6.0 Emerging Technologies

While the previous chapters describe major steelmaking processes and the research needs related to each, there are also emerging technologies around the world which are generally applicable to steel and/or to competing materials. Advancing those technologies with the potential to positively impact steelmaking and monitoring those that may make alternative materials more competitive are also priorities of our industry. Specific examples are described below.

6.1 Modeling, Visualization and Simulation

Modeling, simulation, and visualization (MSV) are the three discrete components that make up computer-generated representations of a real-world process or system. Modeling refers the development of a mathematical or logical representation of a physical system or process. Simulation uses computers to implement modeling over time to generate data about key characteristics or behaviors of the physical system or process. Visualization is the two- or three-dimensional depiction of the results of a simulation. These three components can be used together to provide a basis for managerial or technical decision making and other applications such as training, education, analysis of technology performance, and safety for industry to increase productivity and reduce costs.

Trends and Drivers. The need for efficiency in iron and steelmaking processes to stay competitive is an important driver for the development and utilization of MSV technologies. Interest in MSV has increased significantly in recent years with the capability of a well-constructed and validated computer model allowing systems designers, users, engineers and managers to pursue efficiency by understanding in advance the detailed consequences of their decisions and the investments prior to actually making commitments.

MSV enables people to "go inside" virtual environments and provides a unique, and effective tool for understanding complex physical processes, and thus innovate to make significant improvements in a time and cost efficient way. MSV also provides tools to create better designs, determine better solutions for troubleshooting and process/product optimizations, scale-up new concepts, and predict the effects of alternative conditions or courses of action. Simulation can also be useful when it is too dangerous, expensive, or otherwise unacceptable to access the real system. As a design or planning tool, simulation is useful for looking at potential design scenarios before systems, facilities, or equipment are built.

The combination of MSV with three dimensional (3D) graphics and “serious gaming” technologies have also resulted in development of interactive software for education and training in the areas of operations, maintenance, troubleshooting, safety, and workforce development. The integration of these technologies allows trainees to experience virtual scenarios of real world conditions, providing many of the benefits of hands-on experience in a safe and controlled virtual environment without the risk of damage to personnel or equipment.

Organizations focused on the development and application of MSV technologies such as the Steel Manufacturing Simulation and Visualization Consortium (SMSVC) and the Center for Innovation through Visualization and Simulation (CIVS) have demonstrated that the integration of these technology can provide innovative ways to provide value-added solutions and has potential to transform steel manufacturing.

Continuous efforts are desired to develop and apply advanced computer simulation and visualization technologies to ensure a competitive advantage for North American steel manufacturing.

Technological Challenges for MSV. While there are many benefits to MSV, a number of challenges impede its development and use for iron and steelmaking.

- ***Limited resources:*** Limited resources (people, time, money) are available for acquisition of computing software, hardware, and infrastructure as well as for training on sophisticated MSV tools. Sustained funding and commitment is needed to support computational teams and reap the benefits of MSV. In times of constrained budgets there is substantial competition for resources for product development versus improvement projects.
- ***Lack of proven value proposition:*** It is hard for companies to justify and commit resources to advanced MSV without strong returns and a demonstrated value proposition. A strong return on investment (ROI) justification is especially needed for significant capital or operational investments, such as those needed to create and deploy new tools and systems.
- ***Legacy cultural issues:*** There is a lack of foresight, vision and buy-in, and awareness of computational tools and their effectiveness and utility. A perception persists that simulation/visualization is more useful as a training tool and to address a specific problem rather than being used to solve broad tech challenges.
- ***Protection of intellectual property:*** Real and perceived concerns exist about the release of proprietary information via MSV tools.
- ***Access to practical knowledge and process environments***: Creating good MSV tools requires access to the people and equipment in steel facilities, as well as collection of real-time data. Without this access it is difficult to facilitate the development of accurate tools.
- ***Advanced IT resources:*** There is no pipeline of code developers familiar with high performance Computing (HPC) for steel industry problems.

New and Emerging Technologies. There is great potential for the use of MSV to generate operational and productivity improvements in iron and steelmaking. The advent of high performance computing, advances in computational technology, and dramatic improvements in telecommunications are creating important new opportunities for MSV in steel and all manufacturing. These improvements represent better, faster ways to manufacture products, investigate efficiency of alternative operating conditions, conduct business planning, and perform important training and safety functions.

Research and development (R&D) efforts are interdisciplinary in nature, often with collaborations occurring across multiple organizations.

Major research activities

- Integration of computational simulation, virtual reality visualization, and high performance computing
- Application of advanced simulation and visualization technologies to industrial processes for process/product design, trouble-shooting and optimization and scale-up
- Development of 3D interactive simulators or virtual processes of steel manufacturing with situation –based scenarios as well as real conditions and phenomena for problem solving and training

More specifically, CIVS with support from the National Institute of Standards and Technology (NIST) hosted two workshops in late 2014 to explore the challenges and future needs for MSV in the steel industry. The combined events brought together over 80 interdisciplinary experts from industry, government, national laboratories, and academia with a dual interest in the steel industry and MSV

Eight priorities identified for MSV and steel optimization:

- Workplace Safety
- Energy Efficiency
- Production Efficiency
- Reliability and Maintenance
- Workforce Development
- Environmental Impacts
- Raw Materials
- Smart Steel Manufacturing

These reflect the big-picture goals that could potentially be achieved over the next 5 to 10 years in the areas important to steel production and operations. From those eight focus area seven research projects are being conducted in the SMSVC in the topics of Safety Training, Blast Furnace, Electric Arc Furnace, Reheating Furnace, Ladle, Casting SEN and Spray cooling It is expected that these projects will provide virtual steel manufacturing simulators for improving processes and training through the integration for simulation and visualization.

6.2 Covetic Nonomaterials

Covetic nanomaterials are metals that have been infused with nano-particles of carbon using a unique electrical process. The term “covetic” is derived from the words “covalent” and “metallic” – two different types of chemical bonds. In general, covetic materials conduct heat and electricity more efficiently than conventional metals. Covetics hold commercial interest because the process is scalable to tonnage quantities with widespread implications for energy savings in thousands of potential applications. The process can be performed on variety of metals, such as Al, Cu, Au, Ag, and Fe. Micron-scale, activated carbon powder is mixed into the molten metal under forced convection (via an impeller). Electrodes are inserted into the melt, with hundreds of amperes of direct current flowing between electrodes, and the carbon particles are converted to nanoscale particles through a mechanism that is still not understood. The process is able to produce structures that seem to be thermodynamically unavailable via conventional processing methods but remain stable once established. The nanocarbon particles are tenaciously bound to the metal, increasing the elevated temperature strength, electrical conductivity, and thermal conductivity. Some of the unusual characteristics of covetic materials are: ~40% increase in the electrical conductivity of aluminum, ~50% increase in the thermal conductivity of copper, ~30% increase in the electrical conductivity of copper, and ~30% increase in the yield strength of warm-worked aluminum and as-cast copper. Although we know that covetic materials display unusually strong bonding between the carbon particles and their metallic matrix, the exact nature of the attraction is still unknown.

Iron Covetics:

Covetic conversion in Class 25 grey iron doubled its thermal conductivity at room temperature and increased its thermal conductivity at 500°C by ~45%. A significant increase (~20%) in the thermal conductivity of covetic 1018 steel at 500°C has also been observed, which bodes well for the ~$12 billion heat exchanger applications market. An increase in the thermal conductivity of steel improves performance of die-cast products, increases solidification rates, and reduces shrinkage porosity, hot cracks, and corrosion of the steel surfaces by the reactive molten metals. An ultimate tensile strength (UTS) of ~590 MPa was measured for rolled and annealed covetically converted 1018 steel compared to an UTS of ~400 MPa for rolled and annealed 1018 steel (parent material). Enhanced mechanical strength could potentially pay dividends for its use in structural applications. Since the material is stable once it has been covetically converted, it can be re-melted, diluted, or alloyed, and it appears that the covetically bound nanocarbon phase will survive the effect of oxygen lancing to produce low carbon steels.

Research is underway to better understand the conversion process, properties of covetic materials, establish structure-property-processing relationships, and consistently produce large quantities of covetic materials. Once the critical processing parameters have been identified to reliably reproduce the materials, the process is suitable for scale-up to tonnage quantities for commercial applications.

6.3 Thermomagnetic Processing

Thermomagnetic processing of the type under development at Oak Ridge National Laboratory has demonstrated new phase equilibria, accelerated kinetics, novel microstructures and enhanced properties warranting continued monitoring (and possibly further research) by the steel industry.

ORNL's approach utilizes electromagnetic heating with thermomagnetic processing and has shown simultaneous improvements in strength and ductility noted in contemporaneous presentations as 10-25% increase in strength without loss of ductility.

6.4 Additive Manufacturing/3D Printing

Additive manufacturing is a rapidly maturing technology as it relates to metals, having the potential to impact steel as well as competing materials. It relies on the application of advanced models which can consider many variables due to the computing power available today. The ability to cost-effectively manufacture in high production volumes remains a challenge and the applications are likely to be more in the marketplace (making parts from steel) than in the steel works (making steel). For example, 3D printing steel automotive closures could be a breakthrough vs. the challenge of aluminum and carbon fiber in these applications.

6.5 Collaboration with Steel Founders' Society

Opportunities for working together with other steel organizations include research into areas of common interest such as those topics identified below by AISI members and members of the Steel Founders' Society.

6.6 Welding of High Strength Steels

The goal of this project is to establish welding procedures for restoring the strength of welds on cast precipitation hardened (PH) stainless steels 17-4 and 13-8+Mo. Research involves microstructural characterization, mechanical testing, and thermodynamic and kinetic modeling.

6.7 Air Entrainment in Steel Castings

Steel cleanliness remains a major challenge for steel manufacturing. The entrainment of air during pouring is one of the main sources of reoxidation, forming inclusions in steel castings. Inclusions form first as oxides on the surface of the molten steel, then breaks and folds into the liquid, and quickly dissolves and disperses into the casting. The greater the amount of air entrained, the greater the number of oxide macro-inclusions will form. The objective of this project is to determine parameters that affect air entrainment and develop a tool that could accurately predict the amount of air entrained during pouring.

6.8 Porosity in Manganese Steel

Current porosity prediction algorithms in commercial solidification software do not work well for manganese steel castings. The goal of this project is to develop a model for improved predictions of surface shrink and internal macro-shrinkage and micro-shrinkage in manganese steels. Gas porosity was excluded in this study. Accurate mold and steel datasets will be developed.