RHEOLOGICAL BEHAVIOUR OF CHOSEN LIQUID FERROUS SOLUTIONS

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Abstract

This paper presents the results of the rheological analysis of selected ferrous solutions. In metallurgical processes, gradient of the dynamic viscosity parameter is an important indicator characterizing the behavior of liquid metal in the industrial aggregates. It affects the processes of heat exchange and mass transport occurring in the existing liquid, solid and gaseous phases. Only a small number of high temperature viscosity measurements is available. This is due to the fact that the experiments are difficult to conduct and due to the general assumption that the molten ferrous solutions are a liquid exhibiting similarities to Newtonian liquids body. In general liquid metal processes are affected by dynamic forces. Values of the parameters which could be treated as rheological in those real processes are very difficult to measure therefore the influence of the following factors: time of shearing, force value, force direction and shear rate are neglected. The significance of these dynamic parameters seems to be particularly important in the metal founding and thixoforming process. In this work authors analyzed, from the rheological point of view, chosen types of ferrous solutions. Measurements were taken using a high temperature viscometer FRS1600 in the range of liquidus temperatures as well as above the liquidus for variable shear rates.

Keywords: viscosity, pig iron, cast iron, steel, rheometer

1. INTRODUCTION

The viscosity effect in metallurgical processes is amongst the most important of those effects that influence the behaviour of reacting phases (metallic, slag and gaseous) with regard to the kinetics of mass exchange or chemical reactions [1]. Viscosity plays a significant role in all metallurgical processes - ironmaking, steelmaking, ladle refining, steel casting, and also in processes that are related to solidification. From the perspective of the flow of liquid phases - which are continuously moving during those processes - viscosity is very important. It is also significant due to the internal structure of the metallic or slag phases, along with related capabilities to absorb impurities or the ability to deform. For the purposes of simulation of metallurgical processes, it is necessary to have access to experimental data on a broad range of chemical compositions and temperatures as regards not only metal, but also oxide phases - metallurgical slags [2]. Data originating from measurements taken at high temperatures is necessary for the engineering of new processes, and for the optimization of those already in existence - that is, a better control of the process, and/or improvement of product quality. Many mathematical models have been created in the past few years that can assist in describing the thermodynamics, kinetics, fluid flow and heat exchange. Obtaining 'good', i.e., 'correct' measurement data has been the basis for the creation of accurate models. Due to the difficulties concerned when it comes to obtaining access to specialist instrumentation such as high-temperature rheometers - along with the degree of complexity that burdens rheological measurements - very little data [3, 4] concerning liquid ferrous solutions can be obtained from subject literature that is available. **Fig. 1** presents a diagram showing the stages of mathematical modelling of physical phenomena, including those phenomena that occur in the steelmaking processes. The modelling is performed at four levels [5]:

- carrying out an experimental analysis - as covered by the author's area of interest - in the context of rheological tests of liquid ferrous solutions,
- the application of artificial intelligence tools for modelling, including neural networks, expert systems, etc.,

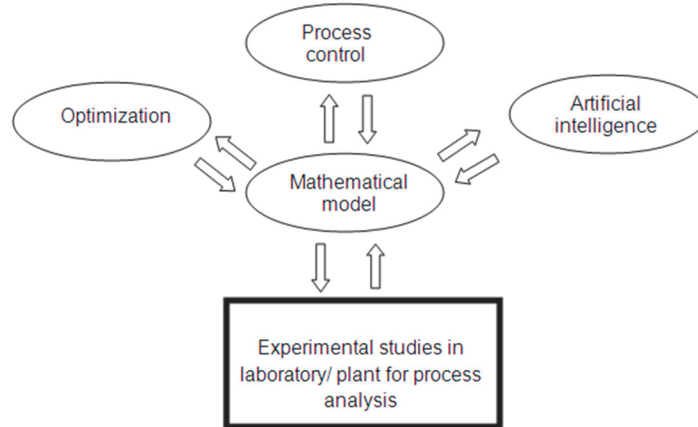- process optimization,
- process control.

Fig. 1 A diagram of mathematical modelling of physical phenomena [5]

2. EXPERIMENT

Fig. 2 shows a high temperature rheometer scheme. A detailed description of the equipment and calibration of measuring systems is presented in paper [6,7]. It is equipped with a pipe furnace which makes it possible to obtain temperatures up to 1530 °C. It allows to maintain a protective atmosphere in the course of long rheological measurements.
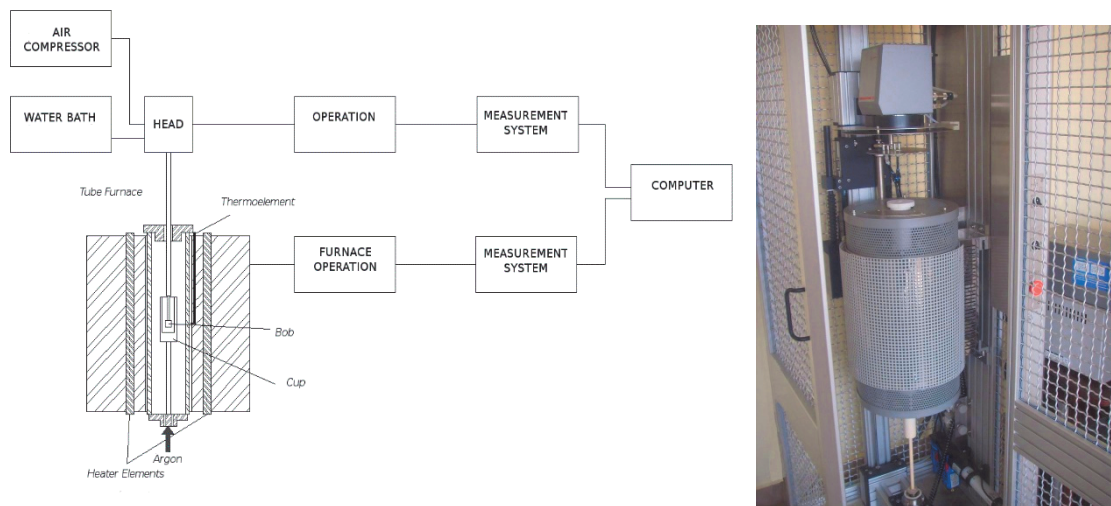

Fig. 2 Scheme of a high temperature rheometer FRS1600 [6,7]

In this study, the measurement methodology in a system of coaxial Searle type cylinders was used for conducting high-temperature rheometric tests of ferrous alloys. The cylindrical measurement method is based on a system consisting of an inner cylinder (bob) and an outer cylinder (cup). The picture and schemes of the used systems are presented in **Fig. 3**.
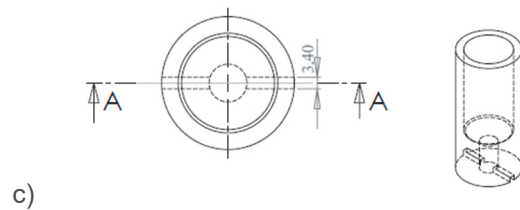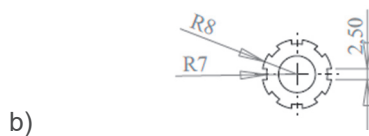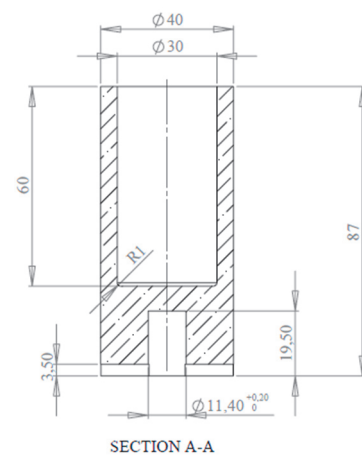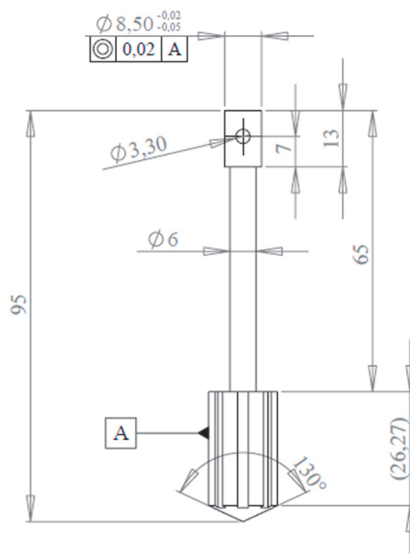
Fig. 3 Measuring systems: **a** photo of used measuring system; **b,c** schemes of used measuring system [6,7]

The rheological tests were conducted for three ferrous solutions with different chemical compositions (**Table 1**). The tests were carried out at and over their liquidus temperatures.

Table 1 Chemical composition of conducted ferrous solutions

Type of solution	C	Mn	Si	Cr	Ni	Mo	V
Pig iron	4.2	0.41	0.93	0.06	0.04	0.01	0.01
Cast iron	4.2	0.30	4.24	0.20	0.10	0.01	0.02
Steel 90CrV6	0.89	0.26	0.19	1.43	0.44	0.06	0.106

3.   ANALYSIS OF FINDINGS

Figs. 5 and **6** present the flow curves of three ferrous solutions differing with chemical compositions. The objective of this presentation of results is to picture the differences between the values of shear stress and shear rate for a given chemical composition at various temperatures: 1500 and 1450 ºC.
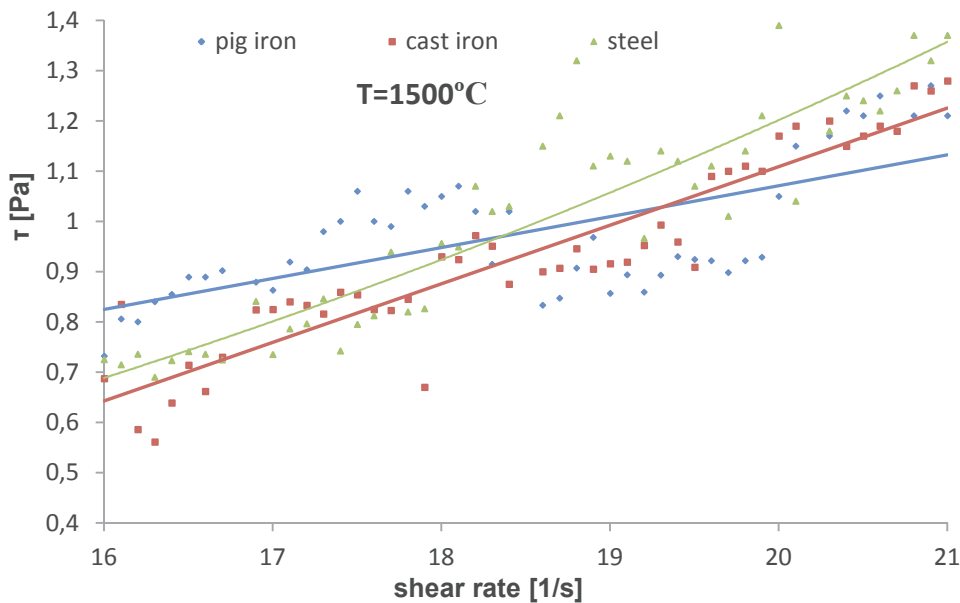

Fig. 5. Flow curves for different ferrous alloys at 1500 ºC

The stress values - at a temperature of 1500 ºC, at which all solutions tested are fully liquid - range between 0.65 and 1.3 Pa, at a change in the shear rate from 16 to 21 s^{-1}. The nature of the flow curve course for steel and iron is similar, whereas the hot metal flow curve has a slightly different inclination angle towards the x-axis. This may be caused by the influence of the chemical composition on the various 'natures' of flow curves of the ferrous solutions tested, or disturbances of the laminar flow during measurement.
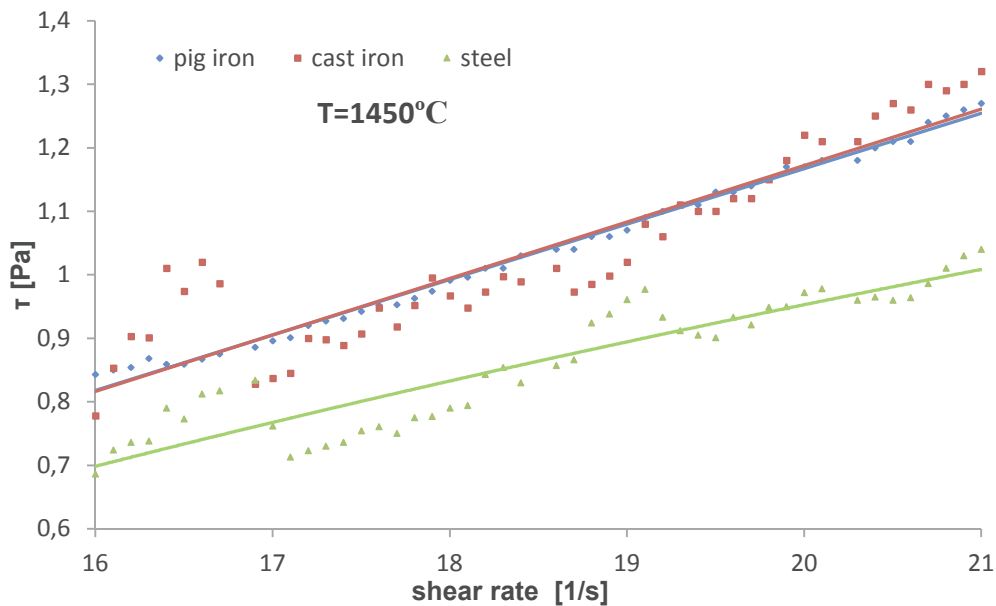
Fig. 6 Flow curves for different ferrous alloys at 1450 ºC

The flow curves of ferrous solutions tested at a temperature lower by 50 degrees - yet still around the liquidus temperature of the solutions analysed - have slightly different courses than those presented in **Fig. 5**. The stress values range from 0.7 to 1.4 Pa (for the shear rate range 16 - 21 s^{-1}), which is confirmed theoretically - a slight increase in the tangent stress value occurs when the temperature decreases.

4.   OBSERVATIONS AND CONCLUSIONS

Based on the conducted experiments we can find that high temperature rheological examinations of ferrous solutions are difficult and require specialist measurement instrumentation and a broad knowledge of metallurgy as well as rheology and rheometry.

The performed experiments allow us to state that completely liquid ferrous solutions are similar to Newtonian liquid, with some deviations which may be effect of turbulent during flow.

Further rheological measurements of ferrous solutions will be extended by:
- research as regards the influence of individual alloying elements on the dynamic viscosity coefficient value,
- rotary and oscillation tests in a semi-solid state taking into account microstructural examinations.

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