Rheological Modelling of Plaster Deposition for Painting Restoration

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Abstract:
This paper reports on the result of rheological modelling of plaster deposition for paintings restoration. A typical plaster recipe was changed in order to check the effect of water level on rheological properties, both performing oscillatory tests and measuring plaster viscosity at two different temperatures. A model based on momentum balance on a vessel-nozzle geometry for a shear thinning fluid was set-up to simulate the deposition process and numerical results were compared to experimental data. A good agreement was found for moderate deposition times. At high process time, due to phase-separation in plaster, a loss in matching between the simulation and experimental point was found, because the modelling assumption of "pseudo-homogeneous" behaviour does not apply anymore. Simulations allowed operating charts to be prepared reporting the deposited plaster volume as a function of the main process variables (temperature and pressure) and rheological properties of the plaster. This model could effectively support the development of an automatic deposition system able to recognise the filling volume over the painting surface and to control autonomously feeding of the plaster from a vessel through the deposition nozzle.

Zusammenfassung:
In diesem Artikel wird über die Ergebnisse der Modellierung der Gipsabscheidung bei der Restauration von Farbschichten berichtet. Eine typische Gipsformulierung wurde variiert, um den Einfluss des Wassergehalts auf die rheologischen Eigenschaften zu untersuchen. Dabei wurden sowohl Oszillationsexperimente als auch Viskositätsmessungen mit Gips bei zwei verschiedenen Temperaturen durchgeführt. Ein Modell basierend auf der Impulserhaltung in dem Container-Düse-System wurde für ein scherverdünnendes Fluid aufgestellt, um den Abscheidungsprozess zu simulieren. Die numerischen Daten wurden mit experimentellen Resultaten verglichen. Eine gute Übereinstimmung wurde bei mittleren Abscheidungszeiten festgestellt. Bei langen Prozesszeiten wurden Abweichungen zwischen den Simulations- und den experimentellen Daten aufgrund der Phasenseparation im Gips gefunden, da die Annahme eines „pseudo-homogenen" Verhaltens bei der Modellierung nicht mehr zutrifft. Durch die Simulationen konnten Diagramme erstellt werden, die das abgeschiedene Gipsvolumen als Funktion der wesentlichen Prozessvariablen (Temperatur und Druck) und der rheologischen Eigenschaften des Gipses beschreiben. Dieses Modell könnte die Entwicklung eines automatischen Abscheidungssystems effektiv unterstützen, das in der Lage ist, das Füllvolumen auf der Farboberfläche zu erkennen und die Abscheidungsmenge des Gipses automatisch zu kontrollieren.

Résumé:
Cet article traite de la modélisation rhéologique de la déposition de plâtres utilisés pour la restauration des peintures. Une recette typique de plâtre a été modifiée dans le but de vérifier l'effet de la quantité d'eau sur les propriétés rhéologiques, qui ont été caractérisées à l'aide d'essais oscillatoires et en mesurant la viscosité du plâtre à deux températures différentes. Un modèle basé sur l'équilibre de moments pour un fluide rhéo-amincissant dans une géométrie récipient-applicateur a été mis au point afin de simuler le procédé de déposition, et les résultats ont été comparés aux données expérimentales. Un bon accord a été trouvé pour les temps de déposition modérés. Pour des temps plus longs, et à cause de la séparation de phase qui prend place dans le plâtre, la simulation coïncide mois avec la donnée expérimentale. Ceci est du au fait que l'hypothèse de comportement « pseudo-homogène » faite lors de la simulation ne s'applique plus. Les simulations permettent de préparer des graphiques de fonctionnement qui présentent le volume de plâtre déposé en fonction de la variable principale du procédé (température et pression) et des propriétés rhéologiques du plâtre. Ce modèle pourrait aider efficacement le développement d'un système de déposition automatique capable de reconnaître le volume de remplissage sur la surface d'une peinture et contrôler de manière autonome l'alimentation du plâtre depuis le récipient jusqu'à la buse de déposition.

Key words: plaster, suspension, flow modeling, viscosity, collagen, painting restoration

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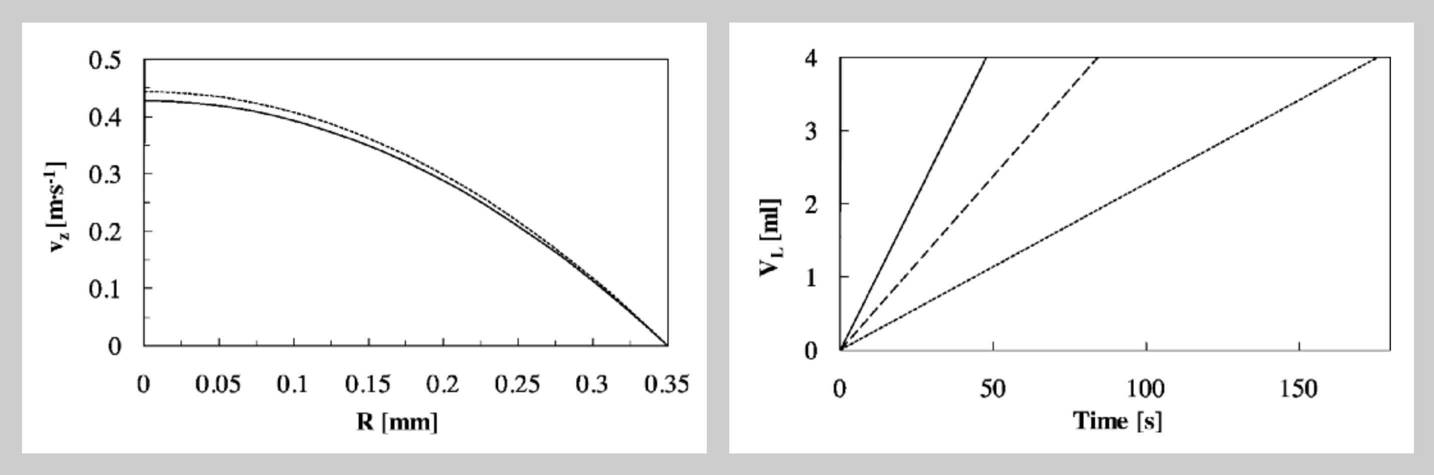

Figure 9 (left): Simulated data for the sample ST 1 at T = 37°C [-], T = 45°C [···] and P = 2 atm.

Figure 10: Operating curve for sample STD1 [-], STD2 [---] and STD3 [···] (T = 37°C and P = 2 atm).

ing samples at different water levels on the third day after the preparation because n decreases as the water level decreases (Table 3). Simulation results (Figure 8) revealed that velocity profile tend to be flatter for LW3 (i.e. when n decreases). In addition, the maximum in velocity is in agreement with the *k* trend for the three samples: the lower *k*, the lower the maximum in velocity. When the dependence of viscosity on temperature in considered, the data of Table 3 revealed a small variation of rheological parameters when the temperature is increased from 37 to 40°C. Simulation for sample ST1 (Figure 9) confirmed that, as an effect, the velocity profile did not change with temperature.

5.3 NUMERICAL RESULTS: OPERATING CONDITION EFFECTS

Simulation results, in term of plaster volume deposited from the nozzle, are reported for all samples and investigated days at different operating conditions (temperature and pressure) as a function of time. This use of the predictive tool allows the drawing of characteristic operating curves as temperature, pressure and application day function for all the investigated materials. As a consequence of the model validation, the plaster volume is calculated up to 4 ml because the nozzle model matches the experimental results up to this volume value, as an effect of solid deposition in the vessel. Figure 10 reports simulation results when the application day is changed for sample STD. The simulation results show that extrusion process time increases with the application day as an effect of the rheological properties variations. Specifically, the consistency index k on day 3 becomes three times the value of day 1. This simulation reveals that plaster application on the third day is less convenient and the same effect was found when changing the water level because the viscosity has the same trend with time for all the samples. In Figure 11(a)-(i) are reported operating curves for all the plasters analysed at two temperature and pressure values.

Simulation results show that the plaster extrusion process is faster at high pressure ensuring both that the plasters flow through the nozzle and faster processes for a quick restoration. Moreover, simulations revealed that sample LW3 cannot be extruded at low pressure, in reasonable times, because of its high consistency index value (Table 3). In this case increasing the pressure is the only way to deposit this very consistent material, therefore only simulations at 2atm are shown in Figure 11. For all the samples, the results also confirmed that temperature does not affect the material behaviour because of the weak dependence of viscosity on temperature in the considered range.

6 CONCLUSION

This work reports the results of a research project aimed at supporting the development of an automatic device for crack filling in the restoration of ancient paintings by plaster deposition. These special plasters are water-based suspensions of calcium sulphate dihydrates and animal glue. Some characteristic formulations were rheologically characterised. Results showed a viscoelastic behaviour in the linear region under small amplitude oscillation conditions. Dynamic tests allowed both to define the best performing formulation on the base of mechanical parameters and to fix the temperature application range of the plaster. In addition steady tests showed that the investigated materials exhibit a marked shear thinning behaviour and viscosity is sensitive both to water level and maturation degree (time dependence).

With a view to a complete automation of the crack filling process, a simulative model of the plaster flow through a nozzle under constant pressure was set up. The model allows the calculation of the plaster flow rate under different process conditions and for different properties of the material. Model results in terms of mass injected plaster as a time function were compared successfully with experimental data, even

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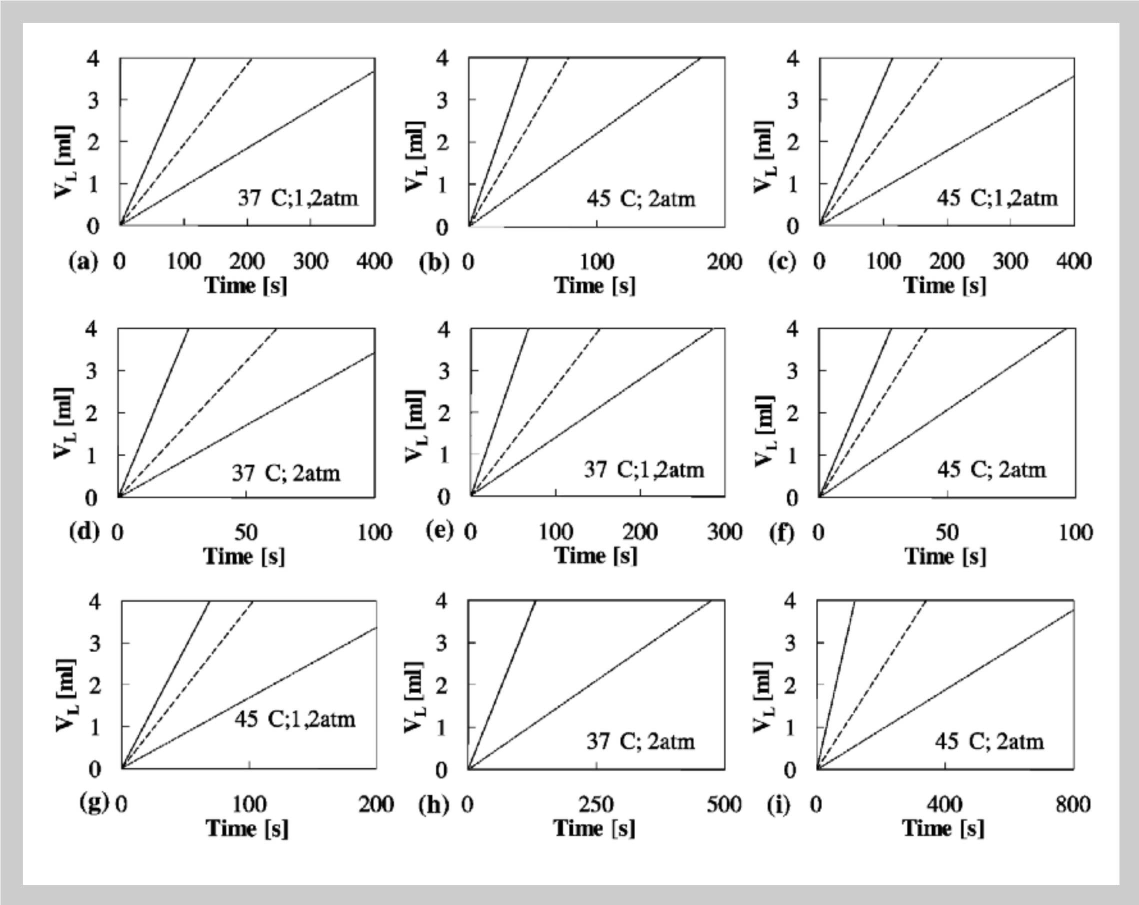

Figure 11: Operating curves for samples STD [a, b, c], HW [d, e, f, g] and LW [h, i] (day 1 [-], day 2 [---], day 3 [···]).

though the agreement is poor at long deposition times. This effect was attributed to the poor stability of the plaster, causing phase separation in the storage vessel. On the other hand, when short application times are considered, the model is able to predict the plaster flow rate as a function of the main operating conditions and rheological parameters. Simulation at different conditions allowed operating charts to be prepared that can be useful in supporting the development of a crack filling device prototype, able to deposit the appropriate amount of plaster after the volume identification and quantification.

REFERENCES

[1] Nevin A Cather S Anglos D Fotakis C: Analysis of protein-based binding media found in paintings using laser induced fluorescence spectroscopy, Anal. Chim. Acta 573/574 (2006) 341-346.

[2] Popescu C M Dobele G Rossinkaja G Dizhbite T Vasile C: Degradation of lime wood painting supports: Evaluation of changes in the structure of aged lime wood by different physico-chemical methods, J. Anal. Appl. Pyrolysis 79 (2007) 71-77.

[3] Ar›oglu N and Acun S: A research about a method for restoration of traditional lime mortars and plasters: A staging system approach, Build. Environ. 41 (2006) 1223–1230.

[4] Arcolao C: Le ricette del restauro - Malte, intonaci, stucchi dal XV al XIX secolo. Marsilio Editori, Venice (1998) 57-59.

[5] Matteini M Moles A: La chimica nel restauro - I materiali dell'arte pittorica. Nardini Editore, Florence (1989) 65-70, 192-196.

[6] von Endt D W Baker MT: Protein Chemistry for Conservators, ed C L Rose D W von Edt. American Institute for Conservation of Historic and Artstic Works, Washington DC (1984).

[7] Cauflin B Lapasin R Papo A :Rheological behavior of gypsum plaster pastes, Ind. Eng. Chem. Process Des. Dev. (1985) 24 49-53.

[8] Colussi I Lapasin R Papo A: Shear-Dependent behavior of gypsum plasters, Ind. Eng. Chem. Process Des. Dev. (1982) 21 514-21516.

[9] Gmouh A Eve S Samdi A Moussa R Tricha L Aazzab B Hamel J Gomina M: Development and validation of a dimensional variation measurement set-application to the plaster setting, Mater. Sci. Eng. A-Struct. Mater. Prop. Microstruct. Process. (2004) 372 123–127

[10] Gabriele D de Cindio B D'Antona P: A weak gel model for foods, Rheol. Acta 40 (2001) 120-127.

[11] Bird R B Steward WE Lightfoot EN: Transport phenomena. John Wiley and Sons, New York (1960).

[12] Tanner RI: Engineering rheology. Clarendon Press, Oxford (1985).

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