Standardization of representation of materials, manufacturing process and their simulation through metamodeling driven ontology

25-02-2019
TCS PREMAP and ICME R&I Program: Vision and Mission

Develop tools, technologies and a digital platform for enabling integrated design of materials, manufacturing processes and products leveraging physics-based simulations, data-driven reasoning, decision-support tools and knowledge engineering systems.

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“A Platform for Knowledge-Assisted and Data-Supported Simulation-Driven Integrated Engineering of Materials, Manufacturing Processes and Products

“Digital Thread” & “Digital Twin” to enhance core engineering functionalities with physics, data and knowledge driven systems and digital platforms.
Engineering Challenges in the Digital World

- Knowledge Integration
- Data Integration
- Simulation Integration
- Decision Integration

Making all these available to different stake holders

Some pictures taken from internet sources
Digital Enablement: Key Concepts

- **Machine Learning**
- **Instances / Data Sources / Transformers**
- **Engineering Workflows**
- **Knowledge Elements**
- **Domain Representation**

Knowledge Repository

- Models
- Functions
- Procedures
- Documents
- Expert Inputs
Metamodeling and Ontology

- Meta Model
- Product
  - Material
  - Process
- Subject Model
  - Gear
  - Forging
- Instances
  - Steel
  - DP Steel
  - PN101
  - DP600
  - Machine 1

Knowledge Engineering
- Integration
- Extensibility
- Code generation

Domain Models

Model-driven engineering
Material Ontology

**MATERIAL**

**STEEL**

Chemical composition

- **Chemical Element**
  - C
    - Value wt%
    - Value vol%

- **Phases**
  - Ferrite
    - Volume fraction
    - Value vol%
    - Morphology
      - Type: Globular
    - Grain size
      - Value ASTM No.
  - Pearlite

- **Property**
  - YS: Mechanical property
  - Density: Thermo-physical property
  - Thermal Conductivity: Thermo-physical property

**Property Relationship**

- Type: Table
  - Thermal conductivity Table
  - Temperature vs Thermal conductivity

**Table**

- **Value**
  - wt%
  - vol%

**Notes**

- ASTM: American Society for Testing and Materials

**Thermophysical properties**

- Density
- YS (Young's Modulus)
- Thermal Conductivity
Material Metamodell
Material Metamodel – Steel Ontology
Metamodels – Manufacturing Process with Equipment
Interconnected Metamodels

Design/Engineering Process/Workflow

- Product / System
- Component / Part
- Manufacturing / Testing / Plant Process
- Simulation Process

- Material
- Equipment
- Simulation Tool
- Mesh

FMEA Process (In Progress)

Knowledge Representation
Knowledge Representation Using Ontology

- **Ontology Model**
  - Model the space of decision problems, tasks and questions that are relevant.
  - Meta and subject ontologies
  - Domain axioms and rules

- **Intent Model**
  - To describe contexts of interest
  - Knowledge serves an intent in a context

- **Context Model**
  - Knowledge is generated in a context
  - Support multiple forms of knowledge such as models, rules, cases, design templates, documents, etc.

- **Knowledge Element Model**
  - Support automated as well as human reasoning

**Knowledge Repository**

**Retrieval Engine**

**Knowledge Elements**

- Text
- Tables
- Documents
- Expressions
- Rules
- Cases
- Functions
- Procedures
- Workflows
Ontologies Driven Data Integration

- Data of materials and processes is available in a multitude of sources
  - Laboratory Databases
  - Factory Floor Databases
  - Third Party Proprietary Data

- Integration by mapping source specific data models to domain ontology
Optimization of Ladle-Tundish-Caster Operations

Refractory temperature profile

Temperature contours - Tundish

Columnar to equiaxed - Casting
Curation of Knowledge from Documents

- General Literature
- Enterprise Reports and Documentation
- Text Mining / Natural Language
- Ontology Mining
- Domain Specific Information retrieval
- Rule Extraction

**DOMAINE MODEL HELPER**

- Relations:
  - (boc) < Verb : is called > (ferrite)
  - (ferrite) < Verb : is > (iron)
  - (ferrite) < Verb : is > (iron)
  - (ferrite) < Verb : is > (iron)
  - (ferrite) < Verb : changes > (iron)
  - (iron) < Verb : is heated > (austenite)
  - (iron) < Verb : will remain > (ferrite)
  - (iron) < Verb : is > (austenite)
  - (ferrite) < Verb : are arranged > (boc)
  - (ferrite) < Verb : are arranged > (body-centered cubic)
  - (iron) < Verb : is called > (austenite)
  - (austenite) < Verb : are arranged > (face-centered cubic)
  - (austenite) < Verb : are arranged > (bcc)

**Search Collection**

- Search for:
  - tempering [time > 20min & temperature:[300, 500] C] & elongation

- Found 2 hits:
  - Intelligent Search
  - Text Search

**Screenshots of our system**

- (a) matches 2 publications for the given input query
- (b) snippets of the first matched publication – the text content matching user constraint is highlighted.
Summary

- Need flexible hierarchical ontological models of all entities of interest, enabling progressive specialization of concept models
- Ontologies should enable interconnectedness amongst different subject areas (products, processes, materials)
- Need enabling mechanisms to define ontologies and deploy them in digital infrastructures of the enterprise
Material Metamodel – Steel Ontology
Knowledge related to **sum of volume fraction of phases** in **Material** is **one** as an axiom.

Knowledge of **steel** having **certain types of crystallographic phases**

Knowledge of **phases** of **DPSteel** should have **restriction of phases** to ferrite, martensite and retained-austenite.
Models for Simulation Tool & Mesh

Simulation Model

Mesh Model
Ontology Elements to Knowledge Elements

Parameters calculated in the intermediate steps of MS Calculation
1. Coefficient of Rigidity
2. Stress allowable
3. Radius of gyration
4. Effective length
5. Etc.

Material
- Steel
  - Properties
    1. E, nu,
    2. YS, UTS

Instances
- Code XX – Comp2524 DP600 Sheet Property (E, G, Nu etc..)
- CodeYY- Comp196 HSLA Extrusion Property (E, G, Nu etc..)

Design Process: Compute MS in Buckling -> Analytical

Design Process
- Simulation / Design Tool
- Simulation / Design Params.

Knowledge

Component: XYZ

Req: MS-Buck

Context

Intent

1. Method to compute coefficient of rigidity
2. Method to compute radius of gyration