Chapter 11
Materials Design, Development, and Deployment in Manufacturing Industry:
A Digital Paradigm

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ABSTRACT

The materials and manufacturing industry is undergoing transformation through adoption of various digital technologies. Though the adoption of digital platforms for operational needs is significant, their adoption for core design and development of products and their manufacturing are limited. While the use of physics and data-driven modeling-and-simulation tools is increasing, these are not systematically leveraged for larger benefit. Besides these tools, product design and development requires deep contextual knowledge necessitating systematic capture of data and knowledge. To achieve this, we need flexible digital platforms that enable integration of diverse design domains and tools through a common semantic basis and construction of engineering decision workflows leveraging various simulation tools and knowledge. This chapter builds these requirements through presenting three case studies from the materials manufacturing industry and presents requirements for a digital platform. Finally, one such platform, TCS PREMAP, being developed by the authors is described in some detail.

INTRODUCTION

Across the ages of civilization, materials played an important role as stepping stones for progress to the next era. The science and engineering of materials, their manufacture and utilizing them in products has evolved over many centuries making significant contributions to the strides of human development.

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Our understanding of the underlying physics of materials has advanced tremendously in the recent past. Yet, despite these advances, materials engineering practice still remains somewhat traditional, heavily dependent on expertise and knowledge of individuals and trial and error driven experiments. For example, deploying a new aerospace material takes about 20 years from conceptualization to deployment in a flying aircraft (Pollock, et al., 2008). Even in less critical industries, it still require many years, up to a decade, for full-scale realization of new materials in products. This is not a desirable state to be in for the enterprises of the future.

The advent of computers has made significant contributions to the utilization of various forms of modeling and simulation of materials under diverse circumstances and this has led to significant acceleration of materials and manufacturing engineering, all the way from design and development to deployment. Mathematical modeling based on the physics of the material behavior, coupled with judicious empirical relationships laid the foundation for modeling and simulation in materials engineering. This along with advances in high performance computing and numerical methods such as finite element methods contributed to what can be seen as the "Materials 3.0" revolution (Jose & Ramakrishna, 2018). Yet, the materials engineering remains largely expertise and experimentation driven and the design of materials and their manufacture and deployment of products remains in silos to a large extent. Apart from the design and development of materials, production of materials and converting these materials in raw-forms to products in a manufacturing set-up requires simultaneous analysis of the material evolution and the corresponding manufacturing process. Modeling and simulation for manufacturing processes is utilized to varied degrees of success in the manufacturing industry and cannot be said to have made the same kind of inroads that it has for product design (McDowell, et al., 2010). There has also been considerable research on the use of expert systems to aid decision making in manufacturing processes and to some extent even exploited in the industry (Wong, Chong, & Park, 1994). Further, usage of digital technologies for continuous monitoring of the performance of a manufactured product in service and the related decision making is still in its infancy, at least from the perspective of materials engineering. The recent advances in integrated computational materials engineering (Pollock, et al., 2008) are allowing to break these silos and make "integrated engineering" a reality. In parallel, the advances in application of AI to mine the large amount of experimental and simulation data generated during the discovery and design of materials is attempting to reduce the serendipity involved in material discovery (Rodgers & Cebon, 2006), (OSTP, 2011), (Ramprasad, Batra, Pilania, Mannodi-Kanakkithodi, & Kim, 2017), (Agrawal, Deshpande, Cecen, Basavarsu, & Choudhary, 2014). The concepts of "Digital Thread" for tracking the life cycle of products in a circular economy and "Digital Twin" to enable analysis, diagnostics and prognostics of various outcomes of manufacturing processes and product performance in the field have been gaining widespread industrial acceptability (Lieder & Rashid, 2016).

In light of these rapid developments and adoption of newer paradigms and technologies, there is a significant need to re-look at the entire life cycle and transform the way materials are designed, manufactured and deployed into products, to make the next level of difference to the manufacturing and materials industry. The transformation is made feasible by new digital technologies, better sensors, availability of large amounts of data and deeper understanding of materials. Leveraging all this requires significant changes in the way engineering is carried out and this in turn requires powerful, versatile and flexible digital infrastructure.

This chapter focuses on the transformation coming from the key digital forces of computing, big data and artificial intelligence (AI) on core engineering activities involving material design & development, deployment of materials in products and manufacturing of materials and products and the authors views

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