Journal of Computer-Aided Materials Design, **7:** 143–144, 2001.
KLUWER/ESCOM

Guest Editorial

NEW AGE OF DESIGN

G.B. OLSON
Northwestern University

At the dawn of a new millennium, a Science Age of three centuries draws to a close, replaced by a Technology Age based not in scientific discovery but in a revolution in engineering design led by U.S. industry. The resulting New Economy, which we now desperately seek to sustain, is based in technology not found in a laboratory, but deliberately created from the human mind in response to perceived needs. While we tend to be nostalgic about exploration ages, at this point in history humankind not only enjoys an unprecedented ability to create wealth from thought, but holds all the tools for a much-needed transformation from mere technology to responsible technology.

At the strategic level, this revolution is founded in new systems-based design methodologies that accelerate the total product development cycle while achieving new levels of product reliability. At the tactical level, it integrates a new understanding of human team creativity with new opportunities in information technology to create powerful computational tools tailored to strategic needs.

Meanwhile, our "modern" research universities have continued to train explorers for a bygone era. Dominated by a culture of reductionist analysis, university engineering has been replaced by engineering science, leaving industry on its own to advance engineering practice, and leaving the teaching of modern engineering to business schools and corporate universities. While this cultural incongruity has affected all fields of engineering, no field has suffered more damage than the materials profession. Left on its own, the industrial practice of materials development has languished in a slow and costly empirical discovery process that cannot keep pace with the compressed product development cycle, leaving no chance for participation in concurrent engineering. Despite a widespread deeply-held goal of scientific engineering from within the community, the academic materials enterprise has been diverted under external forces through funding policies toward reductionism and the pursuit of novelty, leading to highly dissipative random-walk exploration that yields much paper but no materials.

Against this background, the multi-institutional Steel Research Group (SRG) was founded in 1985 to build within a modern systems engineering framework the methods, tools and databases to support the rapid computational design of materials, using high-performance steels as a first example. Treating materials as dynamic multilevel-structured systems, integration of process/structure/property/performance relations has generated a hierarchy of design models. The methods, tools and models, and their successful application in the thermodynamics-based parametric design of new alloys, are described in detail elsewhere (1-3). Credibility of computational materials design based on the SRG success has helped to bring about major initiatives supported by the Defense Advanced Research Projects Agency (DARPA) and other DoD agencies expanding computational design capability to accelerate the full materials development and qualification cycle with application in a broad range of materials. Bringing such activities to our universities creates a fertile environment for education reform. While significant progress is being made in restoring design education in our undergraduate programs, the grand challenge is the reformation of our analysis-dominated medieval doctoral system to embrace the higher-level skills of the modern engineer. Doctoral-level design can develop creative synthesis skills that can only be learned by experiencing the design process, still employing scientific rigor in model development, but with a new sense of purpose.

Two papers (4,5) in this issue demonstrate what can be achieved in a single doctoral thesis. Motivated by ambitious property objectives for the hardened case, a new class of thermally-stable carburizable stainless steel without case primary carbides was designed for high performance bearing applications. The design-driven research entailed four areas of scientific model development: (a) mechanistic modeling of martensitic transformation kinetics to accurately control case transformation temperatures, (b) rigorous modeling of the secondary-hardening carbide precipitation dispersion trajectory for input into strengthening theory, (c) thermodynamic modeling of corrosion resistance in terms of both film stability and film properties as governed by Cr partitioning, and (d) validation of numerical solidification microsegregation simulations to constrain alloy processability at the ingot scale. These models were then integrated with other available models in the design of a complete alloy (specifying both composition and processing) as a fully computational exercise. While primary objectives emphasized the structure and properties of the ultrahard corrosion-resistant case, secondary objectives for the core required a Ni-toughened lath martensitic microstructure with hardness adjustable through alloy carbon content.

Remarkably, evaluation of a single 50 lb. prototype heat revealed that a single iteration of computational design had met all case requirements of transformation temperatures, microstructure, hardness and corrosion resistance. In the carburized and secondary-hardened condition the case demonstrated the desired hardness near R_c65 without primary carbides. Through the elimination of the latter, the alloy showed much less reduction of corrosion resistance with carburizing, and less tendency for quench cracking compared to previous steels. The only significant deficiency of the first-iteration design was insufficient core toughness in the secondary-hardened condition. Fully exploiting the single prototype, a series of decarburization and fractography experiments identified a core carbon content and associated hardness that would provide sufficient fracture resistance (in terms of critical flaw size at yield) for desired core performance. Having validated this prediction in commercial-scale heats, the new alloy is now available as Ferrium CS62 through QuesTek Innovations LLC and is currently running in product trials. Delivering a useable alloy with a significant performance advance in only two iterations of prototype evaluation heralds a new era bringing materials into the Design Age.

References

1. "Designing a New Material World," G. B. Olson, *Science* Vol. 288, 12 May 2000, pp. 993–998.
2. "Computational Design of Hierarchically Structured Materials," G. B. Olson, *Science*, Vol. 277, No. 5330 (1997) pp. 1237–1242.
3. "Science of Steel," G. B. Olson, in *Innovations in Ultrahigh-Strength Steel Technology*, ed. G. B. Olson, M. Azrin, and E. S. Wright, Sagamore Army Materials Research Conference Proceedings: 34th (1990) 3–66.
4. "Systems Design of High Performance Stainless Steels: I. Conceptual Design," C. E. Campbell and G. B. Olson, *J. Computer-Aided Mat. Des.*, this issue.
5. "Systems Design of High Performance Stainless Steels: II. Prototype Characterization," C. E. Campbell and G. B. Olson, *J. Computer-Aided Mat. Des.*, this issue.