Magnetic Properties of Simulated Fault Gouges from the Seismogenic Groningen Gas Field

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1. Introduction

The Groningen gas field (NE Netherlands) stands as one of the largest onshore gas fields in the world. In recent years, a substantial number of induced earthquakes (maximum magnitude ML = 3.6 occurred in 2012) has sparked considerable public concern. Knowledge of the mechanical behavior of fault gouge is indispensable to decipher the mechanics of fault motion, induced seismicity, and associated hazards. Recently, friction experiments of fault gouges and resultant changes in rock magnetic properties were proposed as a diagnostic tool to trace elevated temperature and/or fluid motion tied to seismic activity.

2. Methods and facilities

Here we focus on the rock magnetic properties of powdered natural samples of the Slochteren sandstone, the reservoir rock of the Groningen gas field, sheared experimentally under both dry and wet conditions and slip velocities between 1 and 50 mm/s with 2.5 and 5 MPa normal stress. High-field thermomagnetic runs, acquisition curves of the isothermal remanent magnetization and anhysteretic remanent magnetization at room temperature, and low-temperature hysteresis loops were measured.

	r218	r210
Stress	5 MPa	2.5 MPa
Pore_fluid_composition	none	DI water
Shearing velocity	10-1000 μm/s	5 cm/s

Figure 1. Magnetic measurement facilities employed for our research

3. Results

- **Magnetization-temperature curves (Fig. 2)**

r402_Starting material: heating and cooling curves are almost reversible; continuous decrease between room temperature to 350 ℃.
r218_dry condition: new magnetic mineral is formed during cooling.
r210_wet condition: drops to zero at ~750 ℃; new magnetic mineral is formed during cooling.

- **Low-temperature hysteresis loops (Fig. 3)**

Bc of ~30 mT in r402 and r218; Bc of ~15 mT in r210.

- **Low-temperature ZFC and IFC M-T warming curves (Fig. 4)**

Discontinuities at ~35K and 120K in both heated and unheated curves of sample r402; Discontinuities at ~35K and 120K in unheated curves of sample r218; Discontinuity at ~35K in unheated curves of sample r210.

- **IRM acquisition curves (Fig. 5)**

r402 and r218: reach 70-80% saturation at ~300 mT, not saturation at 2.5T;
r210: reach 90% saturation at ~200 mT, saturating at 0.5T (unheated) and 1.5 T (heated to 1053K).

- **χ/χ_{ARM} values (Fig. 6):** lower than 100.

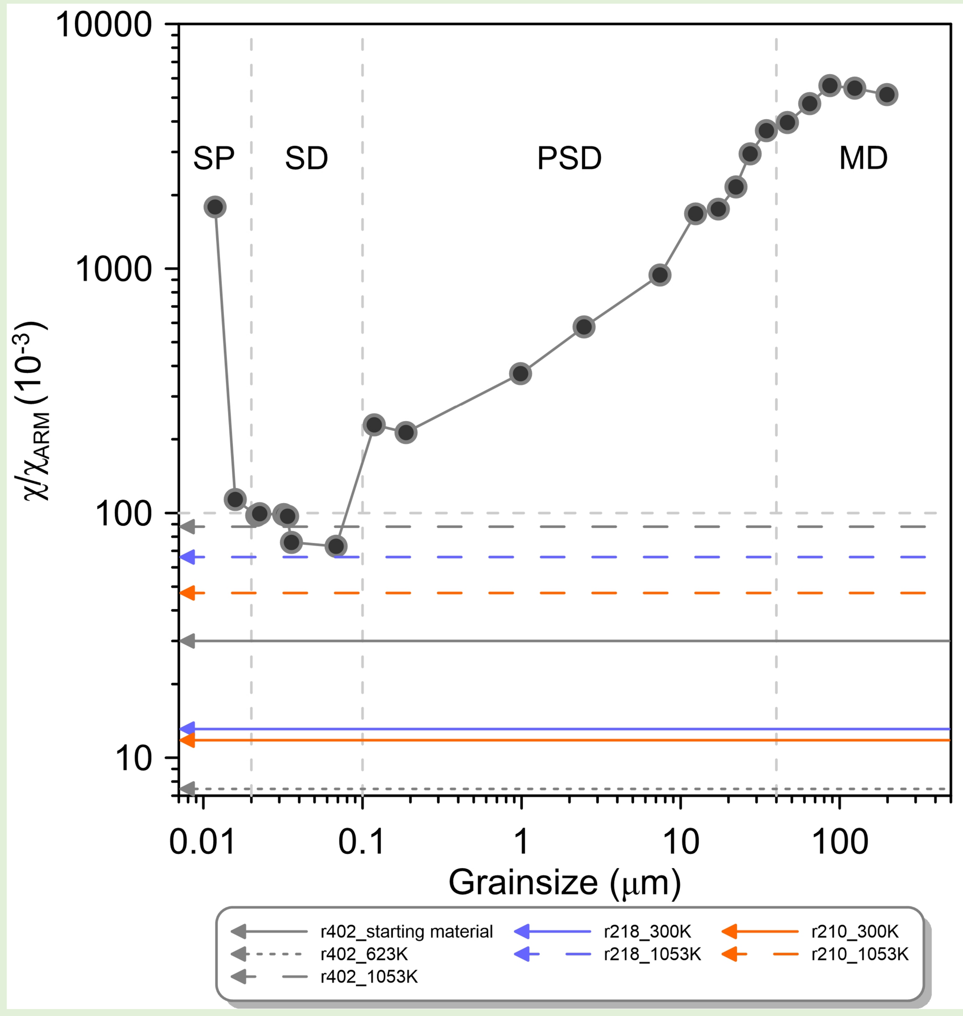

Figure 6. Plot of χ/χARM versus grain size for synthetic magnetite, modified from Liu et al. (2004), black dots mark the χ/χARM ratio summarized by Liu et al. (2004), horizontal solid lines indicate the χ/χARM values of this study.

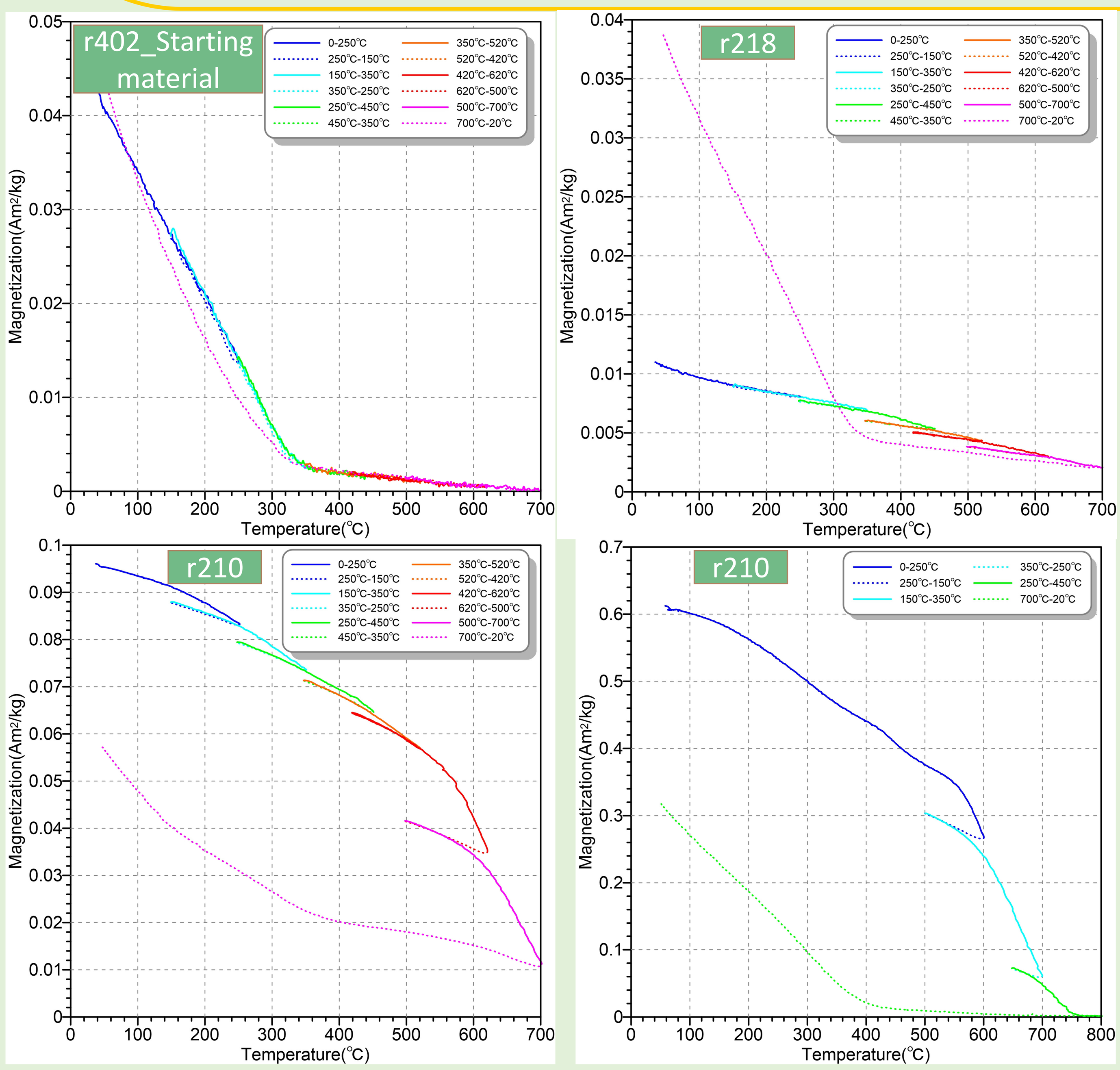

Figure 2. High-field thermomagnetic runs

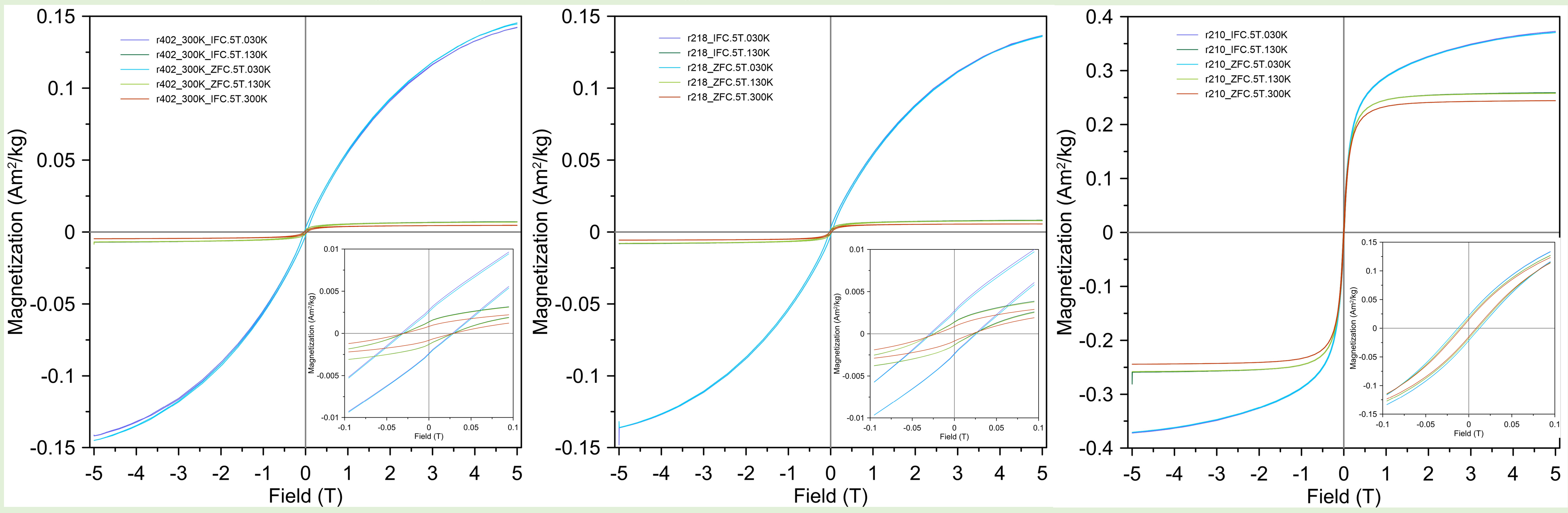

Figure 3. Hysteresis loops at 300 K, 130K and 10 K and enlarged range of the hysteresis loop (inset), IFC: in field cooling; ZFC: zero field cooling.

4. Conclusion

- Siderite and superparamagnetic phase of magnetite/maghemite are present in the starting material.
- Siderite in the starting material was altered to metallic iron during shearing experiments with DI water, but this alteration did not occur under dry conditions.
- The powders sheared under wet conditions are considerably more magnetic than those sheared under dry conditions.
- Sheared experiments may produce a reducing environment, and/or localized high temperature?

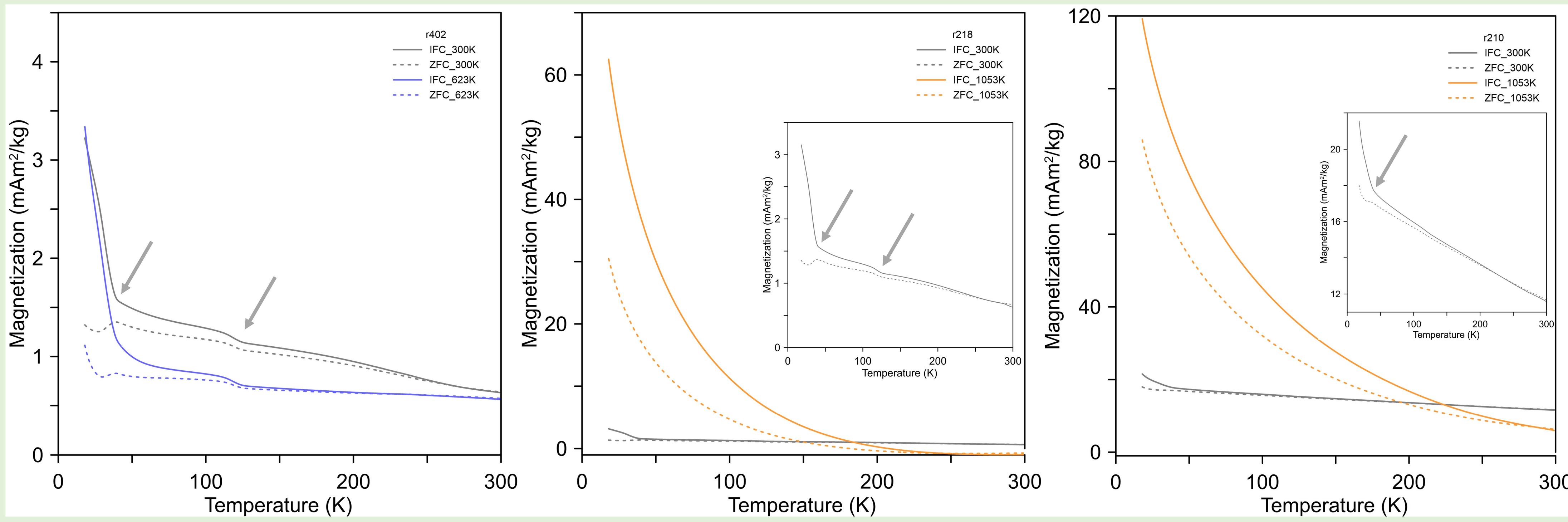

Figure 4. Low-temperature remanence as a function of temperature of three samples: r402 (unheated and heated to 623K), r218 (unheated and heated to 1053K), and r210 (unheated and heated to 1053K), IFC: in field cooling; ZFC: zero field cooling.

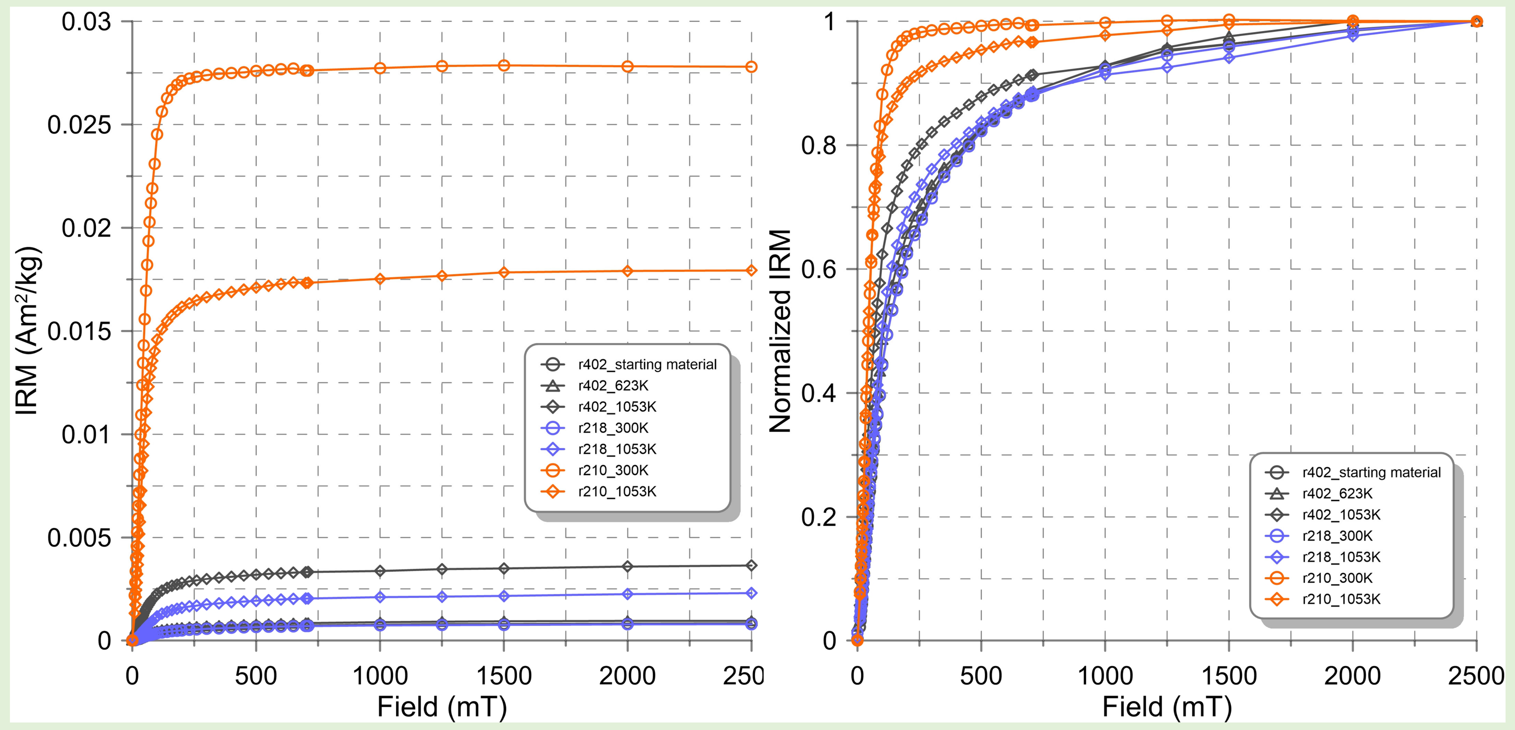

Figure 5. IRM acquisition curves of unheated samples and after heating to the indicated temperatures, the right panel is normalized by the maximum.