Rheological transitions of the solid-bearing metallurgical slag during cooling

Zhuangzhuang LIU, Bart BLANPAIN, Muxing GUO
KU Leuven, Department of Materials Engineering, 3001 Leuven, Belgium

KU LEUVEN

ABSTRACT

The non-Newtonian behavior and its mechanism have not been clarified for the solid-bearing silicate melts, leading to difficulties and even errors in estimating silicate melt viscosity. In this study, a basic oxygen furnace (BOF) slag was employed as a model system of solid-bearing silicate melt. The flow behavior of the slag was measured via a rotational type rheometer at various shear rates. The results demonstrate that as the temperature decreases from above slag liquidus, the slag undergoes the Newtonian, shear thinning, and thixotropy regimes. The shear thinning regime was observed as crystal content exceeds the critical solid fraction Φc, at which the viscosity increases abruptly.

INTRODUCTION

Slag viscosity plays a vital role in metallurgical processes as it directly affects the kinetics of chemical reactions, metal-slag separation, slag foaming, etc. A reasonable viscosity estimation of fully liquid slags is achievable nowadays thanks to numerous viscosity models[1]. However, the flow behaviour of partially liquid slags is not understood well (e.g., shear thinning and yield stress)[2] and a validated viscosity model for solid-bearing slags is still absent. In this work, the viscosity of modified basic oxygen furnace (BOF) slag was measured as a case study to understand the rheology of solid-bearing slags. The non-Newtonian behaviour during cooling is thus measured and the underlying mechanism is discussed.

METHODS AND MATERIALS

A BOF slag was used as an example to investigate various flow characteristics. The high temperature rheometer was used and the following experiments were conducted:

- The slag viscosity was measured continuously during cooling at a constant rotational speed, i.e., 30 rpm.
- The slag viscosity was measured isothermally with various rotational speeds.

RESULTS

The measured viscosity under continuous cooling and at a shear rate of 30 rpm is shown in Figure 1. With the decrease in temperature, the viscosity gradually augments and then undergoes a sharp increase.

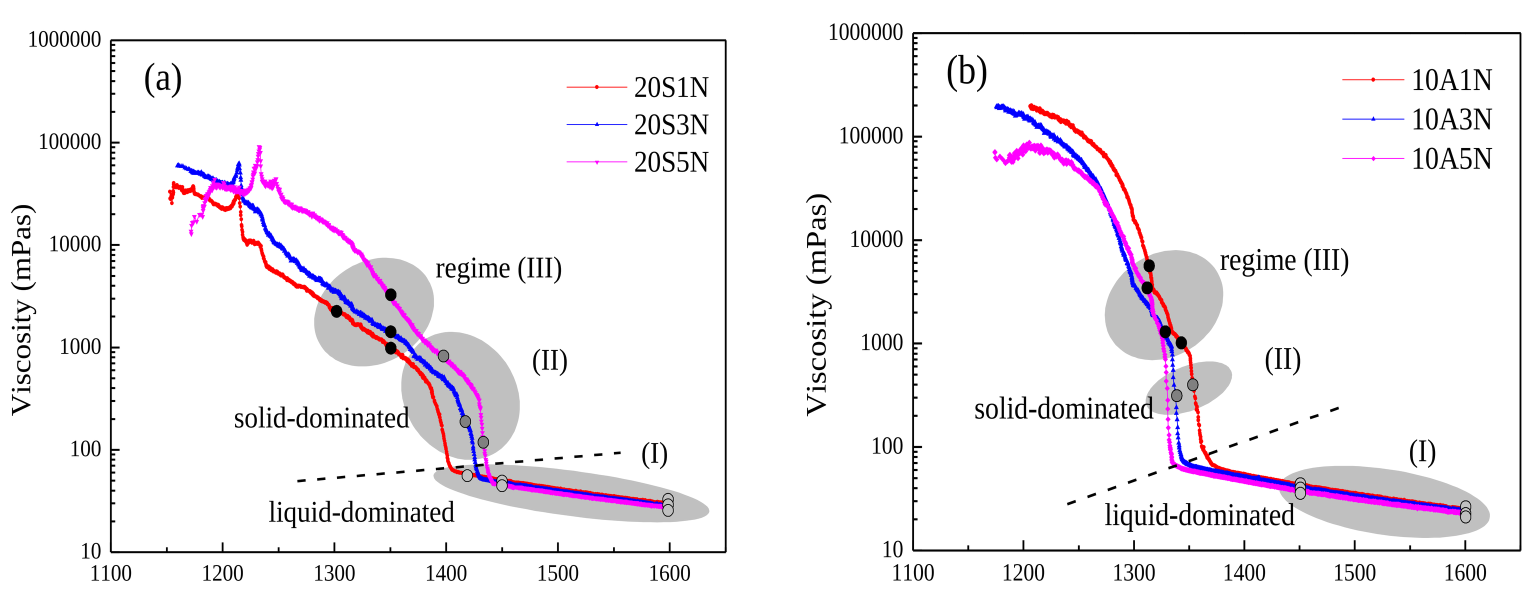

Figure 1: Three regimes distinguished by different flow properties. The round dots indicate the temperature at which the viscosity was measured isothermally (see Table 1 and Figure 2).

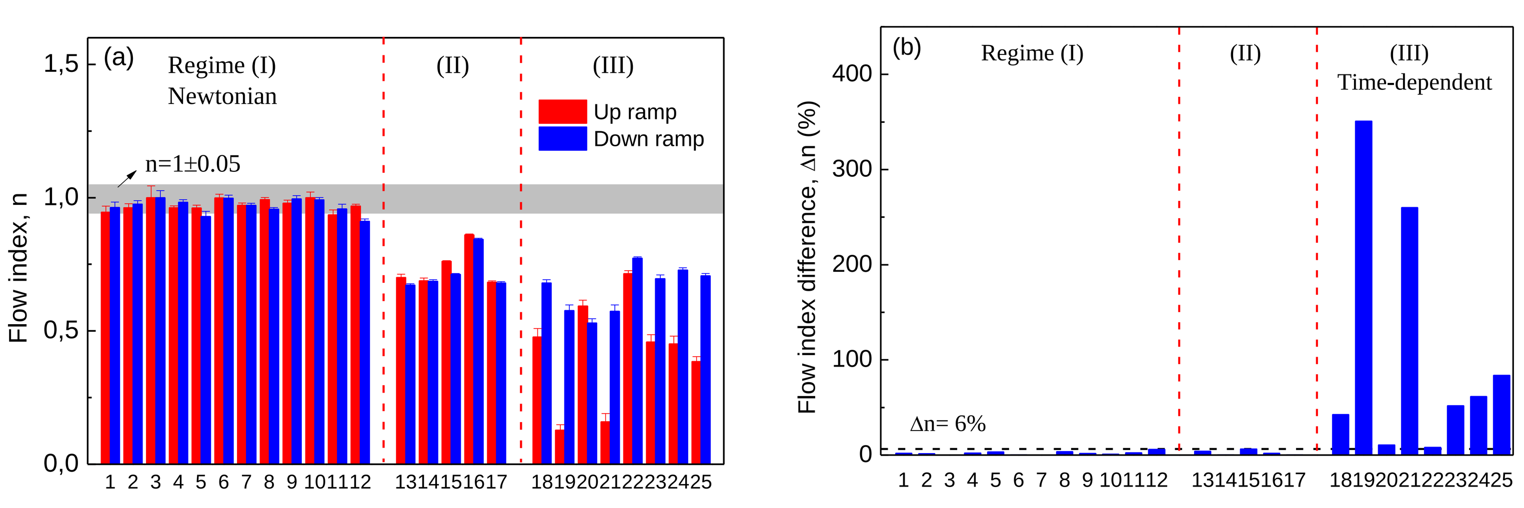

Figure 2: The calculated (a) flow index (both up ramp and down ramp) and (b) relative flow index difference ($\Delta n = |n_{down} - n_{up}| \times 100\% / n_{up}$) in the three regimes. The relation between numbers 1-25 and the measurements is shown in Table 2.

As shown in Figure 1 and Figure 2, in regime 1, the viscosity is independent on shear rate, exhibiting a Newtonian characteristic. In regime 2, the flow index is <1, indicating a shear thinning phenomenon. In regime 3, the relative flow index difference Δn is >6% (the measuring error), implying a thixotropic property.

Table 1: Sample/measurement and the corresponding number in Figure 2

Regime	Sample	T (°C)	Number	Regime	Sample	T (°C)	Number
(Ⅰ)	10A1N	1600	1	(Ⅱ)	10A1N	1355	13
		1450	2		10A3N	1338	14
	10A3N	1600	3		20S3N	1420	15
		1450	4		20S5N	1435	16
	10A5N	1600	5			1400	17
		1450	6	(Ⅲ)	10A1N	1340	18
	20S1N	1600	7			1315	19
		1420	8		10A3N	1325	20
	20S3N	1600	9		10A5N	1315	21
		1450	10		20S1N	1350	22
	20S5N	1600	11			1300	23
		1450	12		20S3N	1350	24
-	-	-	-		20S5N	1350	25

CONCLUSIONS

✓As the temperature decreased from above slag liquidus, the slag undergoes the Newtonian, shear thinning, and thixotropy regimes.

✓The shear thinning regime was observed as crystal content exceeds the critical solid fraction Φc, at which the viscosity increases abruptly.

REFERENCES

1.Z. Liu, L. Pandelaers, B. Blanpain and M. Guo, ''Viscosity of Heterogeneous Silicate Melts: A Review'', Metall. Mater. Trans. B, 49 (5) 2469-86 (2018).

2.Z. Liu, L. Zhang, A. Malfliet, B. Blanpain and M. Guo, ''Non-Newtonian behavior of solid-bearing silicate melts: An experimental study'', J. Non-cryst. Solids, 493 65-72 (2018).

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