# Continuous twin-screw extrusion and rheological analysis of electrode slurries for optimizing lithium-ion battery manufacturing

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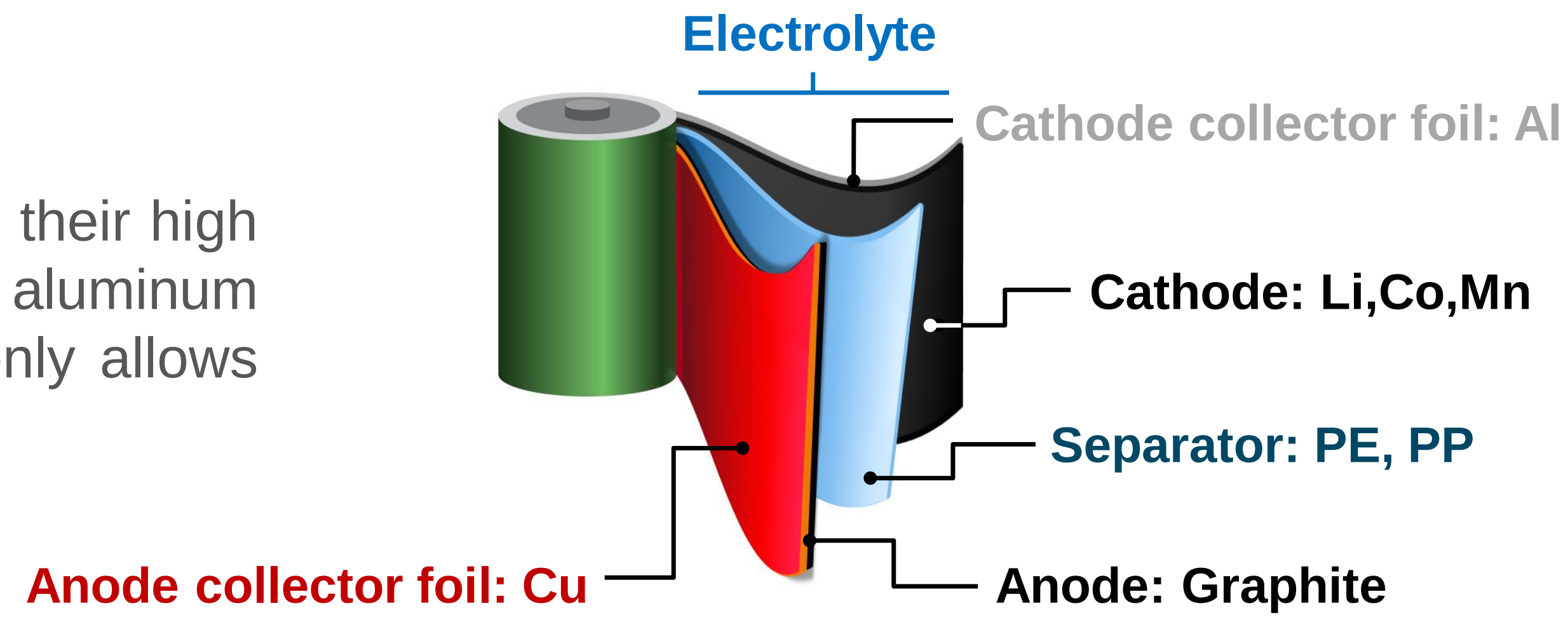
## INTRODUCTION

Lithium-ion batteries (LIBs) are widely used in portable electronics, electric vehicles, and grid storage due to their high energy density and long cycle life. LIBs consist of a graphite-coated copper foil, which acts as the anode, an aluminum foil coated with active materials as the cathode, and a polymer film that separates both electrodes and only allows lithium ions to pass. A liquid electrolyte in which lithium salt is dissolved completes the setup:



The lithium-ion battery manufacturing involves many steps, including preparing and coating anode and cathode slurries. Proper mixing of the individual components and a homogenous coating process are essential for achieving batteries with a high capacity and many available charging cycles.

## SLURRY MANUFACTURING

Continuous twin-screw compounding for manufacturing electrode slurries is a compact energy-saving alternative to the use instead of planetary batch mixers and offers the following advantages:

Finer dispersion
- Twin-screw extruders provide better distributive and dispersive mixing than dissolvers

Reduced amount of solvents
- Solvents drying and recycling is highly energy consumptive
- Strong shear forces acting onto the material allow to reduce the solvent content of electrode pastes

Scalability
- Volume to surface ratio varies less than in batch mixers
- Good scalability from lab to production

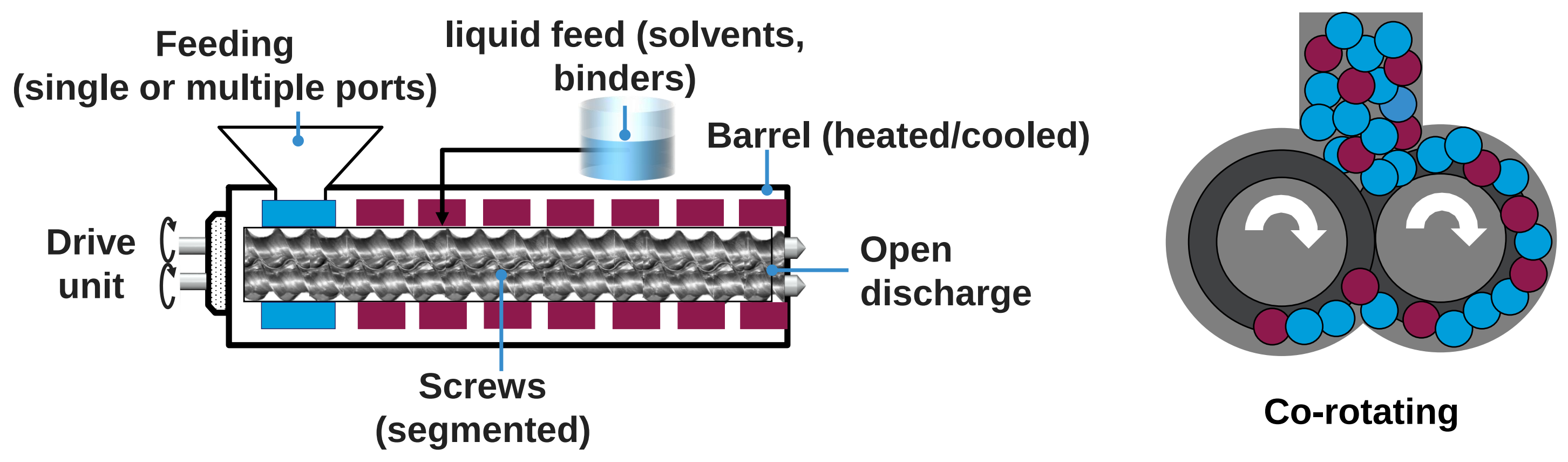


Fig.1 Working principle parallel twin screw extrusion

### Materials

Cathode slurries were prepared from the following raw ingredients:

- Solvent: water
- Active ingredient: LiFePO4 (LFP)
- Conductive agent: carbon black (CB)
- Binder: CMC/SBR

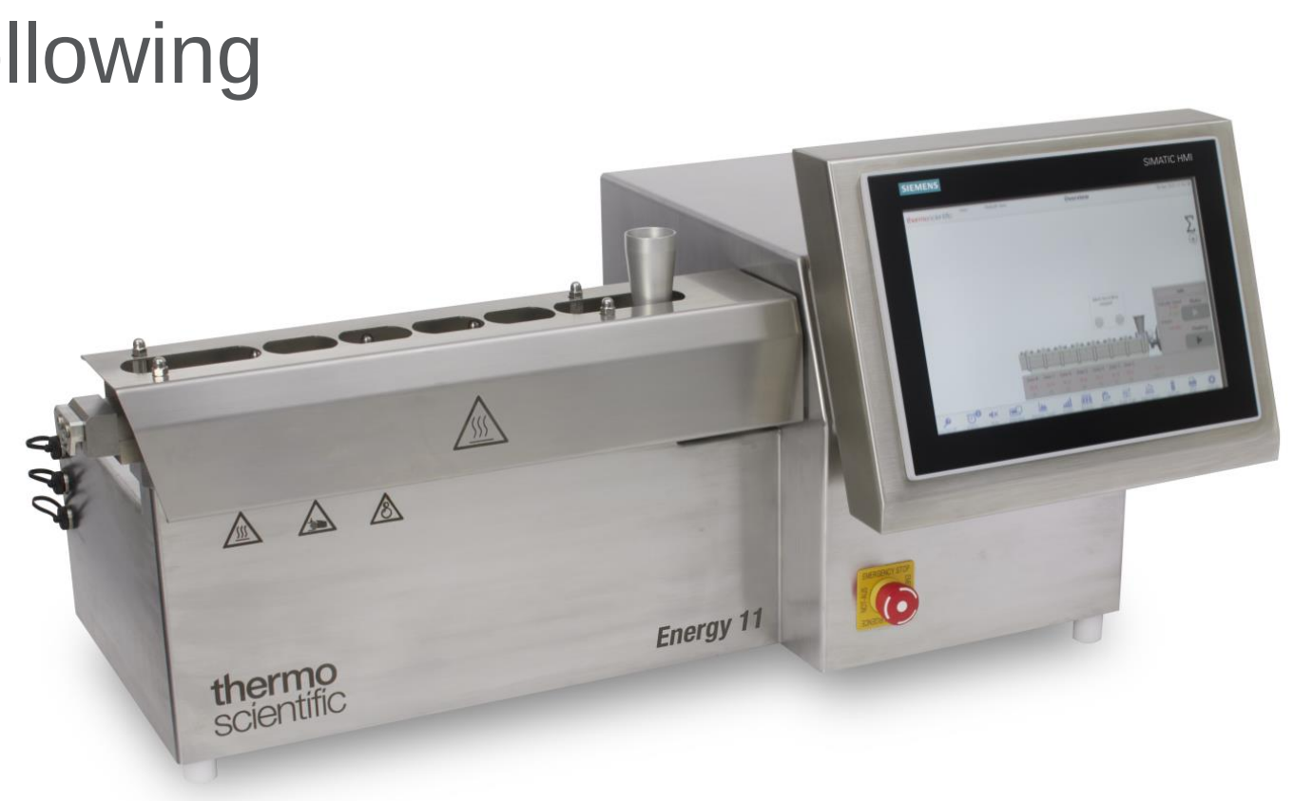


Fig.2 Thermo Scientific™ HAAKE™ Energy 11 Twin screw extruder

### Extrusion

Slurries were prepared using a Thermo Scientific™ HAAKE™ Energy 11 Twin Screw Extruder (Fig.2) with a two-stage mixing screw at room temperature. Solids were dosed into the extruder with a gravimetric twin-screw feeder and water was dosed with a peristaltic liquid pump. The solid content was set to 50% with a total mass flow of 800 g/h. Samples were collected at 120 rpm or 1000 rpm screw speed. A sample with 43% solid content mixed at varying screw speed was also collected.

### Scanning Electron Microscopy

Fig.3 Thermo Scientific™ Phenom™ G2 Desktop SEM

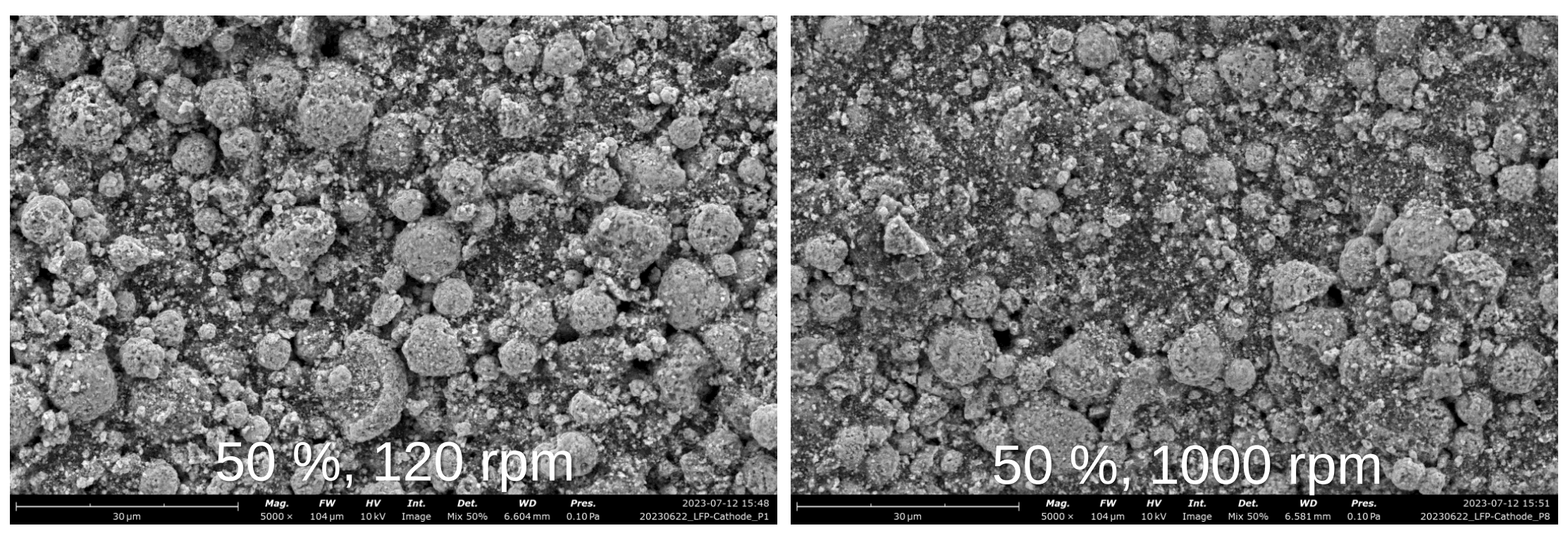


Fig.4 SEM images of cathode slurries

## RHEOLOGICAL ANALYSIS OF BATTERY SLURRIES

Rotational and oscillatory rheometry enables the quantification of the viscoelastic properties needed to

- verify a proper mixing and a homogeneous distribution of active components within the electrode slurries.
- predict storage behavior and stability.
- understand behavior during the coating process

Fig.5 Thermo Scientific™ HAAKE™ MARS 60 Rheometer

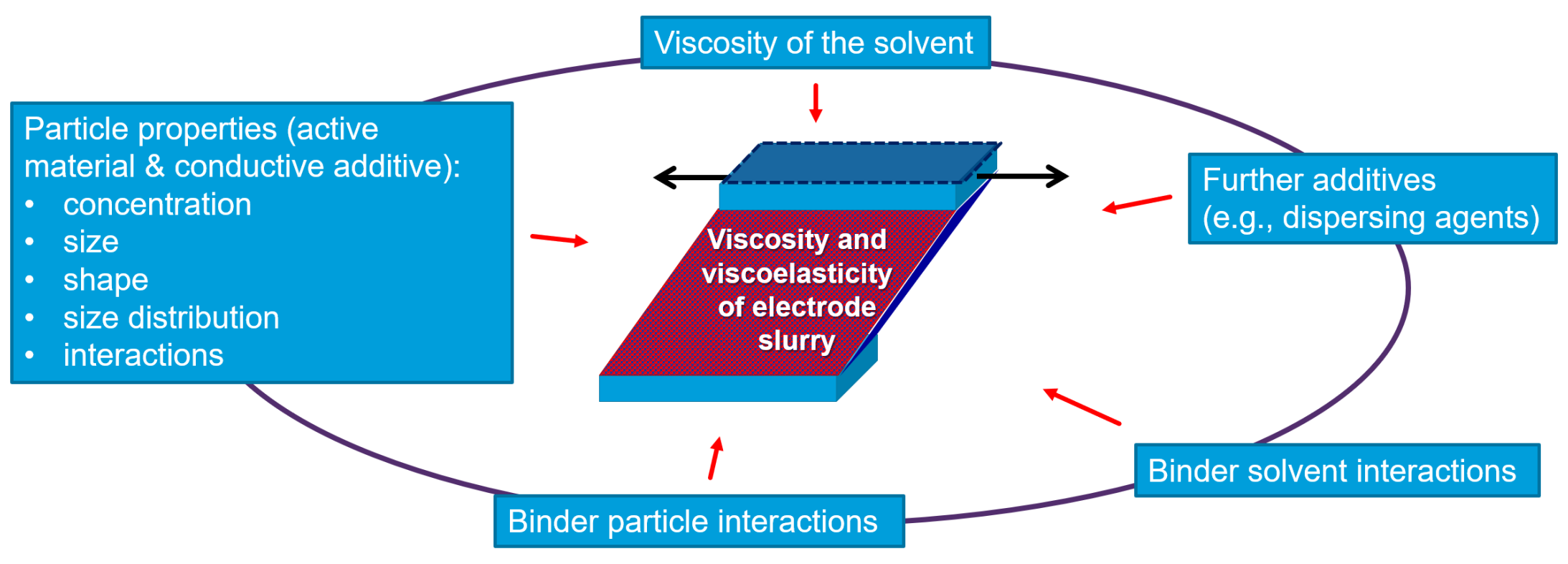


Fig.6 Factors influencing the rheology of battery slurries

### Rheological testing methods

Rheological measurements were performed using a Thermo Scientific™ HAAKE™ MARS™ 60 rheometer equipped with a 35 mm parallel-plates geometry with sandblasted surfaces and a Peltier temperature control module (Fig.3). The measuring gap was set to 0.5 mm and the following tests were performed at 20 °C:

- Strain amplitude sweep (LVR, slurry stability)
- Frequency sweep (printing properties, electrochemical performance)
- Shear stress ramp for yield stress determination (slurry stability)
- Creep test for zero shear viscosity determination (slurry stability)
- Steady state shear viscosity (slurry stability, printing properties)
- Shear recovery test for thixotropy determination (stability, printing properties)

### Results

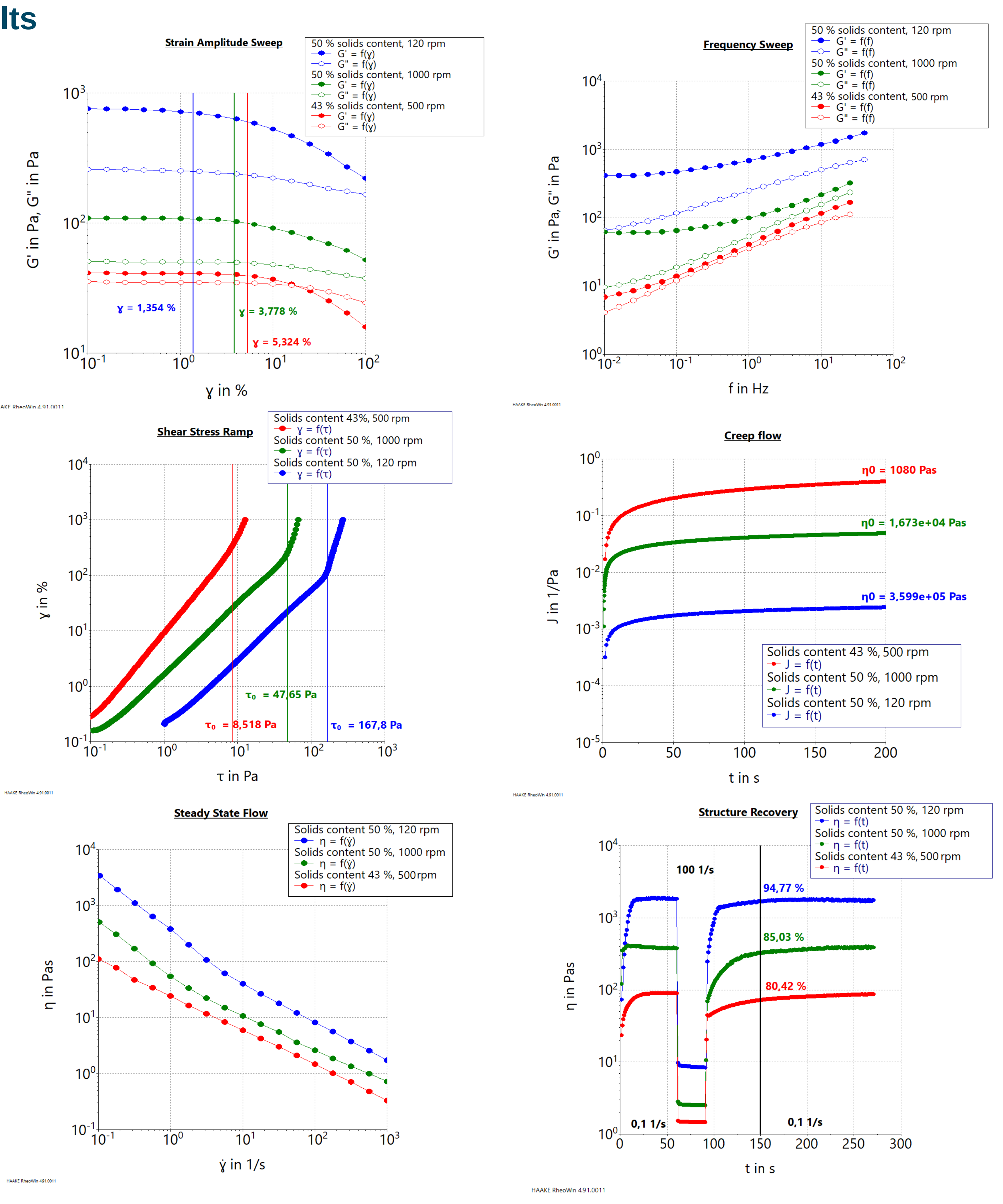


Fig.7 Results of rheological characterization

## CONCLUSIONS

- All slurries showed viscoelastic properties and yielding behavior.
- Viscosity, firmness and network (gel) character were increasing with increasing solids content.
- Higher shear forces during slurry compounding reduced final shear viscosity, firmness and gel character of the cathode slurry.

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