Memory of flow in paste and its visualization as crack pattern

Lab. of Physics, Coll. of Science and Technology, Nihon Univ.
A. Nakahara[1], Y. Shinohara, S. Inagaki, A. Katsuki and Y. Matsuo

ペースト（高濃度のコロイドサスペンション）が揺れや流れを記憶することを実験的に見出した。これらの記憶は、ペーストを乾燥させて収縮破壊を起こさせた際に生じる亀裂パターンとして可視化できる。流れを流線としてペーストに記憶させることによって、リングやスパイラルなどの様々な形状の亀裂パターンを自在に作成できるようになった。

1. Crack formation in drying process

We prepare densely packed colloidal suspension, i.e., paste, by mixing powder such as calcium carbonate with water. When the paste is dried, water evaporates, paste shrinks, and if the paste sticks to the bottom of the container, paste divides itself into smaller fragments to release the stress induced by the shrinkage. Usually, crack pattern becomes isotropic and cellular, as shown in Fig. 1, with sizes of these fragments almost same as the thickness of the paste.

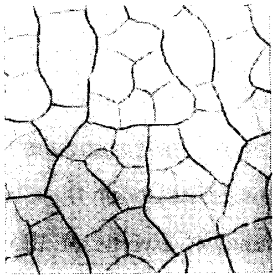

Fig. 1: Isotropic and cellular crack pattern

2. Memory of paste: Type I—Memory of vibration

When we vibrate a paste horizontally for a short time before drying and the strength of the vibration is just above the value of the yield stress of the paste, we find that paste remembers the direction of the initial vibration. Due to the plasticity, paste maintains the longitudinal density fluctuation of densely packed colloidal particles induced by initial vibration even after the vibration is removed. The memory in paste is visualized as anisotropic crack patterns, such as lamellar, with directions of these cracks all perpendicular to the direction of the initial vibration [1-2].

3. Memory of paste: Type II – Memory of flow

On the other hand, when we use some powders, such as magnesium carbonate hydroxide or carbon, to make paste, we find that these pastes have two kinds of memories, one is a memory of vibration (Type—I) and the other is a memory of flow (Type—II). The transition from Type—I to Type—II memory is obtained by decreasing the solid volume fraction in paste ρ or by increasing the strength of the vibration, as shown in Fig. 2. Note that in Fig. 2(b) which shows the memory of flow, directions of lamellar cracks are no longer perpendicular to the direction of the vibration. They are parallel to the directions of flows induced by the initial vibration [3].

[1]E-mail : nakahara@phys.ge.cst.nihon-u.ac.jp

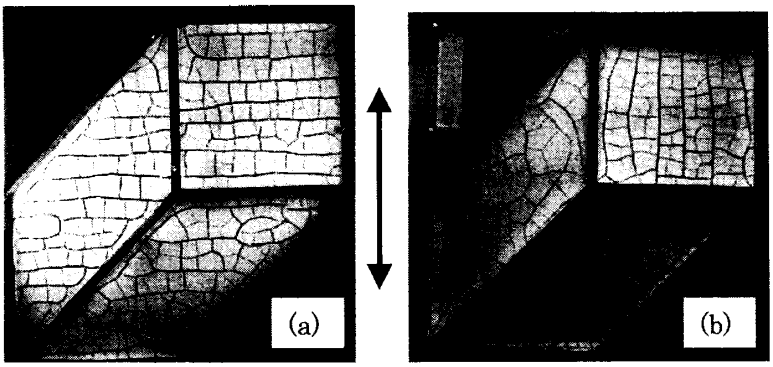

Fig. 2: Transition of memory of paste. (a) Type −I memory of vibration, (b) Type − II memory of flow. The arrow indicate the direction of the initial vibration

4. Morphological phase diagram of crack patterns

To investigate the mechanism of the transition of memory, we perform experiments changing the value of the solid volume fraction in paste ρ at the initial vibration and also the strength of the initial vibration. Results are summarized as Fig. 3. The solid guide curve represents the yield stress of paste. The vertical dotted and dash-and-dotted guide lines represent liquid-limit at ρ=4% and plastic-limit ρ=18%, respectively. In region A below the yield stress curve, since paste did not move at all, it has no memory of vibration, so we have cellular crack pattern. In region B just above the solid yield stress curve, paste is vibrated by the initial vibration so it has a memory of vibration. On the other hand, in region C where flow appeared at the initial vibration, paste has a memory of flow. In region D turbulent flow blows up memory from paste and we again have cellular crack pattern.

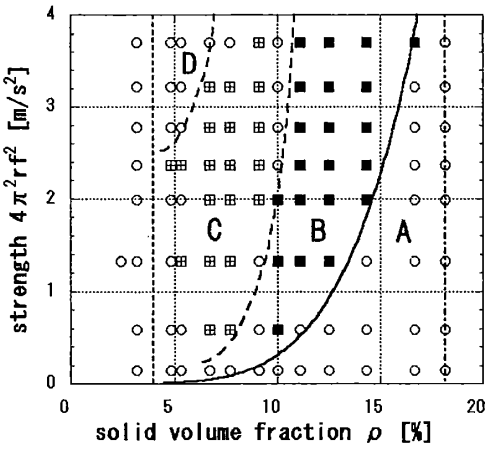

Fig. 3: Morphological phase diagram of crack patterns, shown as a function of a solid volume fraction ρ and a strength of the initial vibration. ○(regions A, D): isotropic cellular crack patterns, ■(region B): Type − I lamellar crack patterns with memory of vibration, ⊞(region C): Type − II lamellar crack patterns with memory of flow [3].

Then, why some pastes have two types of memories? We find that colloidal particles interact only via van der Waals attractive interaction. The lack of Coulombic repulsion allows a formation of dilute network structure even at low solid volume fraction, so it can be elongated along the direction of flow. Also the alignment of disk-like particles plays role.

Since paste can remember flow pattern, we can design various crack patterns, such as lamellar, radial, ring and spiral by changing the shape of container and the way of shaking.

References

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