Materials Modeling

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Who is TimkenSteel?

- **Start-up with 100 years** of experience, knowledge, and expertise
- Leading manufacturer of special bar quality (SBQ) large bars and seamless mechanical tubing.
- Our business model is **unique** in the industry, focusing on pushing the bounds of **what’s possible** by creating steel products and services to overcome our customer’s toughest challenges
- **100%** made to order steel
TimkenSteel: At a glance

Overview
- Headquartered in Canton, Ohio
- Annual melt capacity of ~2m tons
- Only focused North American SBQ producer
- Widest size range of SBQ bar capability
- Largest domestic capacity of seamless mechanical tub capability

2017 net sales by end market

Alloy steel bars (SBQ)
- ~75%\(^1\)

Value-added solutions
- ~15%\(^1\)

TimkenSteel Applications
- High SBQ
  - Bearings
  - Fuel injectors
  - Gun barrels
  - Crankshafts
  - Tri-cone bits
  - Percussion bits
  - Energy CRA production
  - CV joints
  - Gears

Low (Not SBQ)
- Fasteners
- Hand tools
- Leaf springs
- Shopping carts
- Table legs
- Reinforcing bar

Non-TimkenSteel Applications
- Machining, honing and drilling
- Components
- Seamless mechanical tubing
- Supply chain

Source: TimkenSteel
\(^1\) As a percentage of 2017 net sales
\(^2\) Includes billets
Materials Genome Initiative (MGI) announced (2011)
• Increase speed of innovation and acceptance of new materials

MGI Strategic Plan Goals (2014)
• (1) Leading a culture shift in materials research . . .
• (2) Integrating experiment, computation, and theory and equipping the materials community . . .
• (3) Making digital data accessible . . .
• (4) Creating a world-class materials workforce . . .
ICME in Industry

Integrated Computational Materials Engineering (ICME)

- “the integration of materials information, captured in computational tools, with engineering product performance analysis and manufacturing-process simulation.”
- Traditional Methods + Computational Methods + Mfg Feedback Loop

TimkenSteel has used computational simulation to:

- Determine capability of new capital equipment
- Complement forensic evidence during metallurgical investigations
- Redesign existing manufacturing processes
- Identify continuous improvement solutions
- Create new paradigms for viewing Special Bar Quality (SBQ) product
The Bigger Picture . . . Distilled at TimkenSteel

- **MGI Strategic Goals - How do we compare right now . . .**

  **CULTURE SHIFT**
  >90% of TimkenSteel Technology engineers using or guiding use of computational tools

  **ICME**
  Strategic development of our software, hardware, and laboratory suite

  **DIGITAL DATA**
  Storing data with access and usage in mind

  **WORLD-CLASS WORKFORCE**
  Establishing external collaborations, hiring the right people, and training them on ICME tools earlier
Manufacturing Processes Innovation Platform

Use traditional and computational methods to modify, improve and create new manufacturing processes in support of quality, new products, and competitive advantages.

- **Value ➔ Speed, Improved Quality, Visualization and Analysis**
- **Speed**
  - More trials than physically feasible
  - “Where to shine the flashlight”
  - Increased confidence

- **Improved Quality**
  - Forge models ➔ soundness
  - Rolling models ➔ shape & surface
  - Tundish models ➔ cleanness

- **Visualization & Analysis**
  - 1 good picture/video = 1000 minutes spent explaining a complex process to others
ICME Envy . . .

- Presentations from consultants and universities frequently show huge swath of computational tools all chained together

Reality . . . Need vs. Want

- We invest time and money based on the problems we want to solve
  - Urgent quality issues → process improvement
  - New capital investment → build process modeling capability
  - Innovation goals → new products or processes, catalyst for existing research work
ICME Toolkit Mapping

Computational Materials Design Framework (Olson/Kuehmann)

Group Brainstorm of Current/Desired Capabilities

TimkenSteel ICME Toolkit Snapshot

Measurement & Computational Design
Laboratory Trials
Mill Trials
Production
Targeted Alloy Design

Building an ICME framework
- At most basic level: Composition In $\rightarrow$ Properties/Processing Out
- Merging traditional laboratory and computational methods
- Automating traditional laboratory and computational methods
- Data . . . inputs, outputs, visualization

Many tools/methods to convert effort from manual to auto
- Data collection and organization
- Machine learning
- Writing/compiling new tools for existing processes
Targeted Alloy Design Result – More Data!

More results require a way to...

• Store it (thanks IT server team)
• Visualize it
• Make efficient decisions
Launch of *Endurance* steels

- Includes 3 patent-pending ultra-high-strength, high-toughness steels
- Up to 45% increase in HP capacity or 30% reduction in gear mass

2018 American Metal Market award for Best Innovation - Product
Case Study 1:
Process Design for Large Bars with Sound Center

FIA Forge Fair, AIST Long Products (2015)
P. Anderson, M. Byrne
Characteristic of Interest: Soundness

Goal: Produce large bar (> 9”) sound center product that meets customer specifications

Soundness ≈ Microporosity
- Cause → volume shrinkage during solidification
- Mitigate via
  - Casting process parameters
  - Hot work while converting to bar
- Important to know where microporosity forms

Virtual Process Path
- Ingot Casting → Forging → Rolling → Validation via UT Inspection
Virtual Process Path

1. Ingot Casting
2. Open-Die Forging
3. Rolling
4. UT Validation
“Hot work eliminates porosity, but the amount required to produce full density in bars is a function of the method by which the hot work is applied.”

– Adv. Steel Processing and Products Research Center Publication

Now, with respect to deformation:

Physical Trial Results

Non-Optimized Process UT Scan [Indications in Red]:

Optimized Process UT Scan [No Indications]:

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Non-Optimized Process  --  Optimized Process
Large Sound Bar Capability

Ultrasonic (UT) Soundness Specification

Minimum Reduction Ratio Required

- 1:1
- 3:1
- 6:1
- 10:1
- 20:1

Rolled Forged-Rolled Expanded Capability

UT Validated Results:
- Achieve Class B < 3:1
- Achieve Class A < 6:1

5/64" (2 mm) Flat Bottom Hole
1/8" (3.2 mm) Flat Bottom Hole
Case Study 2:
Relative Life Predictions from Steel Cleanness Variation

Unpublished Work
P. Glaws, D. Gynther, P. Hegedus
Modeling Cleanness – Component Fatigue Simulator (CFS)

- **Primary Goal**
  - Quantify Performance Improvements
    - Component Life
    - Power / Torque Handling
    - Weight Reduction

- **Critical Inputs**
  - Maximum Applied Stress
  - Nature of Stress (Contact, Bending)
  - Inclusion Distributions
  - Inclusion Chemistries

- **Primary Output**
  - Stress Field
  - Fatigue Parameters
Contact Stress Example

**Single Cell**
- Define a small volume of Steel
- Add realistic inclusions
  - Globulars, Stringers
  - Sizes, Shapes, Proximities
  - Chemistries
  - Elastic Properties
- Apply Hertzian contact load
  - Line
  - Point
- Calculate Stresses
  - Compare with/without inclusions
Contact Stress Example

- **Whole Components**
  - Define many thousands of simulation cells
  - Add realistic inclusions
  - Apply Hertzian contact load
  - Calculate Stresses
  - Calculate Performance

- **Virtual Life Testing**
  - Multiple Components
    - Highest Stress Riser Detection
    - Average Maximum Stress
Cleanness Simulation Result

- Quantification of performance behavior as a function of steel cleanness without extensive in-lab testing
- Our Ultra premium technology certifies the steel with automated SEM metrics for the inclusion population
Summary

- We see the value – we are increasingly capturing more value
- We’ve created a map – ICME planning wrapped into strategy
- We seek out and train the right skillsets

- Case studies prove out benefits for products & processes
  - Alloy Design ➔ *Endurance* Steels and Beyond
  - Large Bar Sound Center ➔ Forged-Rolled Process
  - CFS ➔ Clean Steel Advantages and *Ultra*premium™
Questions