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Physical Metallurgy Meets Industry: Do Physical Fundamentals Serve Industrial Materials Processing?

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The objective of physical metallurgy is the mechanistic interpretation and theoretical analysis of metallurgical phenomena. Despite of many deficiencies, the conspicuous efforts in the past century, the sophistication of analytical methods and instruments, and the development of advanced theoretical concepts have contributed to a seemingly comprehensive conceptual and mathematical framework that is accepted as an in-depth understanding of materials phenomena and its complexity.

The physical equations of state that characterize the state of a material and its change during processing are typically defined in terms of differential equations which are difficult to solve analytically for realistic boundary conditions. With the advent of high power computers with seemingly unlimited storage capacity these difficulties were overcome by numerical procedures that allow to mathematically address highly complex phenomena. Concurrently, novel computational tools have been developed to create a virtual image of a material on the computer.

The state parameters of materials properties are not the processing conditions but the material microstructure, which in most general terms is defined as the spatial arrangement of elements and defects in a solid. Since the microstructure changes during processing, a prediction of terminal material properties requires computational monitoring of microstructural evolution along the entire processing chain. Respective simulations are possible but also show the limitations of our conceptual framework and of the complexity that can be handled. The approach will be introduced for the case of commercial sheet production of aluminum alloys. For the example of grain growth it will be shown how limitations of current approaches can be overcome by a more sophisticated approach to the underlying physics.