késleltetett rugalmassági tulajdonságának változása az agyagtartalom függvényében

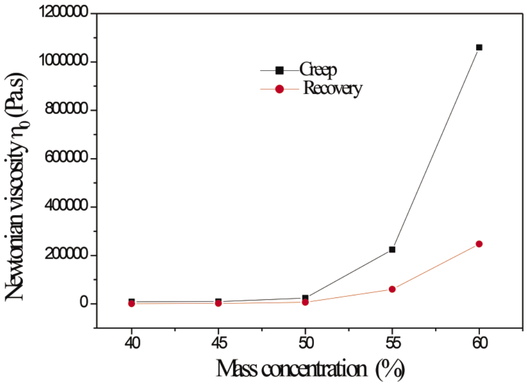

Fig. 8 Variation of Newtonian viscosity as a function of mass concentrations of clay

8. ábra A newtoni viszkozitás változása az agyagtartalom függvényében

4. Conclusions

The viscoelastic properties of clay and slip used in the manufacture of ceramic by New Company of Ceramic tiles of Remchi, Algeria at different times and mass concentration were studied. The generalized Kelvin-Voigt model was chosen to adjust the dependence of elastic compliance as a function of time for creep and recovery times range between 50 s and 700 s and mass concentrations range between 40% and 60% in solid particles. The increase in the creep-recovery applied time shows a slow increase in the Newtonian viscosity of the clay and of the slip corresponding to the steady state and of the instantaneous and delayed elastic compliance. For a creep-recovery time, the study shows that the concentration of 40% to 60% causes a rapid increase in the Newtonian viscosity of Nedroma clay. The study also shows a decrease in instantaneous elastic compliance J_0 and delayed J_1 of clay with mass concentration.

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