On the Magnetic Field Influence on the Viscosity of Liquid GaInSn with Suspended Solid Particles

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Abstract:
Experimental and numerical studies have been undertaken to check the influence of a magnetic field on the viscosity of liquid GaInSn with suspended solid particles. The rheological investigations show a significant change of the slope of the measured flow curves between the situation B = 0 and 0.02 T. By means of numerical simulations of the flow in the presence of Lorentz forces it could be shown that the influence of magnetohydrodynamic damping of the flow reduces the measured changes but does not annihilate them. As conclusion a 15 % change of viscosity of the melt in a magnetic field with B = 0.02 T could be fixed.

Zusammenfassung:
Der Einfluß eines Magnetfeldes auf die Viskosität einer GaInSn-Schmelze mit suspendierten Partikeln wurde experimentell und numerisch untersucht. Dabei zeigten die rheologischen Messungen eine deutliche Änderung der Steigung der gemessenen Fließkurven bei Erhöhung der Induktion des magnetischen Feldes von B = 0 und 0.02 T. Mittels numerischer Simulationen konnte die magnetohydrodynamische Dämpfung der Strömung in der Scherzelle durch Lorentz-Kräfte bestimmt werden. Dabei zeigte sich, dass die Berücksichtigung dieses Effekts die gemessenen Änderungen der Fließkurven zwar reduziert aber nicht kompensiert. In Summe kann eine 15 %-ige Steigerung der Viskosität der Schmelze für B = 0.02 T festgestellt werden.

Résumé:
Des études expérimentales et des simulations ont été entreprises afin de vérifier l'effet d'un champ magnétique sur la viscosité d'une suspension de particules solides dans du GaInSn liquide. Les recherches rhéologiques révèlent un changement significatif de la pente expérimentale des courbes d'écoulement entre la condition B = 0 et 0.02 T. Grâce à des simulations numériques de l'écoulement en présence de forces de Lorentz, on a pu montré que l'influence de l'amortissement magnétohydrodynamique de l'écoulement réduit les changements mesurés, mais ne les annihilent pas. En conclusion, un changement de 15% de la viscosité du fondu dans un champ magnétique B = 0.02 T a pu être résolu.

1 INTRODUCTION

The investigation of the rheological behavior of metallic melts is of severe importance not only for basic research but also for a number of industrial metallurgical tasks as well. The experimental determination of thermophysical properties like the viscosity of melts has been an intense research topic for a long time. Due to the low viscosity of metallic melts, their high melting point as well as their chemical reactivity only a few experimental methods have been proven to be suitable: capillary viscosimeters, oscillating vessels and rotational rheometers. The most commonly used method is the oscillating cup technique, which has been introduced already around 1940 [1 – 3]. In this method the viscosity is determined from the decrement and time period of the motion of a vessel filled with the investigated liquid which is put into oscillation around its vertical axis. There are numerous publications reporting on mathematical treatments of the measured data as well as on the technical improvements of the equipment to obtain better experimental results [4 – 10]. Aside the wide use of oscillating cup viscosimeters, many rheological studies of liquid metals and alloys were done with the help of rotational rheometers. As examples, studies of the rheological behavior of some alloys in the mushy state [11] or of the rheology of partially solidified alloys [12 – 14] could be mentioned here.

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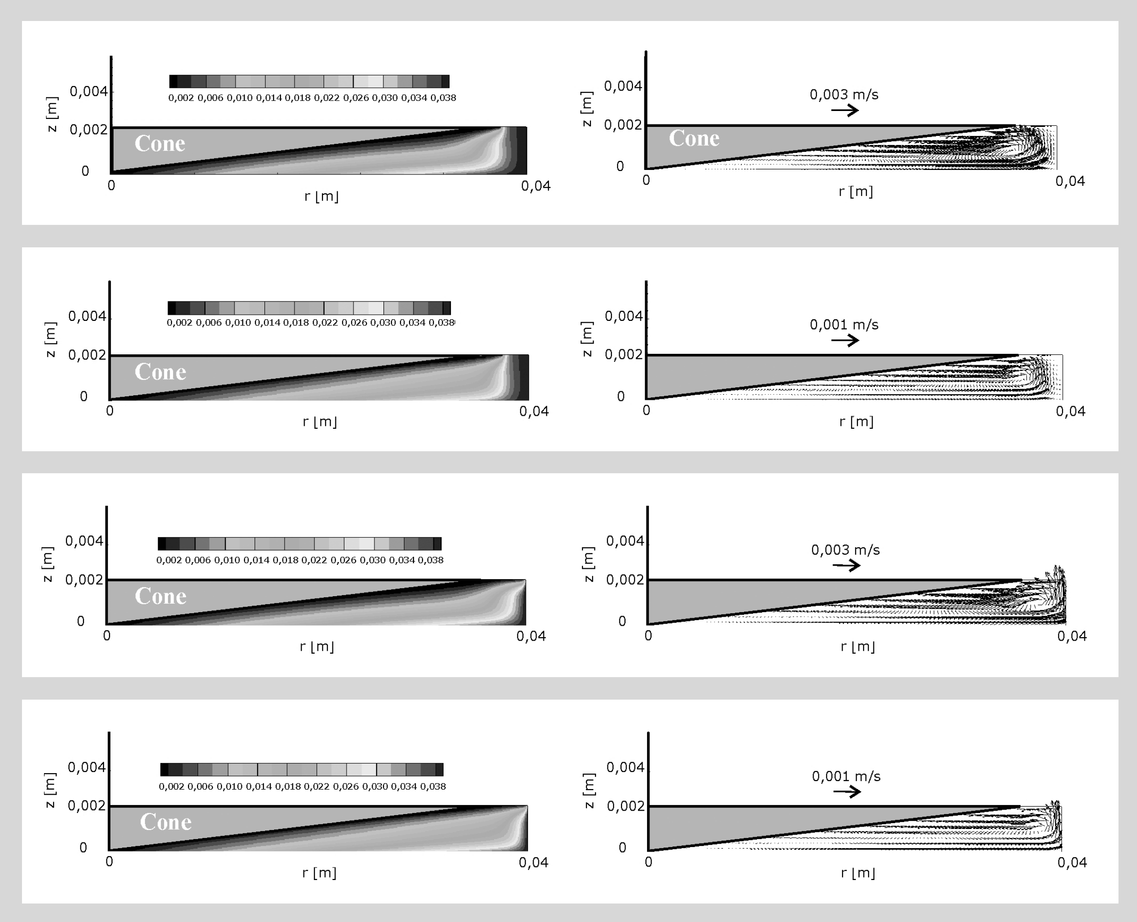
from top to bottom:
Figure 3:
Azimuthal (left) and meridional (right) flow for B = 0 T for a completely oxidized (closed) surface between the cone and the wall of the cup containing the fluid.

Figure 4:
Azimuthal (left) and meridional (right) for B = 0.05 T for a completely oxidized (closed) surface between the cone and the wall of the cup containing the fluid.

Figure 5:
Azimuthal (left) and meridional (right) for B = 0 T for a not oxidized (free) surface between the cone and the wall of the cup containing the fluid.

Figure 6:
Azimuthal (left) and meridional (right) for B = 0.05 T for a not oxidized (free) surface between the cone and the wall of the cup containing the fluid.



numerical simulations enables discrimination between the effects of magnetohydrodynamic damping and rheological changes. Therefore the numerically determined flow profiles have been used to calculate the torque *T* transmitted to the cone using Equation 12 for different experimental conditions. Figure 8 shows the shear rate dependent variation of the relative change of the transmitted torque for the free surface as well as for the fully oxidized one. As seen the magnetohydrodynamic damping is very effective for small shear rates and decreases significantly with increasing shear. As seen in Figure 2 the mean shear rate used for the experimental investigations has been about 150 s^{-1}. For a completely oxidized surface the numerically determined change of the torque is about 10 %. Comparing this with the measured change of the slope of the flow curves of 25 % one can state that the magnetic field induces a change of at least 15 % in viscosity of the metallic melt for a magnetic induction of 20 mT.

4 CONCLUSION AND OUTLOOK

With oscillating cup viscosimetry it could be shown that solid particles suspended in a metallic melt lead to strong changes of the melts viscosity far beyond the effects expected from normal colloidal rheology. Since the combination of solid particles in melts with magnetic fields used to control the flow in the melt by means of magnetohydrodynamic effects is as well an intense research field as a question with high application potential, the mayor part of the paper has been devoted to the question whether magnetic fields change the viscosity of a melt containing solid particles. With a combination of rheological experiments and numerical simulations it has been proven that a significant field induced change of the viscosity of a GaInSn melt containing solid particles of its own oxides appears. The change could be clearly distinguished from magnetohydrodynamic effects on the flow in the shear cell leading to a damping of the secondary flow induced at the free surface layer of the shear cell. It is assumed that the effects are driven by the influence of the magnetic field on the flow around the solid particles leading to a change of the particle motion in the melt and correspondingly to a change of their diffusion coefficient. Future investigations will now have to provide a systematic variation of the mayor parameters influencing the rheological behavior. Especially the volume content and size of the suspended particles as well as the magnetic induction applied to the fluid will have to be varied. From the results we expect a possibility to clarify the basis of the observed influences of solid particles on the rheology of metallic melts and to provide data for metallurgical as well as magnetohydrodynamic applications.

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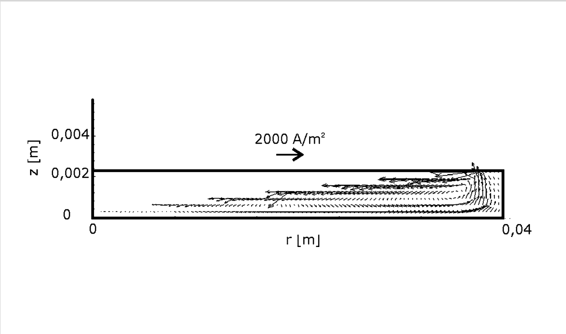

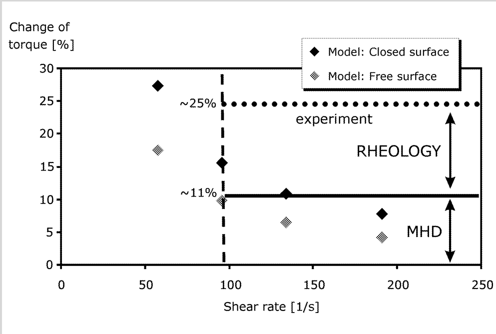

Figure 7 (left): Electric current distribution for the situation of Figure 3 (every 5th vector is shown).

Figure 8: Change of the torque transmitted in the rheometer due to magnetohydrodynamic damping of the secondary flow calculated from the simulation of the flow profile as a function of shear rate. The open symbols represent the results for a clean surface while the closed symbols show the effect for a fully oxidized one.

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