Chapter 5
Introduction and Definitions for Rheology and Modeling

The semisolid state in a metallic alloy can be obtained either during solidification from the liquid state, or during partial remelting from the solid state.

Metal forming during solidification (rheocasting) has been studied in the early stages of the development of semisolid processing by Flemings and his coworkers, but it was not the main forming method until very recently with the development of the new rheocasting (NRC) process. However, solidification of an alloy with mechanical, passive, or electromagnetic stirring was extensively used to produce globular microstructures. Therefore, knowledge of the rheological properties of alloys subjected to stirring during solidification is of great importance in comparison with non-stirred alloys on the one hand and with partially remelted alloys on the other hand.

Metal forming was thus mainly carried out after partial remelting: thixoforming (thixocasting or thixoforging) is then concerned with solid fractions, which can vary in a quite large range, from 10 to 20% in thixomolding to much larger values in thixoforging. Study of the rheological behavior of alloys during such a treatment is therefore also important for better forming conditions and improved properties of the formed components.

The alloys studied from a rheological point of view belong essentially to three categories: the model alloys like Sn–Pb with a low melting temperature for which the experiments are relatively easy, the aluminum and magnesium alloys, which are the main thixoformed alloys, and the alloys with a high melting temperature for which only feasibility tests have been carried out.

For the characterization of the rheological behavior of these semisolid alloys, two approaches are usually adopted.

The first approach is concerned with the semi-liquid state: the alloy contains low fractions of solid so that the behavior is described in terms of an apparent viscosity. The alloy is considered as a homogeneous medium, which is characterized during shear-dominated experiments. Fluidity measurements are also performed owing to the usefulness of this parameter for characterizing the flow behavior of the alloy during filling of a mould.

The second approach applies to the behavior at large solid fractions. The viscosity is no longer the pertinent parameter owing to the very important agglomeration phenomena, which are taking place between the solid particles. The alloy therefore

David H. Kirkwood et al., *Semi-solid Processing of Alloys*,
Springer Series in Materials Science,
DOI 10.1007/978-3-642-00706-4_5,

behaves more like a porous solid medium saturated with liquid. In this case, the behavior must be described by considering the two phases and their interactions.

Models are interesting if they can be easily integrated in computer simulation codes for optimizing the metal forming process in industrial production. Numerical simulation can indeed avoid long and expensive trial and error experiments by answering, well before the production stage, questions concerning the shape of the mould and the forming conditions. Several codes have already been developed for this purpose and others are still under development. These codes do not take into account all the complex and coupled physical phenomena that are occurring during a thixoforming or rheocasting operation but, even with simplifying assumptions, they can be very useful during the development stage of a new product.

Based on the previous considerations, this part will be divided into two main parts. The experimental determination of the rheological behavior of semisolid alloys will be first presented. The modeling of this rheological behavior will be then considered.