The rheology of highly concentrated suspensions for powder injection molding

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INTRODUCTION

Suspensions are one of the first and relevant objects of interest for rheology. This is determined by the great diversity of suspensions in nature, various fields for their technical and every-day application, as well as the scientific interest in the fundamental relationships between the structure and properties of matter. In our study, we considered the rheological properties of of noncolloidal model suspensions for powder injection molding (PIM) with varying concentrations of a solid phase (Al powder) in oligomeric polyethylene glycol. The most detailed experiments were devoted to the concentration range up to 60 vol. %. This range of the highly concentrated suspensions (HCS) state is of special interest for the PIM technology.

OBJECTS

An object for this study is model systems which are 55 and 60% suspensions of aluminum powder (trademark PAD-1 produced by Valkom-PM, Ltd, Russia) dispersed in low-molecular weight (M=400) poly(ethylene glycol) (trademark PEG-400, produced by OOO Syntanol Production, Ltd, Russia) with the viscosity of 0.11 Pa·s at 25 °C. The average size of Al particles is 24 μm and their density is 2700 kg/m3.

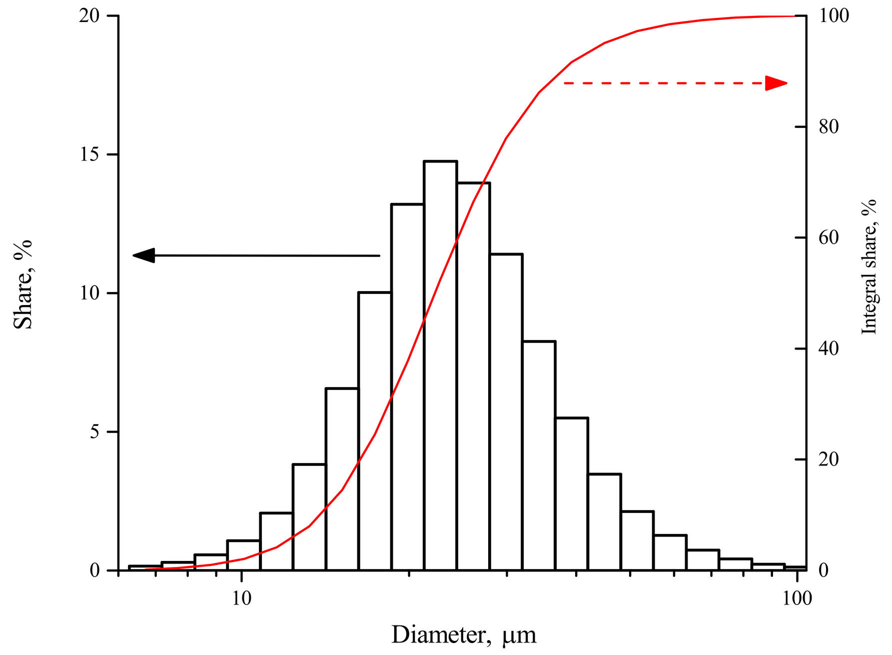

Fig. 1 Size distribution of the Al particles

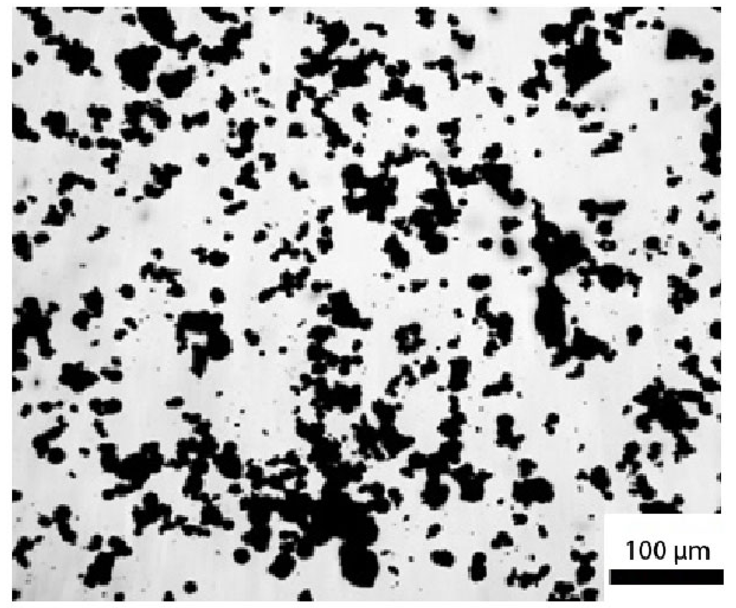

Fig. 2 Micrograph of the Al powder

METHODS

- Size distribution mesurment - performed using analyzer LA-350, HORIBA, Japan
- Scanning Electron Microscopy - microscope JSM-6510 LV, JEOL, Japan
- Rotational rheometry - performed on a rheometer RS-600, ThermoHaake, Germany

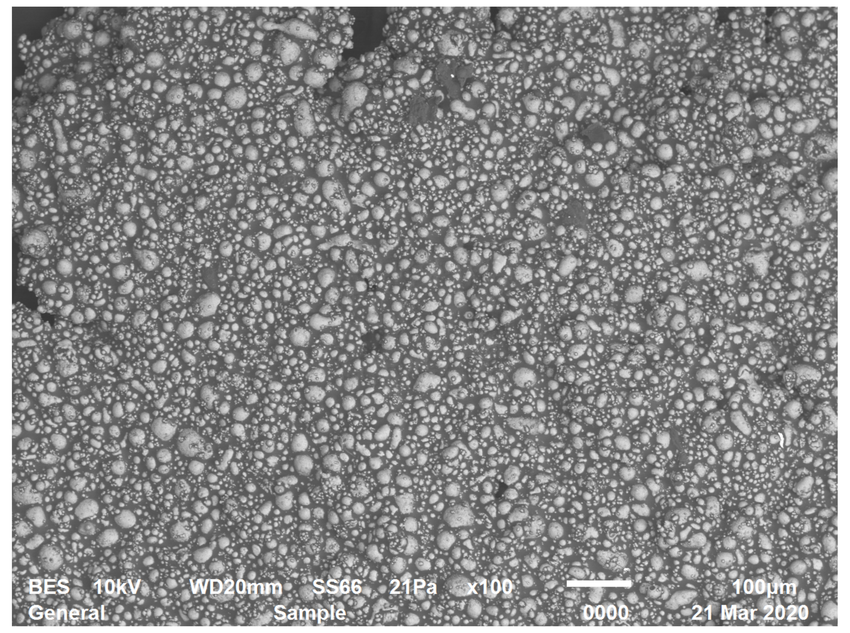

Fig. 3 Microphotograph of a 60% suspension

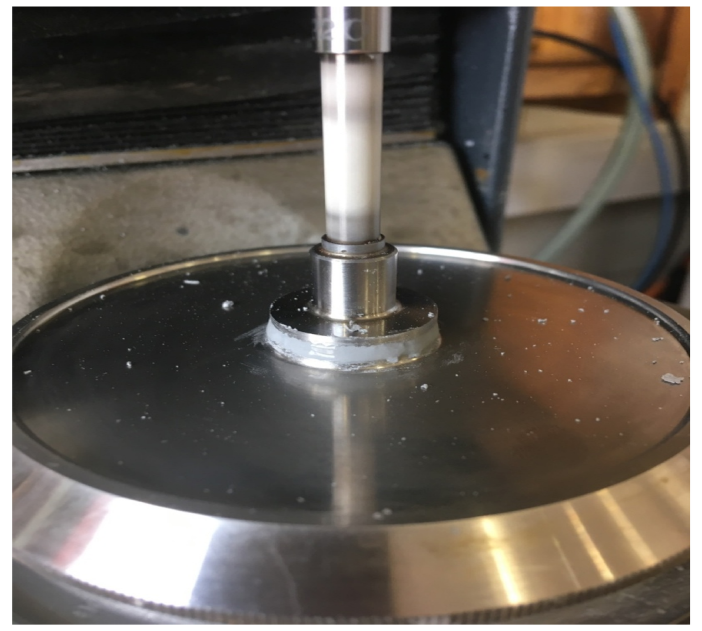

Fig. 4 Photo of 55 % of the sample during the experiment

The rheological properties of the suspensions were measured using two operating units having the geometry of parallel disks with a radius of 20 mm and a gap between them of 1.5 mm. In addition, the original shear device for inducing the squeezing flow with parallel plates was used.

RESULTS

A. Properties of HCS under shearing.

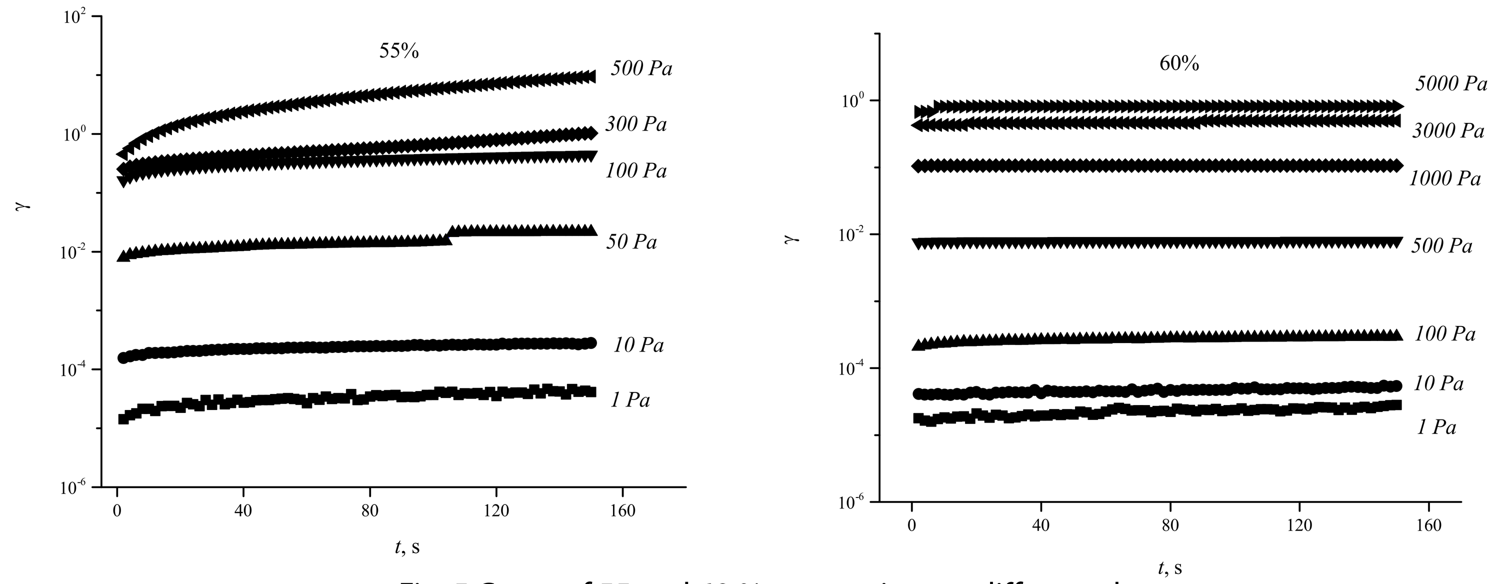

Fig. 5 Creep of 55 and 60 % suspensions at different shear

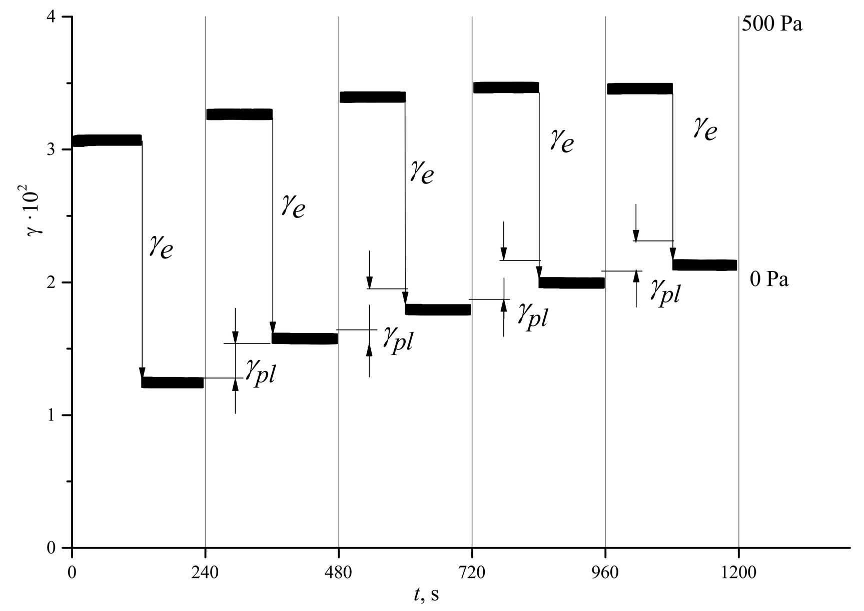

Fig. 6 Changes in elastic and plastic deformation in a cyclic loading-unloading mode for 60% suspension

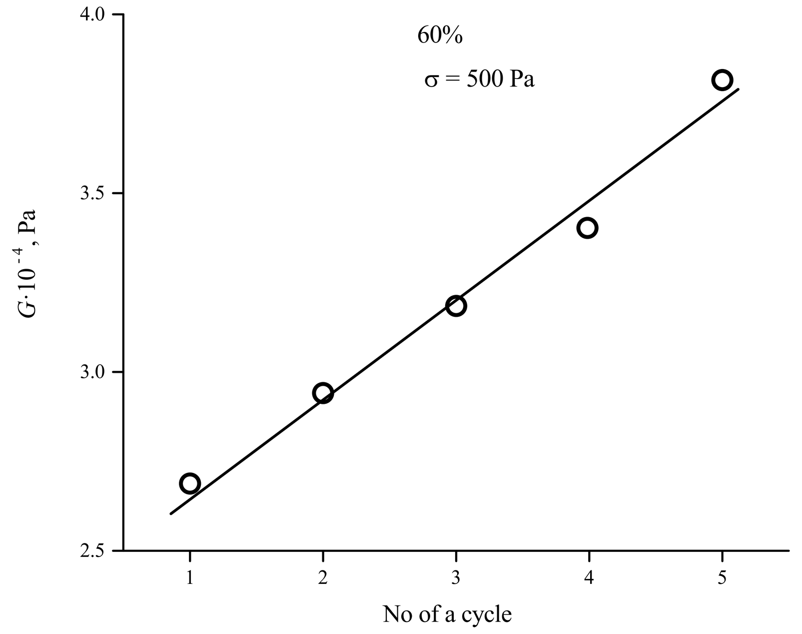

Fig.7 The increase in the elastic modulus of a 60% suspension with consecutive cycles of loading-unloading under a stress of 500 Pa.

B. Properties of HCS under compression (squeezing).

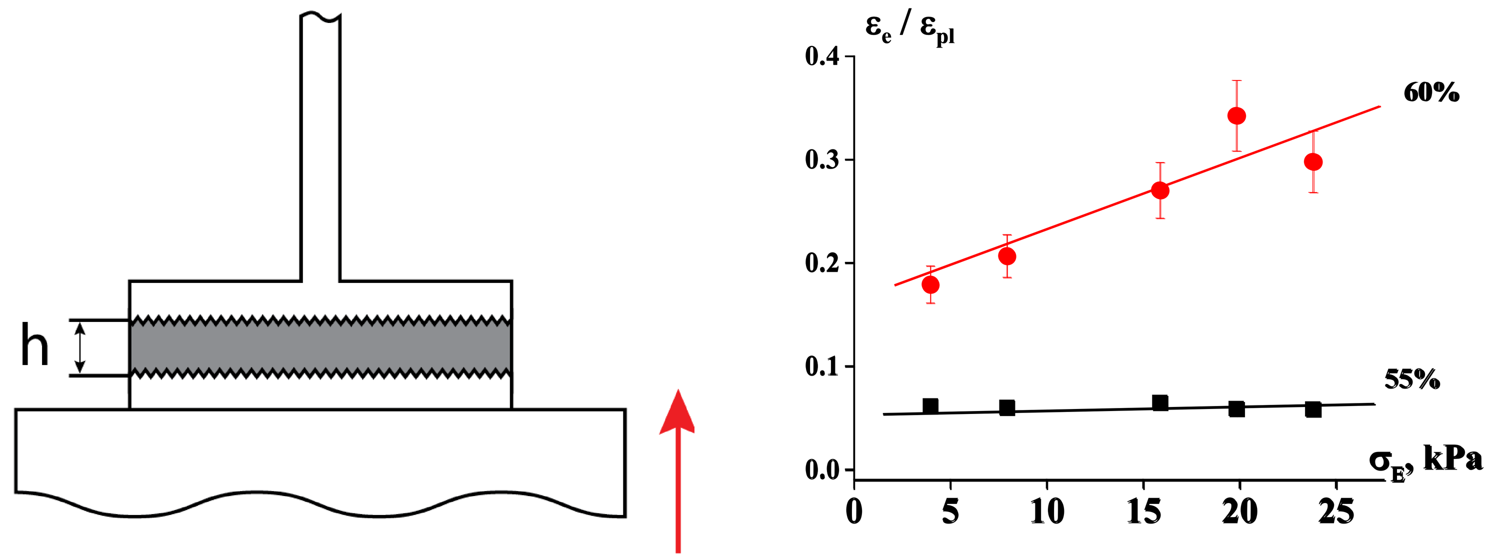

Fig. 8 Relationship between elastic and plastic components of the total deformation during compression.

C. Properties of HCS under superimposed compression and shear.

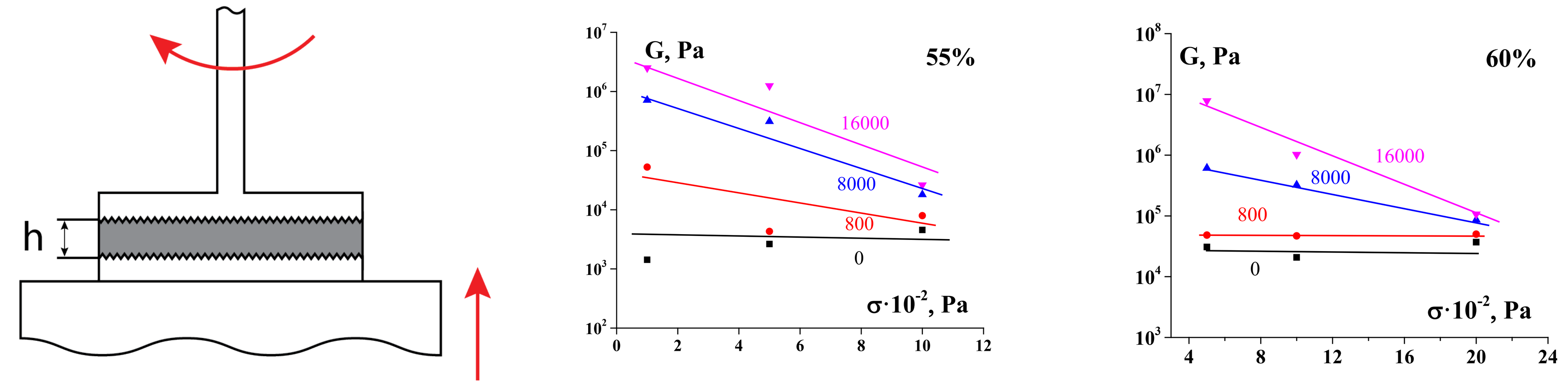

Fig. 9 Shear modulus as function of shear stress at different compression stresses.

CONCLUSIONS

- In a narrow range of concentrations close to 55%, suspensions are viscoplastic and preserve fluidity with superimposed elasticity.
- The experimental results can be presented in the form of a stress-concentration diagram reflecting the different types of rheological states of suspensions (fig.10). The last concentration domain corresponds to the "colloid" glass transition (or gelation), and suspensions with a solid phase content of 60% and more(HCSs) are elastoplastic media that possess dominating plasticity. This is understood as the ability to undergo irreversible deformation under shearing and compression, which (in opposition to flow) is limited, and the value depends on the stress.
- Repeated shearing in the loading-unloading mode leads to a decrease in elastic deformation and to a remarkable growth of the shear elastic modulus.
- Compression does not lead to squeezing flow, but does promote limited plastic deformations due to the local jamming.
- The shear modulus of compressed samples increases with the growth of normal stress.

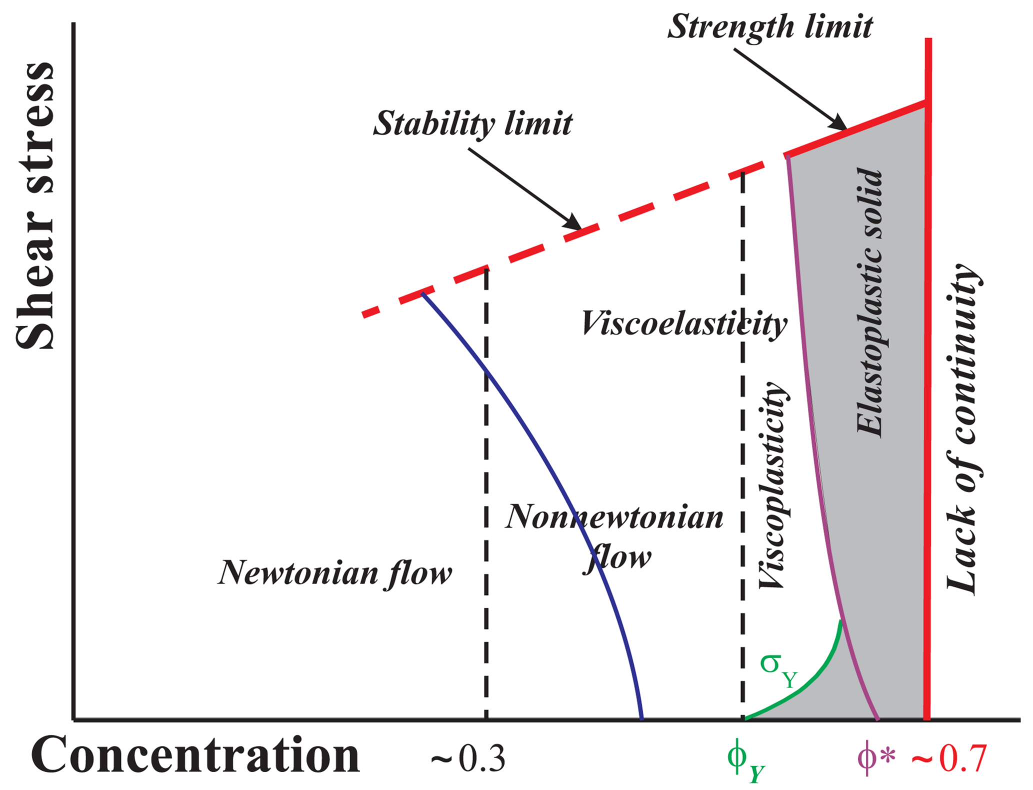

Fig. 10 Diagram of rheological states of concentrated suspensions including a domain of HCS. The solidlike state is shown as a shaded area.

ACKNOWLEDGEMENTS

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