

Glassy behavior of two-dimensional driven granular matter

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液体-ガラス転移の機構解明は長年の未解決問題である。近年の数値計算により、過冷却液体中に結晶的中距離秩序が存在することが示され、これが動的不均一性や緩和時間の増大の起源である可能性が示唆された。この結果を検証するため、我々は駆動下2次元粉粒体系を用いたモデル実験を行った。粒径分散が結晶化を阻害するため、長距離の構造は乱れているものの、中距離の結晶秩序が存在し、その分布が運動の遅い粒子の分布と一致することを見出した。さらに、結晶的中距離秩序の発達と緩和時間の増大との相関を観測し、ガラス化に伴うスローダイナミクスにおける結晶的中距離秩序の重要性を実証した。

Understanding the mechanism of the liquid-glass transition is one of the most long-standing problems in condensed matter physics. The main difficulty comes from the fact that there is little change in the static structure of a liquid while the characteristic time dramatically increases as the transition point is approached. Recent studies have shown the existence of a growing dynamic correlation length associated with dynamic heterogeneity [1]. Furthermore, it was demonstrated numerically that medium-range crystalline order is formed in supercooled liquids, and it may be responsible for both dynamic heterogeneity and the increase of relaxation time [2, 3].

In order to check experimentally the validity of the above numerical results, we study vertically vibrated two-dimensional granular matter (i.e., monolayer of particles) as a model system of the liquid-glass transition. In this system, the transition between solid-like state and liquid-like state is known to occur as a function of shaking amplitude or packing fraction [4, 5]. Here we introduce polydispersity in the particles, which is often used in colloidal systems to prevent crystallization. Indeed, as the packing fraction is increased, the liquid-glass transition occurs; namely, the relaxation time increases while the long-range structure remains liquid-like.

Using this model system, we now study the main issue, that is, whether the correlation between dynamics and medium-range crystalline order also exists in this system. Figure 1(a) is the trajectory of particle motion over the structural relaxation time τ_α , which clearly shows the existence of dynamic heterogeneity. Crystalline order, on the other hand, is evaluated by

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the bond-orientational order parameter $\psi_6^j = (1/n_j) \sum_k \exp(i6\theta_{jk})$ for each particle j , where the sum runs over the n_j nearest neighbors of particle j , and θ_{jk} is the angle between the bond $\vec{r}_k - \vec{r}_j$ and the x -axis. In order to eliminate short-time fluctuations, we calculate the time-averaged order parameter as $\Psi_6^j = (1/\tau_\alpha) \int_{t'}^{t'+\tau_\alpha} |\psi_6^j| dt$. From the spatial distribution of Ψ_6^j (see Figure 1(b)), we confirm that medium-range crystalline order indeed emerges, and that clusters with high crystalline order correspond to the region of slow particles. We also observed that the crystalline correlation length ξ monotonically grows as the packing fraction is increased, and the fitting indicates ξ and τ_α diverge towards the same packing fraction. This simple relationship between the length scale ξ and the time scale τ_α may be the essence of the mechanism of slow dynamics. These experimental results, together with the previous numerical ones, suggest a new possibility to understand liquid-glass transition based on medium-range crystalline order.

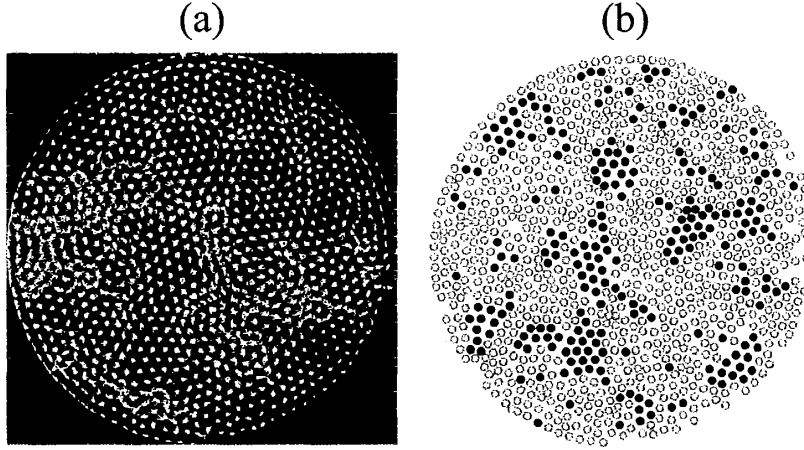


Figure 1: Relationship between dynamic heterogeneity and medium-range crystalline order. (a) Trajectory of particle motion over the structural relaxation time τ_α . (b) Spatial distribution of the time-averaged order parameter Ψ_6^j . Closed and open circles represent the positions of ordered ($\Psi_6^j \geq 0.75$) and disordered particles respectively.

References

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