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Integrated Computational-Experimental Material Engineering of Thermal Spray Coatings

CoBRAIN

Deliverable D1.1

Report on the Open Translation Environment and TBox

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Publishable Summary[2]

This deliverable presents the results of the activities of T1.1 during the first year of the CoBRAIN project, aimed to generate a conceptualization scheme for the creation of an environment ready to represent and host the knowledge and data generated by the project activities in the field of thermal spraying. The key component of this environment is the CoBRAIN ontology for thermal spraying, built on the top of the EMMO (Elementary Multi-perspective Material Ontology)[3], that encapsulates all the concepts used to express thermal spraying knowledge (the so called TBox). Thanks to the EMMO environment, the CoBRAIN ontology can represent the user case entities (e.g., substrate, materials, devices) together with the modelling and characterization workflows, expressed using the MODA and CHADA conceptual diagrams in D1.2 and D1.3, and the datasets summarised in the Data Management Plan.

In the second year of the CoBRAIN project, the ontology will be used by a graph database to build a knowledge base, able to store metadata and map external data, in a more comprehensive Knowledge Management (KM) environment that plays the role of the Open Translation Environment (OTE), similarly to what has been done in the OntoTrans project[4]. As the project progresses, the ontology will be continuously updated to reflect any new developments.

[2] This summary will be used for public dissemination of CoBRAIN's activities.

[3] https://github.com/emmo-repo/EMMO

[4] https://doi.org/10.3030/862136

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Abbreviations

Abbreviation	Definition
ACS	Access e. V.
ANX	Aeonx AI
BAL	Balance Technology Consulting GMBH
CA	Consortium Agreement
CHADA	Characterisation Data
DB	Database
DMP	Data Management Plan
EMCC	The European Materials Characterisation Council
EMMC	The European Materials Modelling Council
EMMO	Elementary Multiperspective Material Ontology
EXE	Exelisis IKE
HHM	High Entropy Hardmetals
HVOF	High Velocity Oxygen Fuel
ISQ	International System of Quantities ISO 80000
KB	Knowledge Base
KME	Knowledge Management Environment
MODA	Materials Modelling Data
MBN	MBN NANOMATERIALIA SPA
OTE	Opern Translation Environment
TRL	Technology Readiness Level
UB	Universitat De Barcelona
UMR	Universita Degli Studi Di Modena E Reggio Emilia
UNIBO	Alma Mater Studiorum - Universita Di Bologna
UR3	Universita Degli Studi Roma Tre

1 Introduction

CoBRAIN is a collaborative initiative in the form of a Horizon Europe project that aims to develop novel hardmetals for thermal spray coatings based on compositionally complex systems of High Entropy Alloy and Carbides as a binder and hard phase, respectively. A Sustainable Decision Support System will be also developed in the context of the project, to identify specific elements and process solutions optimisations for the CoBRAIN solution to be applied in different scenarios. A unique synergy of the resulting experimental and modelled datasets and data on material lifecycle sustainability will be used in Deep Learning (DL) algorithms to provide support in the decision-making processes for the development of industrial components for different end uses.

The use of **Semantic Web** standards is crucial in establishing a framework of interconnected heterogeneous data sources, facilitating interoperability at both the data and system levels. These standards introduce the idea of **linked data**, shifting from hierarchical structures to network-based organization of data and knowledge. This becomes especially important in scenarios where data is dispersed among different content providers or stakeholders, as is the case such for the CoBRAIN datasets, requiring standardized data exchange for effective management of distributed knowledge.

Paramount for the Semantic Web and the concept of linked data is the role of **ontologies**, that have by now established themselves in various hierarchical levels: top-level, middle-level, and domain level. Incorporating top-level ontologies is critical for creating a framework that integrates the other levels. This is especially relevant in dynamically evolving domains like materials science, where new techniques continually emerge. Utilizing top-level ontologies can facilitate a **federation of interoperable databases**, reducing data fragmentation and preventing the formation of data silos.

This approach offers **multiple benefits**: it bridges the disciplinary gap between different domains and helps achieve Industry 5.0 standards, by narrowing the gap between human input and digital tools. It also enhances cross-disciplinary understanding and improves compatibility of domain-specific systems. Importantly, it enhances interoperability between standards, vocabularies, data, and software tools, while allowing more effective data documentation.

Despite these advantages, ontology developers often hesitate to use top-level ontologies, due to the overhead involved. This is further magnified by the fact that terms and approaches in top-level ontologies are not well-understood outside specialized fields, making domain-level ontologies more accessible. Another challenge is the competence bottleneck in formal knowledge representation, as few individuals possess the multidisciplinary skills required for ontology development.

This report summarises the T1.1 activities and results to create an conceptual framework and an ontology for CoBRAIN activities, overcoming the abovementioned gaps, facilitating the ontological representation of knowledge by domain experts, paving the way for the creation of the **Knowledge Management (KM)** environment, in the form of a system of databases linked together through a **Knowledge Base (KB)**, that will establish the framework for the semantic unification of CoBRAIN knowledge and **DataBases (DB)**.

It is important to acknowledge that this deliverable presents the efforts undertaken mainly by UNIBO, UMR and MBN, with the valuable support of the overall CoBRAIN consortium.

2 The Knowledge Management Environment

2.1 KME Architecture

The overall approach to knowledge management in CoBRAIN can be summarised in Figure 1. It consists of a KB system designed to collect user cases and metadata, and to link together datasets that are locally stored by the CoBRAIN partners in their specific storage solution of choice. This architecture has the benefit of maintaining almost unaltered the existing data collection and storage methodologies that domain experts are using in their technological relevant environment, since the KB is built on the top of them, exploiting the virtualisation techniques that are available in commercial graph databases solutions.

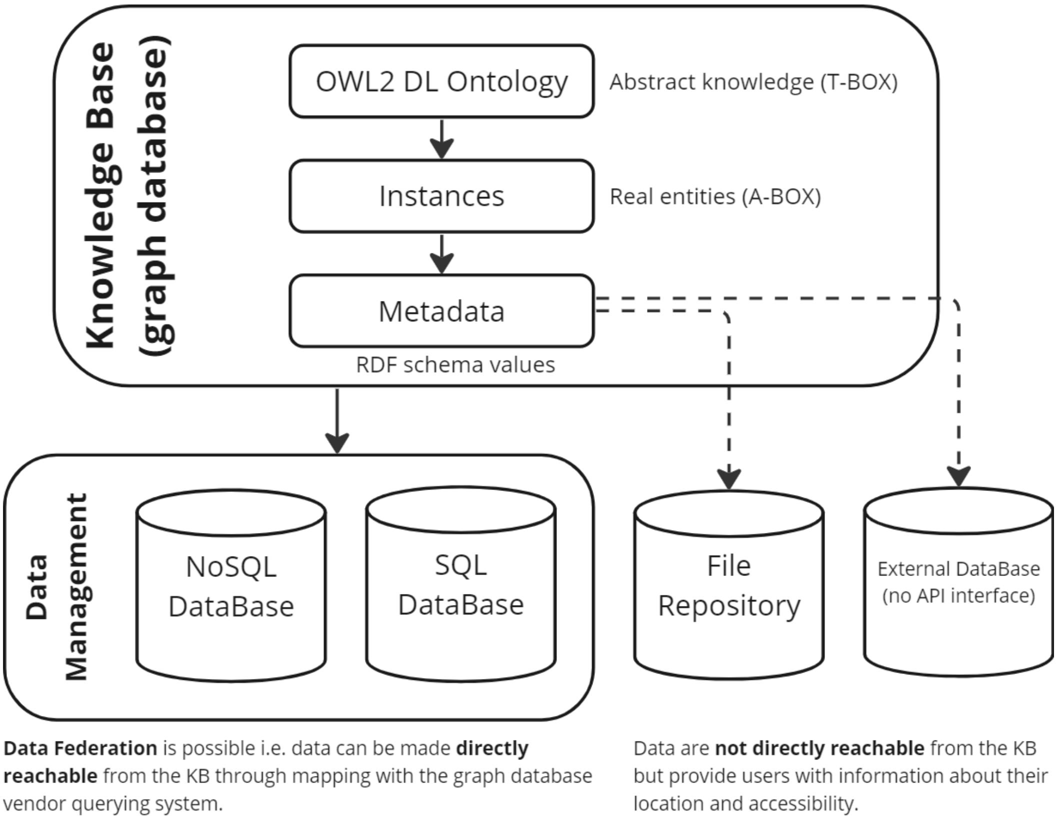
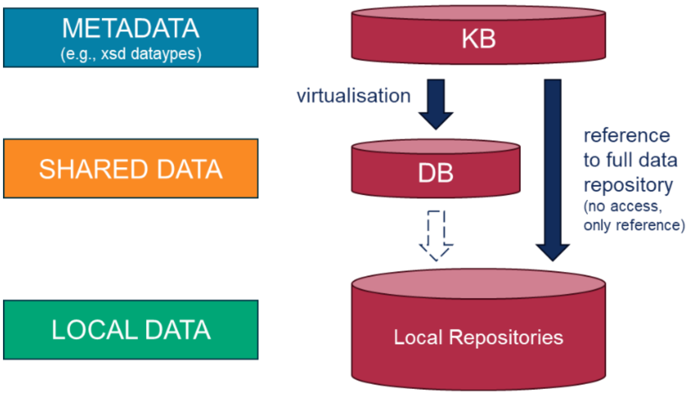


Figure 1 - The overall CoBRAIN KME architecture

More in detail, the KME consists of:

1) A **Knowledge Base** in the form of a graph database (a.k.a. triple store) specifically a graph database (a.k.a. triplestore) that will store:
    a) the **ontology**, representing the abstract knowledge, also called the **TBox**
    b) the information about domain entities taking part and playing a role in each user case implementation (e.g. device, material sample, testing, modeling), represented as **individuals**, also called the **ABox**
    c) the **metadata** needed to describe them (e.g. name, titles, unique identifiers)
    d) the **mapping** between the KB entities and the actual data stored in structured databases or in other external data sources.
2) A **Data Management** system comprising:
    a) **structured DBs** that can be mapped by the graph database virtualisation capabilities
    b) **local data**, in the form of heterogeneously stored data whose location is known but for which automatic access will not be implemented, due to IP restrictions, technical unfeasibility or because they are not relevant for the project scope.



SHARED DATA and METADATA

Field	Description
Sample ID	String: Sample name and identification number of test.
Sample description	String: sample composition and production information.
Test definition	String: Type of test and instrument name (i.e. Nanoindentation-Pillar splitting, MTS G200).
SOP file name	String: indication of the file name containing parameters of measurement (i.e. acquisition rate, max load, loading rate, approach speed etc.) .
Measurement Date Time	dd/mm/aaaa hh:mm:ss
Indenters	String: type of the indenter (i.e. Berkovich); serial number; material of the indenter.
Curves	Indentation curve: Load applied [N] vs penetration depth [m].
P_C	**mN,** the value of the critical load, identified from Indentation curve: (Load applied [N] vs penetration depth).
K_{IC}	**MPa√m,** the value of the fracture toughness calculated from the value of the critical load.

LOCAL DATA

Field	Description
Sample ID	String: Sample name and identification number of test.
Measurement file	**.mss**, located in UNIROMA3's servers, contains all the information related to the measurement and the complete results.
Indentation Data	**.xls**, located in UNIROMA3's servers, contains data, exported from .mss, needed for fracture toughness calculation (i.e. applied load [mN] vs penetration depth [nm]).

Figure 2 - KME and actual CoBRAIN dataset

An example of how the actual datasets expressed in the CoBRAIN DMP are placed within the KME is shown in Figure 2. The nanoindentation metadata are stored directly in the KB, while the actual data (usually bulk of data, such as structured containers like vectors, matrix, or binary data like images of modelling results) are stored in the DB and mapped. The original data, that have been processed to generate the meta- and shared data, are generally stored locally and only referenced by the KB.

It is important to notice that only the component 1.a, the ontology as the environment TBox, is the subject of this deliverable.

2.2 CoBRAIN KME as OTE

An OTE helps industry to respond to manufacturing challenges more efficiently by accessing the relevant information and utilising materials modelling more effectively. There is a need to strengthen the use of translation as a router supporting end users to get to relevant data and models.

An OTE provides a general-purpose ontology-based environment able to support the development of dedicated case-of-use applications, delivering a smart guidance for materials producers and product manufacturers through the whole steps of the translation process[5], by:

1) **Representing** manufacturing process challenges in a standard ontological form as technical and business Innovation Cases
2) **Connecting** innovation cases with existing appropriate information sources i.e. available data and materials modelling solutions
3) **Recommending** consistent materials modelling workflow options
4) **Supporting** simulation and validation activities
5) **Providing** semantic results interpretation to facilitate sharing and re-use of innovation cases and results

with the final aim to improve decision making processes in a smart integration of simulation platforms, data-driven models, materials databases, exploratory and recommendation system, and ontology driven database.

The KME designed within the CoBRAIN project is consistent with the definition of OTE according to the OntoTrans project definition since its architecture can support all the abovementioned steps. The use of the EMMO and a graph database approach makes the CoBRAIN KME compatible with OntoTrans tools, such as the Exploratory Search System and SimPhoNy Open Simulation Platform, enabling a potential interoperability with the results of OntoTrans project.

[5] https://ontotrans.eu/project/

3 The Conceptual Framework

3.1 The EMMO Ontology

There has been considerable improvement in the fields of ontologies, terminology, classification, and data documentation in the last couple of decades. Notably, initiatives like EMMO (Elementary Multiperspective Material Ontology)[6] have emerged. Led by EMMC, EMMO's goal was to create a standardized language and framework for materials modelling across Europe.

EMMO is a multidisciplinary effort to develop a standard representational framework (the ontology) for applied sciences. It is based on physics, analytical philosophy and information and communication technologies. It has been instigated by materials science to provide a framework for knowledge capture that is consistent with scientific principles and methodologies. It is released under a Creative Commons CC BY 4.0 license.

The name *Elementary Multiperspective Material Ontology* should be understood as follows:

- **Elementary** means, amongst others, that EMMO is a discrete ontology assuming the existence of a smallest possible 4D world object in space and time. The term *Elementary* in EMMO refers to objects that cannot be divided further in space. Elementary also emphasizes EMMO being a fundamental, top-level ontology.
- **Multiperspective** highlights a very important aspect of EMMO - that it is possible to describe the world from different perspectives. This makes the ontology both flexible and expressive.
- **Material** (as the opposite of immaterial) emphasises that EMMO is strictly nominalistic, meaning that it assumes that abstracts do not exist. *Material* also refers to the historical scope of EMMO aiming at the description of materials and thus to cover the needs of physicists and applied scientists.
- **Ontology**, EMMO is an ontology. It is based on fundamental philosophical concepts like semiosis, mereology, and topology.

The EMMO ontology is structured in shells, expressed by specific ontology fragments, that extends from fundamental concepts to the application domains, following the dependency flow.

3.1.1 EMMO Top Level

The EMMO top level is the group of fundamental axioms that constitute the philosophical foundation of the EMMO. It starts from causality and mereology, from which it derives space and time. Adopting a physicalistic/nominalistic perspective, the EMMO defines real world objects as 4D objects that are always extended in space and time (i.e. real-world objects cannot be spaceless nor timeless). For this reason, abstract objects, i.e. objects that do not extend in space and time, are forbidden in the EMMO.

EMMO is strongly based on the analytical philosophy discipline semiotics. The role of abstract objects is in EMMO fulfilled by semiotic objects, i.e. real-world objects (e.g. symbol or sign) that stand for other real-world objects that are to be interpreted by an agent. These symbols appear in actions (semiotic processes) meant to communicate meaning by establishing relationships between symbols (signs).

Another important building block of from analytical philosophy is atomistic mereology applied to 4D objects. The EMMO calls it 'quantum mereology', since there is an epistemological limit to how fine we can resolve space and time due to the uncertainty principles.

The mereocausality module introduces the fundamental mereocausality concepts and their relations with the real-world objects that they represent. The EMMO uses mereocausality as the ground for all the subsequent ontology modules. The concept of causal connection is used to define the first distinction between ontology entities namely the *Item* and *Collection* classes. Items are causally self-connected objects, while collections are

[6] https://github.com/emmo-repo/EMMO

causally disconnected. Quantum mereology is represented by the *Quantum* class. This module introduces also the fundamental mereocausality relations used to distinguish between space and time dimensions.

The *CausalObject* is the class of all the individuals that stand for world objects that are a self-connected composition of more than one quantum object and whose temporal parts are always self-connected. It also defines the *Elementary* class, that restricts mereological atomism in space as causal chains of quantum objects and *CausalSystem*, that are non-elementary causal objects.

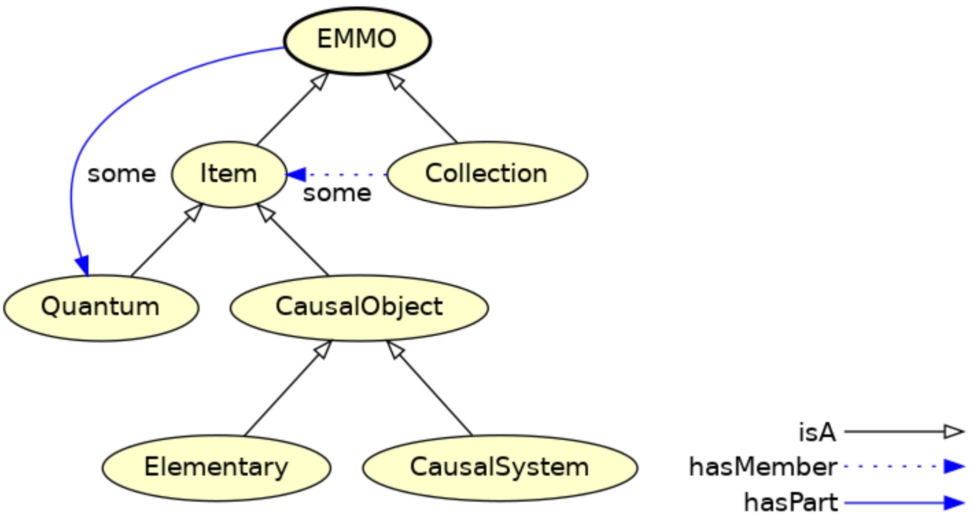


Figure 3 - EMMO Top Level

In EMMO, the only univocally defined real world object is the *CausalSystem* individual called **Universe** that stands for the universe. Every other real-world object is a composition of elementaries up to the most comprehensive object, the **Universe**. Intermediate objects are not univocally defined, but their definition is provided according to some specific philosophical perspectives. This is an expression of reductionism (i.e. objects are made of sub-objects) and epistemological pluralism (i.e. objects are always defined according to the perspective of an interpreter, or a class of interpreters).

3.1.2 EMMO Middle Level

The middle level of EMMO embraces pluralism by providing different ways to describe the world according to different perspectives. EMMO also allows to combine different perspectives to gain additional expressivity.

The *Perspective* class collects the different ways to represent the objects that populate the conceptual region between the elementary and universe levels.

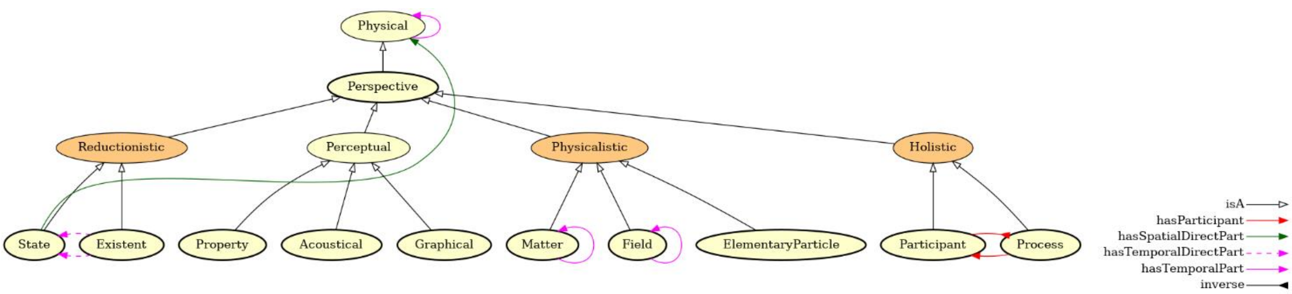


Figure 4 - EMMO Perspective Level

The *Reductionistic* perspective class uses the fundamental non-transitive parthood relation, called direct parthood, to provide a powerful granularity description of multiscale real-world objects. The EMMO can in principle represents the **Universe** with direct parthood relations as a direct rooted tree up to its elementary constituents.

The *Holistic* perspective class considers the importance and role of the whole and introduces the concept of real-world objects that unfold in time in a way that has a meaning for the EMMO user, through the definition of the classes *Process* and *Participant*.

The *Perceptual* perspective class introduces the concept of real-world objects that can be perceived by the user as a recognisable pattern in space or time. Under this class the EMMO categorises e.g. formal languages, pictures, geometry, mathematics, and sounds. Phenomenic objects can be used in a semiotic process as signs.

The *Physicalistic* perspective class introduces the concept of real-world objects that have a meaning for the ontologist under an applied physics perspective.

The *Semiotics* perspective introduces the concepts of the *semiosis* process that have the *semiotic entities* (*Sign*, *Object*, *Interpretant* and *Interpreter*) as spatial parts. It is inspired by Pierce semiotics and forms the basis in EMMO to represent e.g. models, formal languages, theories, information, and properties.

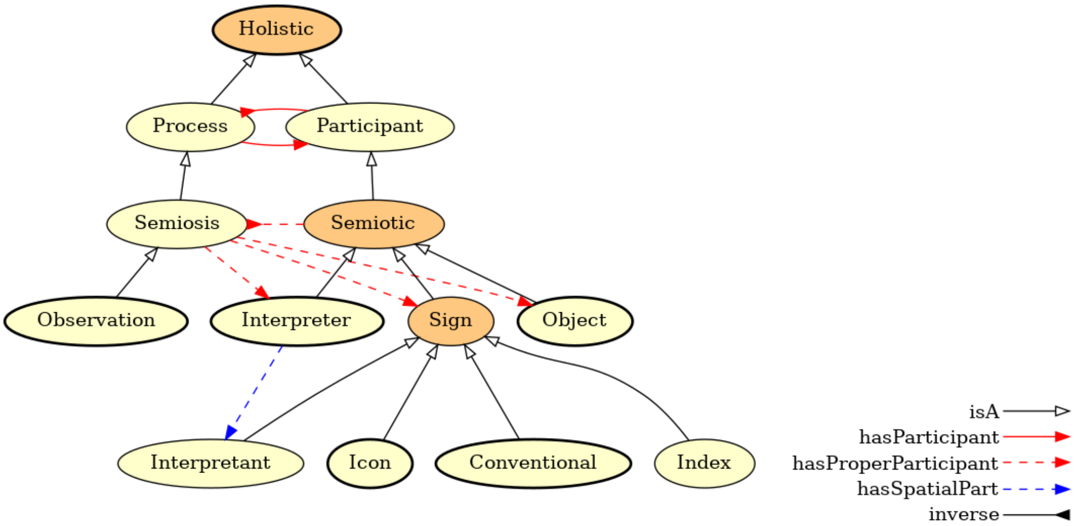


Figure 5 - EMMO Semiotics

The *Persistence* perspective consider 4D objects as they extend in time (*process*) or as they persist in time (*object*). It introduces a sometime useful categorization that characterizes persistency through continuant and occurrent concepts, even though this distinction is only cognitively defined.

3.1.3 Reference Level

EMMO comes with a set of generic reference ontologies that combine perspectives with ontologisation of common concepts like materials, math, units, etc. intended to be shared by domain ontologies. The reference ontologies are intended to be used by domain ontologies and imported separately using the IRIs listed in the table below with the current set of reference ontologies.

Table 1 – EMMO Reference Level Modules

Reference Domain	IRI
Materials	http://emmo.info/emmo/multiperspective/materials
Math	http://emmo.info/emmo/multiperspective/math
Models	http://emmo.info/emmo/multiperspective/models
Properties	http://emmo.info/emmo/multiperspective/properties
Metrology	http://emmo.info/emmo/multiperspective/metrology

Isq	http://emmo.info/emmo/multiperspective/isq
Siunits	http://emmo.info/emmo/domain/siunits
Chemistry	http://emmo.info/emmo/multiperspective/chemistry

3.1.4 Domain Ontologies

Currently there are several domain ontologies in development that use EMMO as the top and middle level ontology. Typically, they import one of the versions of EMMO listed on https://emmo-repo.github.io/. The following table lists the public EMMO-based domain ontologies that we are aware of. Please create an issue if you have a public domain ontology that you think should be listed here.

Table 2 - EMMO Domain Modules

Reference Domain	IRI
Characterisation Methodology Domain Ontology (CHAMEO)	https://github.com/emmo-repo/domain-characterisation-methodology
Battery Interface Ontology (BattINFO)	https://github.com/BIG-MAP/BattINFO
General Process Ontology (GPO)	https://github.com/General-Process-Ontology/ontology
Ontology for the Battery Value Chain (BVC)	https://github.com/Battery-Value-Chain-Ontology/ontology
Crystallography	https://github.com/emmo-repo/domain-crystallography
CIF ontology	https://github.com/emmo-repo/CIF-ontology
Domain Ontology for Additive Manufacturing (DOAM)	https://github.com/emmo-repo/doam
Mechanical Testing	https://github.com/emmo-repo/domain-mechanical-testing
Microstructure domain ontology	https://github.com/emmo-repo/domain-ontology
Datamodel ontology	https://github.com/emmo-repo/datamodel-ontology
Mappings ontology	https://github.com/emmo-repo/domain-mappings
Open Translation Environment Interface Ontologies (OTEIO)	https://github.com/emmo-repo/oteio
Atomistic and Electronic Modelling	https://github.com/emmo-repo/domain-atomistic
EMMO example domain ontologies	https://github.com/emmo-repo/EMMO/tree/master/domain

3.2 The CoBRAIN EMMO Conceptual Subset

The complexity of the EMMO ontology is something that cannot be easily handled by a non-expert in formal ontologies, which is the case among the almost entirety of experts in scientific and technical domains. For this reason, the conceptual framework available to the CoBRAIN domain experts has been reduced to the minimal number of concepts required to express the user cases but still manageable by ontology novices. The CoBRAIN subset is directly mapped to the overall EMMO ontology, so that it is possible to place the CoBRAIN knowledge base within the larger and more logically complex EMMO framework.

In the following sections, the EMMO concepts that constitute the TBox foundations are introduced.

3.2.1 4D Approach

The EMMO is intrinsically four-dimensional, meaning that real-world entities are represented as always extending in 4D. The reasons for this choice are related to the intrinsically evolutionary nature of physical phenomena, just like the concept of bond (which is behind every object definition) which requires the establishment in time of persistent interactions between the bonded entities.

Without entering in the details, a generic entity is represented using a graphical representation like the one in Figure 6, where the evolution in time is expressed by the horizontal extension, while the spatial extension is expressed by the vertical extension, and different entities are represented by polygons that may or may not overlap.

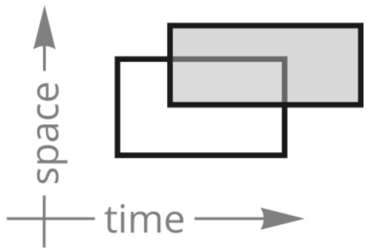


Figure 6 - 4D Representation

3.2.2 Object and Process

In the EMMO the object/process distinction is simply a matter of convenience since in a 4D conceptualisation everything is unfolding in time, and stationarity depends upon observer time scale. However, it is still convenient to retain an object-process distinction since it is naturally rooted in the common sensical way to discuss about the world and may facilitate the comprehension of the concepts by domain experts.

More specifically, an entity is called a **process** if its defining class (or type) is expressed according to how it extends in time (focus on temporal evolution), or an **object** if its defining class is expressed according to how it persists in time (focus on spatial configuration). The same individual may then be a process or an object, or both, depending on the class to which it belongs. For example, the same 4D entity representing a human being, which is an object, can represent the process of aging, which is of course a process.

The OWL 2 DL classes **Object** and **Process** are then the fundamental classes for all physical entities in the CoBRAIN ontology, as shown in Figure 7.

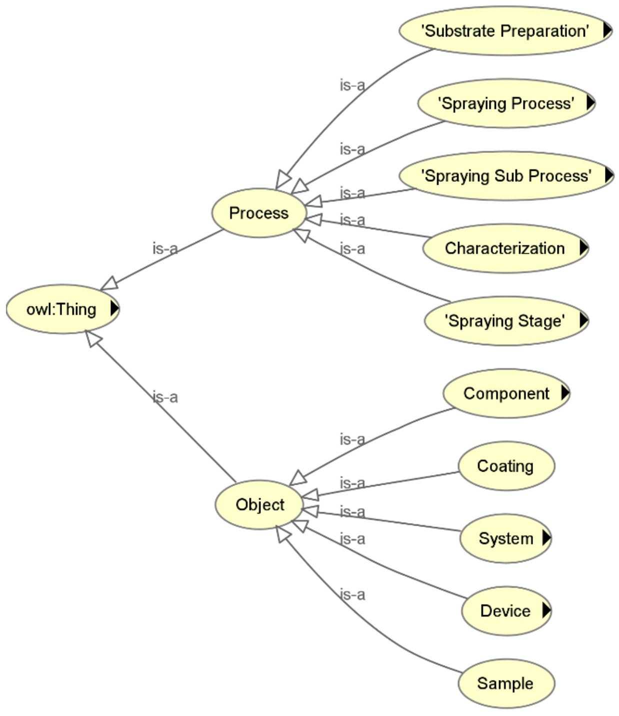


Figure 7 – CoBRAIN Object/Process Taxonomy

3.2.3 Mereological Relations

The mereocausality relationships are the backbone of the EMMO, being the union of a mereology and a causal theory. Mereology is the theory formalising the relations between a whole and its parts, through the fundamental concept of parthood. In the CoBRAIN ontology we make use of a simple subset of mereological relations: overlap, parthood, and spatial/temporal parthood, expressing intuitively their meaning through the above introduced graphical representation.

Proper Overlap

The relation of **proper overlap** occurs between two entities that share some of their parts, but they both still retain some parts that are not shared. Proper overlap is formalized by the **symmetric** object property *isProperOverlapOf* and provides several sub-relations as shown in Figure 8, when the object/process distinction is used to classify the related entities.

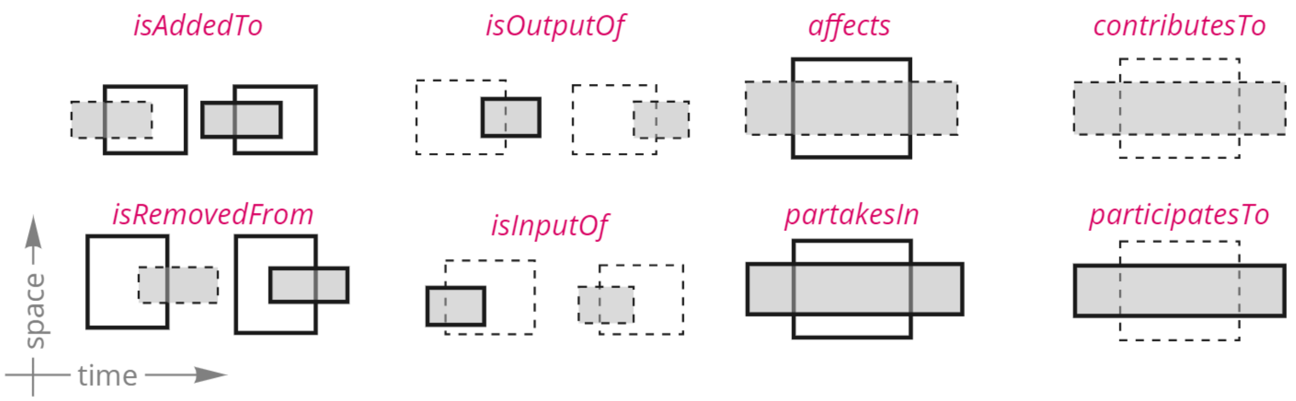


Figure 8 - Proper overlap sub-relations (continuous line standing for objects, dashed line for processes, and relations going from the grey to the white boxes)

The *isAddedTo* and *isRemovedTo* relations are used to represent user cases when a generic entity overlaps an object, within which its temporal evolution starts or ends. For example, it can be used to represent the injection of powders into a HVOF jet, or the ejection of molten particles from the same jet.

The *isOutputOf* and *isInputOf* relations are used to represent user cases when a generic entity overlaps a process, within which its temporal evolution starts or ends. These are the typical relations used to represent the sample coming out from an experimental procedure, or the gas feed used for a spraying process.

The *affects* and *partakesIn* relations are used to represent user cases when a generic entity overlaps an object, and it persists before and after the overlap. For example, these relations can be used to represent a component that is used into a device and then extracted and reused into another device.

The *contributesTo* and *participatesTo* relations are used to represent user cases when a generic entity overlaps a process, and it persists before and after the overlap. These are the typical relations used to represent a device such a HVOF torch that participates to an experimental procedure.

Spatial and Temporal Parts

Parthood occurs when two entities overlap but one is completely comprised within the other. By combining the concepts of process and object, we can introduce different types of sub-relations. The fact that the part covers (or not) the overall spatial extension of the whole leads us to the concepts of **spatial and temporal parts**, which are of paramount importance for the representation of actual real-world user cases. A summary of the parthood sub-relations (always **antisymmetric**) is shown in Figure 9.

The *isConstituentOf* and *isSubjectOf* relations are used to represent user cases when an object is spatial or temporal part of another object respectively. For example, they can be used to represent the constituent parts of a device (e.g., the components of a characterisation system), or a particular configuration expressed by an object.

The *isConstitutiveProcessOf* and *isBehaviourOf* relations are used to represent user cases when a process is spatial of temporal part of an object respectively. For example, they can be used to represent the constituent processes that makes a device work (e.g., heat exchange), or a particular behaviour of a device (e.g., the pre-heating phase).

The *isProperParticipantOf* and *isStatusOf* relations are used to represent user cases when an object is spatial of temporal part of a process respectively. For example, they can be used to represent an entity that participates in a process for the duration of the process itself (i.e., a role such as the experimentalist on a particular test), or a particular state of a process (e.g., a young man as temporal part of the overall human aging process).

The *isSubProcessOf* and *isStageOf* relations are used to represent user cases when a process is spatial of temporal part of another process respectively. For example, they can be used to represent the constituent processes that make a process occur (e.g., heat exchange in a HVOF deposition), or a particular stage of process.

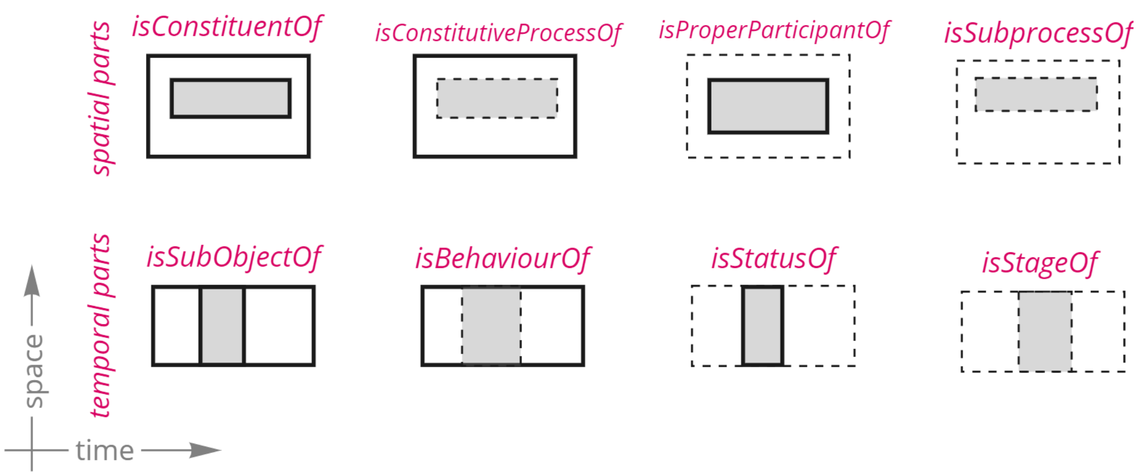


Figure 9 - Spatial and Temporal Parts

3.2.4 Causation

Causality in the EMMO is an extremely powerful relation that extends from the elementary particle level, including the representation of quantum systems, up to the macroscopic level. To reduce the complexity of such approach, the causal relations that have been included in the CoBRAIN EMMO subset refer only to macroscopic entities, and are summarized in Figure 10 and Figure 11.

Causality between macroscopic entities is expressed by two relations families:

- **Temporal causation**, which is always **asymmetric** and expresses the evolution of entities distinguishing between causing entity and effected entity. Direct causation, without intermediaries, is expressed by *hasNext* or *hasNextStep* relations, while causation with intermediate entities is expressed by *precedes* or *hasSubsequentStep* relations.

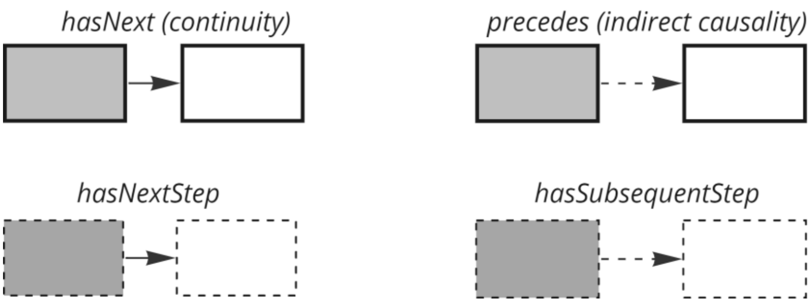


Figure 10 - Temporal Causality Relations

- **Spatial causation**, which is always **symmetric** and expresses the mutual influence between entities. The *isAdjacentTo* and *communicatesWith* relations express a direct interaction between entities, without intermediaries. The *indirectlyAffects* and *indirectlyCommunicatesWith* relations express an indirect interaction, with intermediaries. Spatial causation can be used to represent spatial configurations.

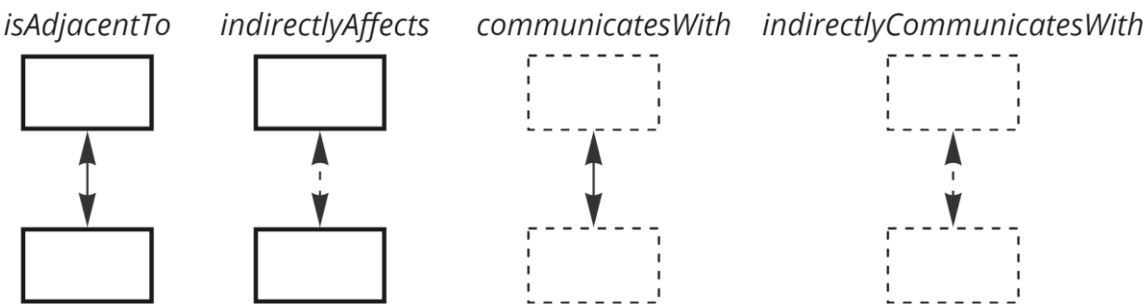


Figure 11 - Spatial Causality Relations

3.2.5 Semiotic Framework

The EMMO is designed to formalise the way in which a property (e.g., physical quantity, names, pictures) is generated according to a particular procedure (e.g., observation, modelling, characterisation) by means of a semiotic based approach.

Semiosis

The semiotic triangle is shown in Figure 12, where the semiotic process (in the centre) hosts the semiotic object (the observed entity), the sign (the entity that stands for it) and the interpreter (the agent responsible for the generation of the sign). This general schema can represent modelling and characterisation activities, keeping track of the details of the generation process.

For example, a cold spray process (semiotic object) can be observed (semiosis) by an experimentalist (interpreter) to keep track of the running time (sign). A SEM (interpreter) can scan (semiosis) a coated substrate (semiotic object) and provide an image (sign). A microstructure (semiotic object) can be modelled (semiosis) by a simulation software (interpreter) to provide a prediction for its mechanical properties (sign).

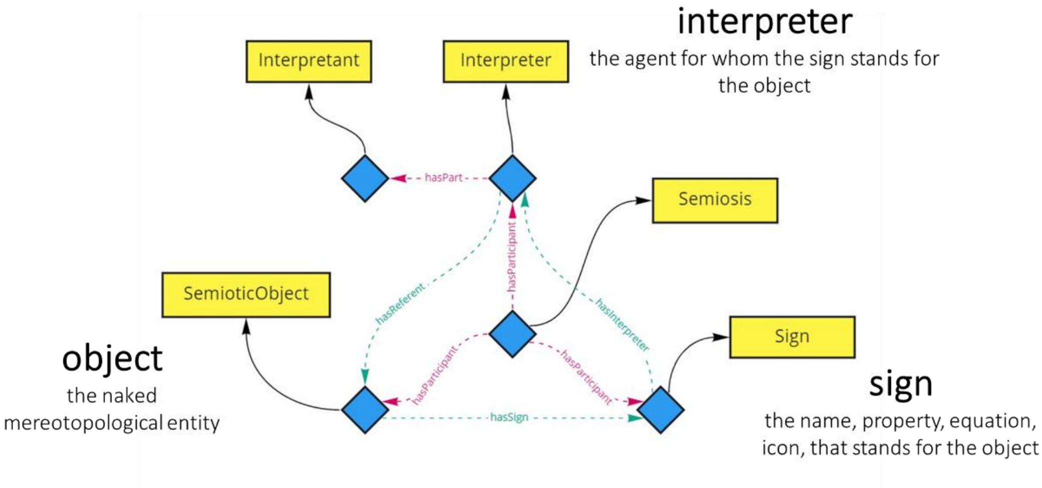


Figure 12 - EMMO Semiotic Triangle

More than one sign can be used to refer to the same entity, reflecting the fact that an entity can be the subject of several measurement or modelling investigations, that can also be in contradiction. In fact, things like physical properties, names, attributes, location, time, or any data in general, are signs generated through a **subjective semiotic process**, that holds only for a particular class of interpreters. In the EMMO a sign is always related to the agent beyond the semiotic statement, and the process of generation of the sign is always documented, as shown in Figure 13.

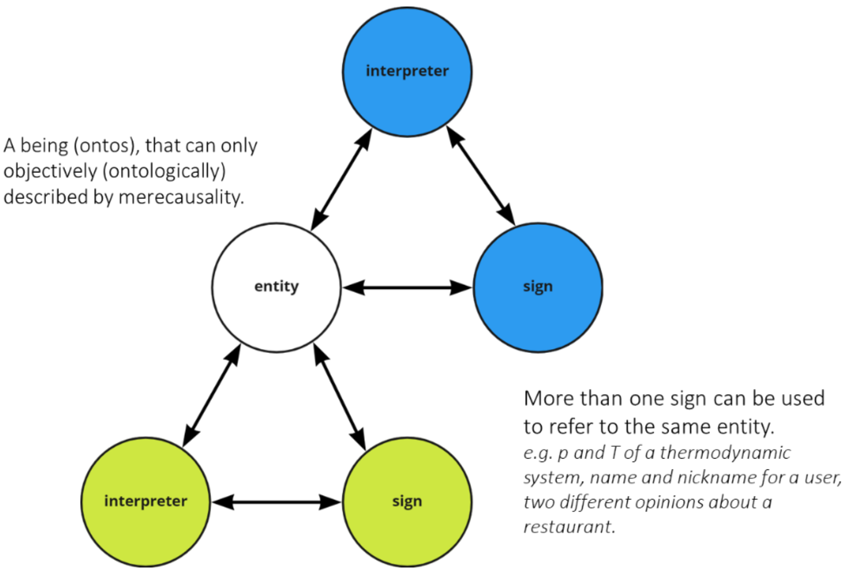


Figure 13 - Multiple Semiosis

Properties, Quantities and Units

In CoBRAIN we are interested in a particular subclass of signs, called **properties**, which are the ones obtained through a well-defined procedure of interaction (e.g., a characterisation procedure, a modelling workflow, using a physical model such as Fourier law for heat conduction). Among all possible properties, we are more likely interested in the subclass of **quantities**, which are the properties that can be quantified and that are represented using units of measurement.

To provide a comprehensive representational framework, that can be shared between different domains, the EMMO includes:

- the quantities formalised by the **International System of Quantities ISO 80000**[7], as shown in Figure 14
- a general metrological framework based on the **International Vocabulary of Metrology**[8], as shown in Figure 15
- a framework for the system of units based in the **International System of Units (SI)**[9], as shown in Figure 16

These EMMO modules, based on semiotics, enable the CoBRAIN ontology to represent in a comprehensive way all the methodologies that can be used to generate information about a particular entity. The network of entities and information collected within the project (i.e., the mereocausally represented states of things and the semiotic processes used to observe them) is the **knowledge base**.

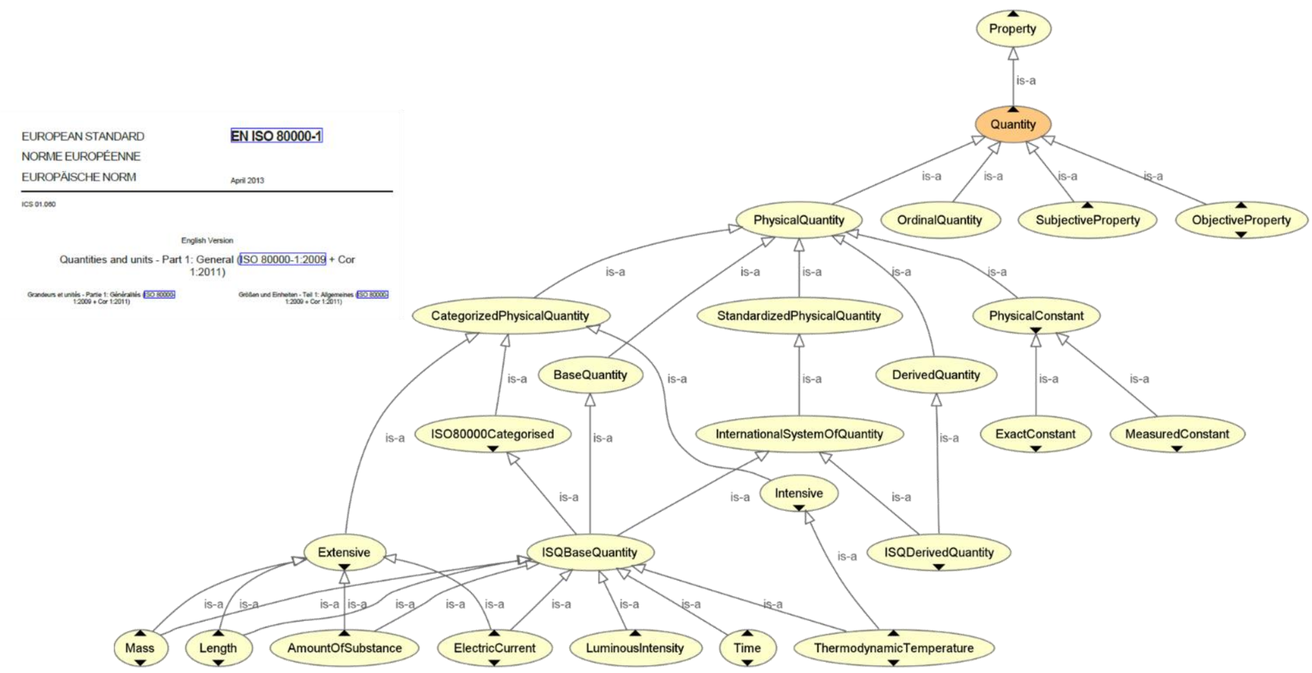


Figure 14 - EMMO International System of Quantity

[7] https://www.iso.org/standard/76921.html

[8] https://www.bipm.org/documents/20126/54295284/VIM4_CD_210111c.pdf

[9] https://www.bipm.org/en/measurement-units

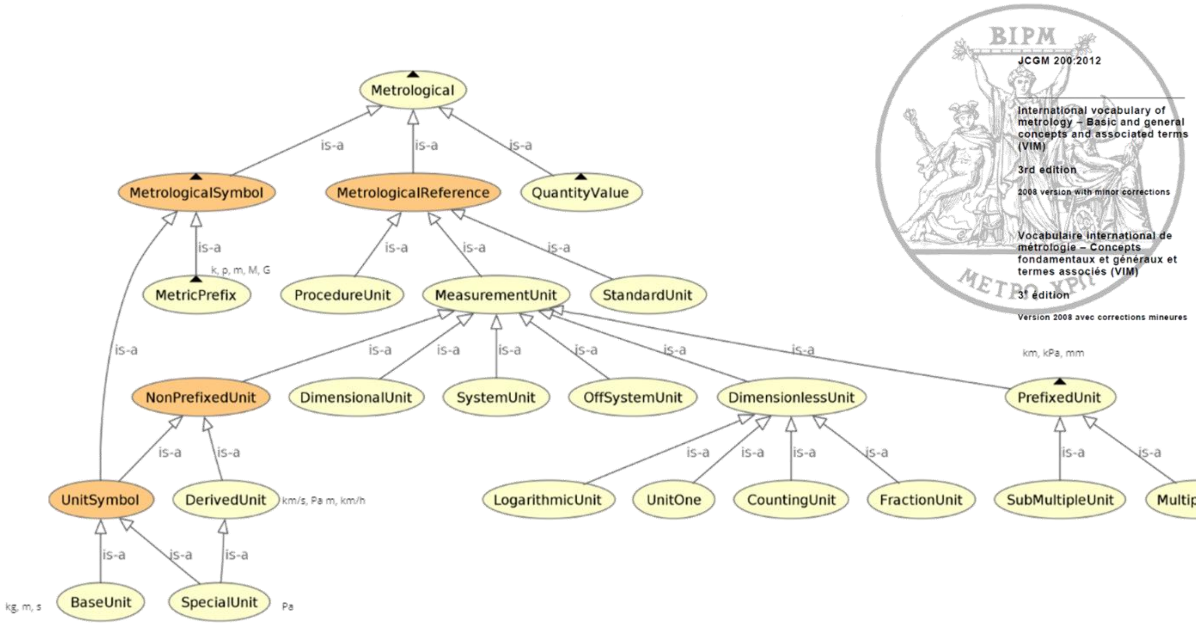


Figure 15 - EMMO Metrology

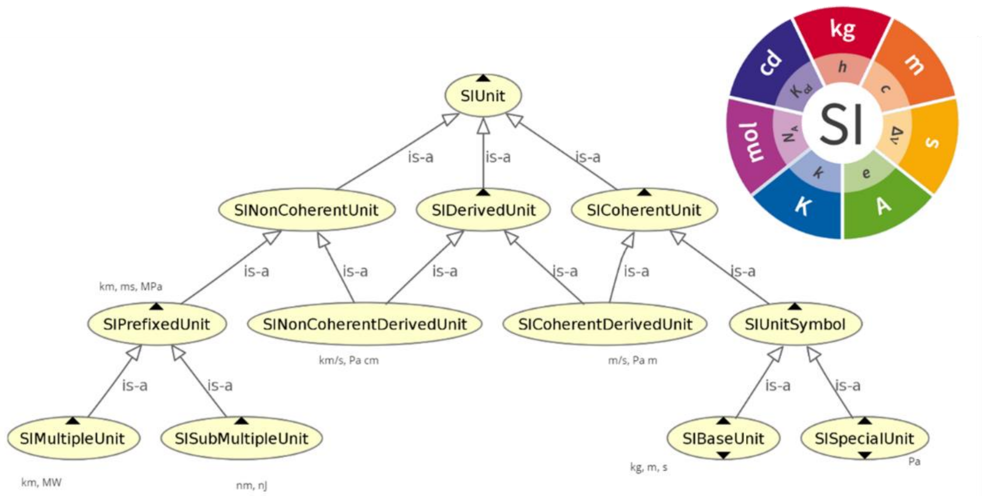


Figure 16 - EMMO International System of Units

3.2.6 Workflows and Knowledge Generation

The combination of mereocausality relations and semiotic processes enables the **representation of workflows** that can be **simulation workflows (MODA)** or **characterisation workflows (CHADA)**, or more generally any potential procedure that generates information about a system. The process of knowledge generation can be represented in the EMMO as shown in Figure 17, where the input (if present), the output and the subject of the observation are related together using mereocausal relationships.

This approach can be used to represent **complex workflows**, such the ones that results from the concatenation of more than on MODA, as shown in Figure 18, and it is possible to focus on the data flow or the task flow representations. Moreover, it can go beyond the MODA, and represent meta-modelling activities such as the usage of data-based models, when AI approach is used to create surrogate models starting from experimental data or physics-based modelling data, as shown in Figure 19.

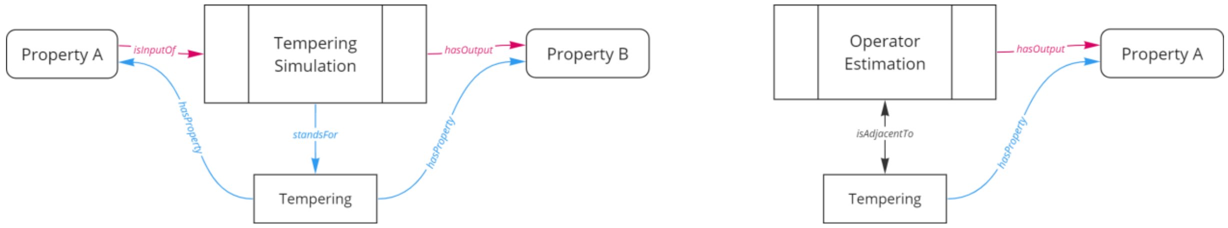


Figure 17 - Knowledge generation examples

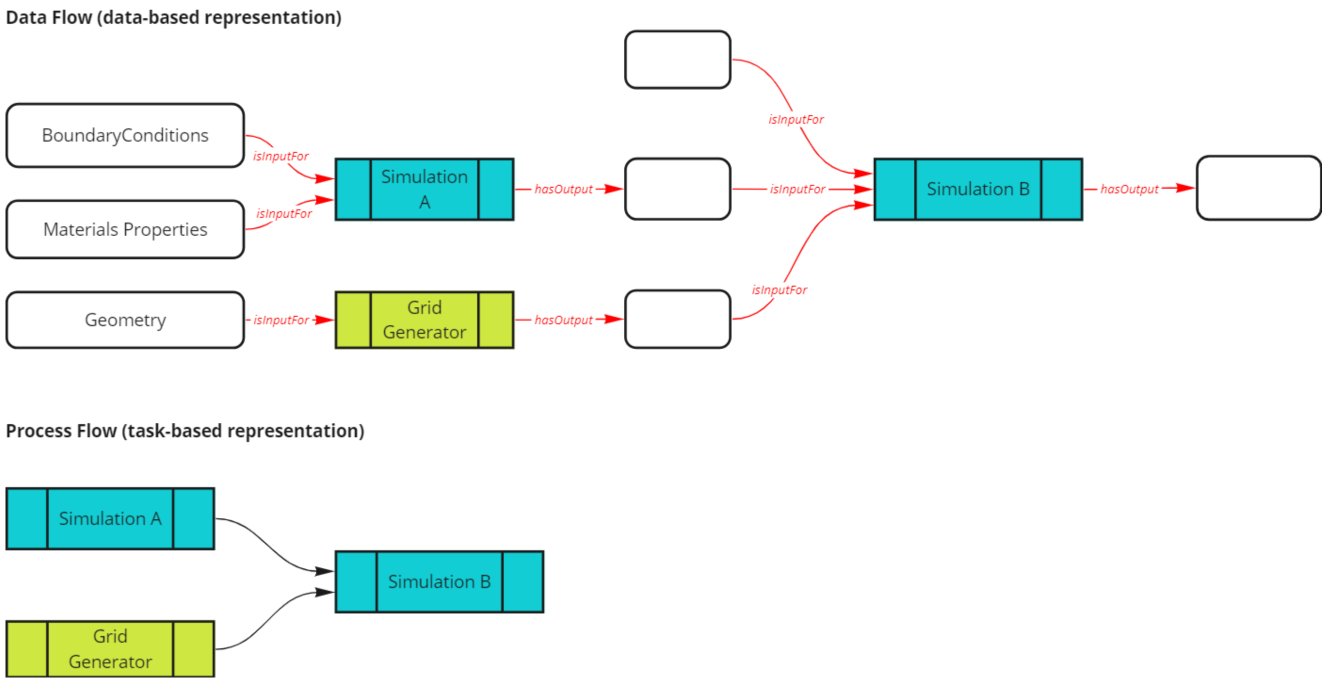


Figure 18 - Data-based and task-based MODA workflow example

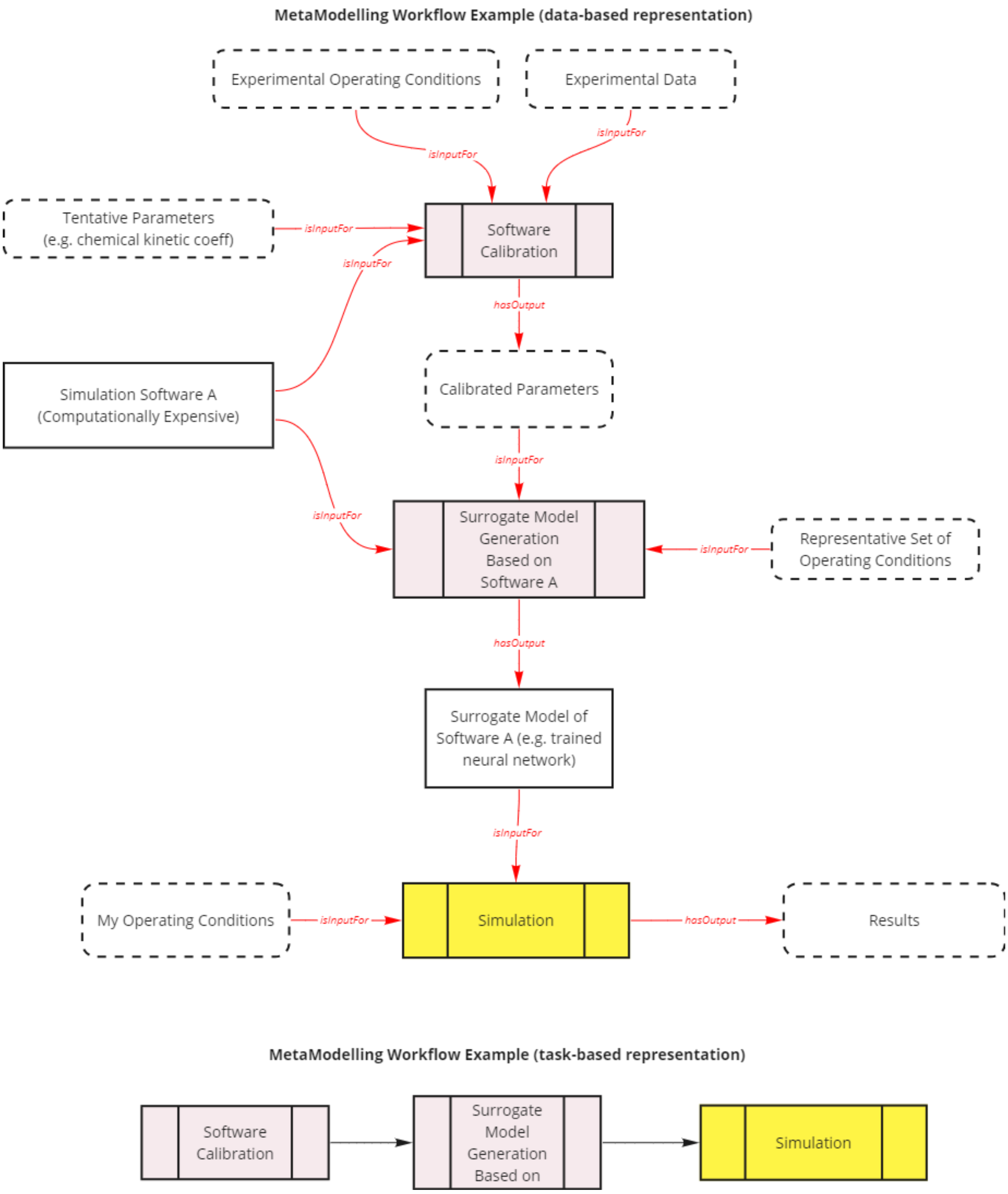


Figure 19 - Meta-modelling workflow example

3.3 Conclusions

The CoBRAIN subset of the EMMO provides a minimum comprehensive set of conceptual tools that can be used to represent the user cases addressed by the project, including the representation of:

- the experimental set-up using mereocausality
- the simulation and characterisation workflow, using a combination of semiotics and mereocausality
- the creation of AI-based models

In the next section this conceptual framework will be applied to thermal spraying, according to T1.1 objectives.

4 The CoBRAIN Ontology

4.1 Bridging the Conceptualisation Gap

One of the most important challenges in developing a domain ontology for a specific community of users is to enable the community to express the concepts that make up their overall knowledge framework in a way that can be easily understood by them and by other potential users with similar or different backgrounds.

Gathering and formalising a domain knowledge is done through the process of **conceptualisation**, i.e., by identifying ontological concepts in the form of classes, relations, and axiomatic constraints that cover the domain of interest. To overcome the **barriers** coming from the lack of expertise in ontology engineering, the OntoTrans project has developed a methodology for the interaction between the **translator** and the industrial stakeholders, aimed to facilitate collective contributions to the conceptualization effort.

The conceptualisation steps performed during the first year of the CoBRAIN project are summarised in the following sections.

4.1.1 The OntoTrans Board for Conceptualisation

The board has been designed to be used in a collaborative online platform (such as MIRO[10]) to enable participants to contribute to the conceptualisation development and is shown in Figure 20. It guides participants from left to right to:

1. Introduce the class concepts needed to **describe** the user case
2. expressing axioms to better define what classes represent **relating** them using mereocausal relations
3. introduce the properties used to **determine** (or characterize) the entities
4. introduce the datatypes used to **express** the properties (e.g., double, string)
5. define the **serialisation** for each datatype (e.g., file format)
6. express how the properties are obtained by introducing the concept of **knowledge generators**
7. formalise the **MODA** and **CHADA** using the concepts introduced in the previous blocks

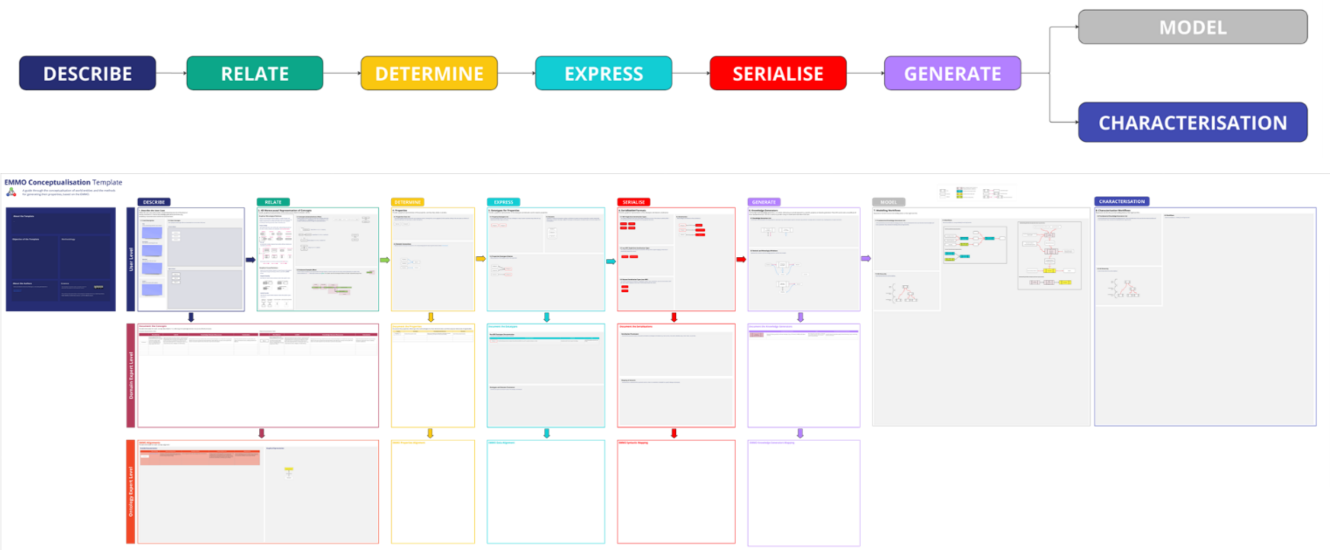


Figure 20 - Conceptualisation board

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[10] https://miro.com

Besides that, it provides a place to list the references to domain literature (e.g., standards) and to propose labels and definitions. The board has been populated through a collaborative effort, involving all WP1 partners.

This deliverable focuses on the points from 1 to 3. T1.4 activities will cover the serialisation of the datatypes, and the populating of the knowledge base with the MODA and CHADA provided by D1.2 and D1.3.

4.1.2 Object and Process Class Concepts

The first block has been populated by classes expressing all CoBRAIN relevant concepts in the field of thermal spraying technology, classifying them as object or process. The results are shown in Figure 21. For each class a set of labels, a definition, a comment, and a list of domain literature sources has been provided to better clarify the concept behind the class.

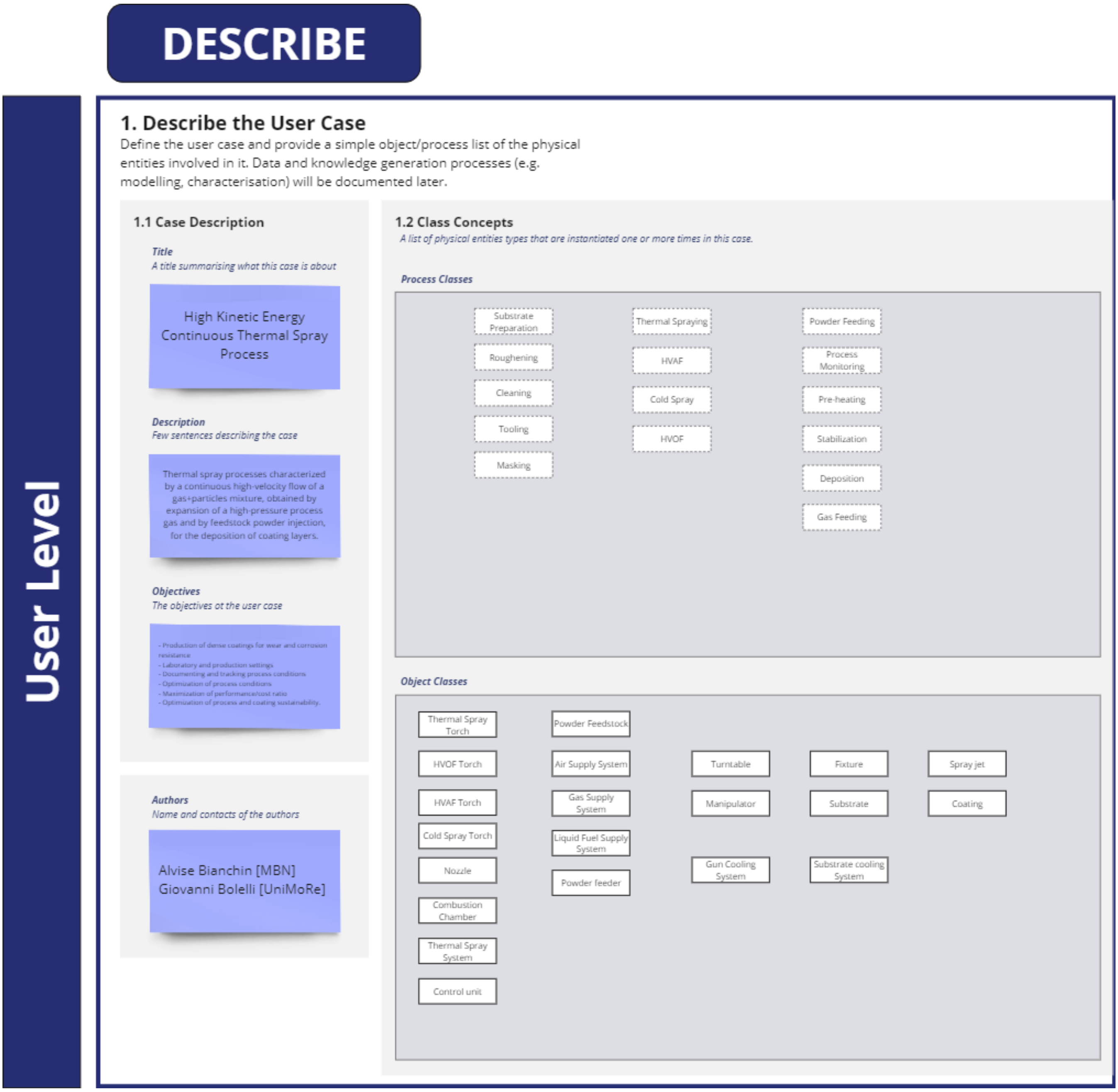

Figure 21 - Describe block, expressing the object/process class concepts

4.1.3 Mereocausal Representation of User Cases

The second block has been populated by expressing the relations between classes using axioms in the *Subject/Predicate/Quantifier/Object* form (e.g., COATING *isOutputOf* **some** THERMALSPRAYING). The mereocausal relations are summarised on the left of the block, to facilitate the users, as shown in Figure 22. An example of user case in 4D diagram has also been provided and shown in detail in Figure 23. The example represents the temporal parts that constitute the sub-objects of a substrate going through the preparation stages (i.e., roughening, cleaning, tooling, and masking) and the thermal spraying deposition process. Besides that, it describes related devices (e.g., the thermal spraying system) and processes (e.g., gas feeding).

It is important to understand **the representation of the user case itself is a form of knowledge without data**, since it documents in a formal way the state of things occurring during a specific run. This arrangement of things can also be analysed using AI tools to find recurring patterns according to a specific KPI (e.g., to find the user case structure that provides samples with highest hardness values).

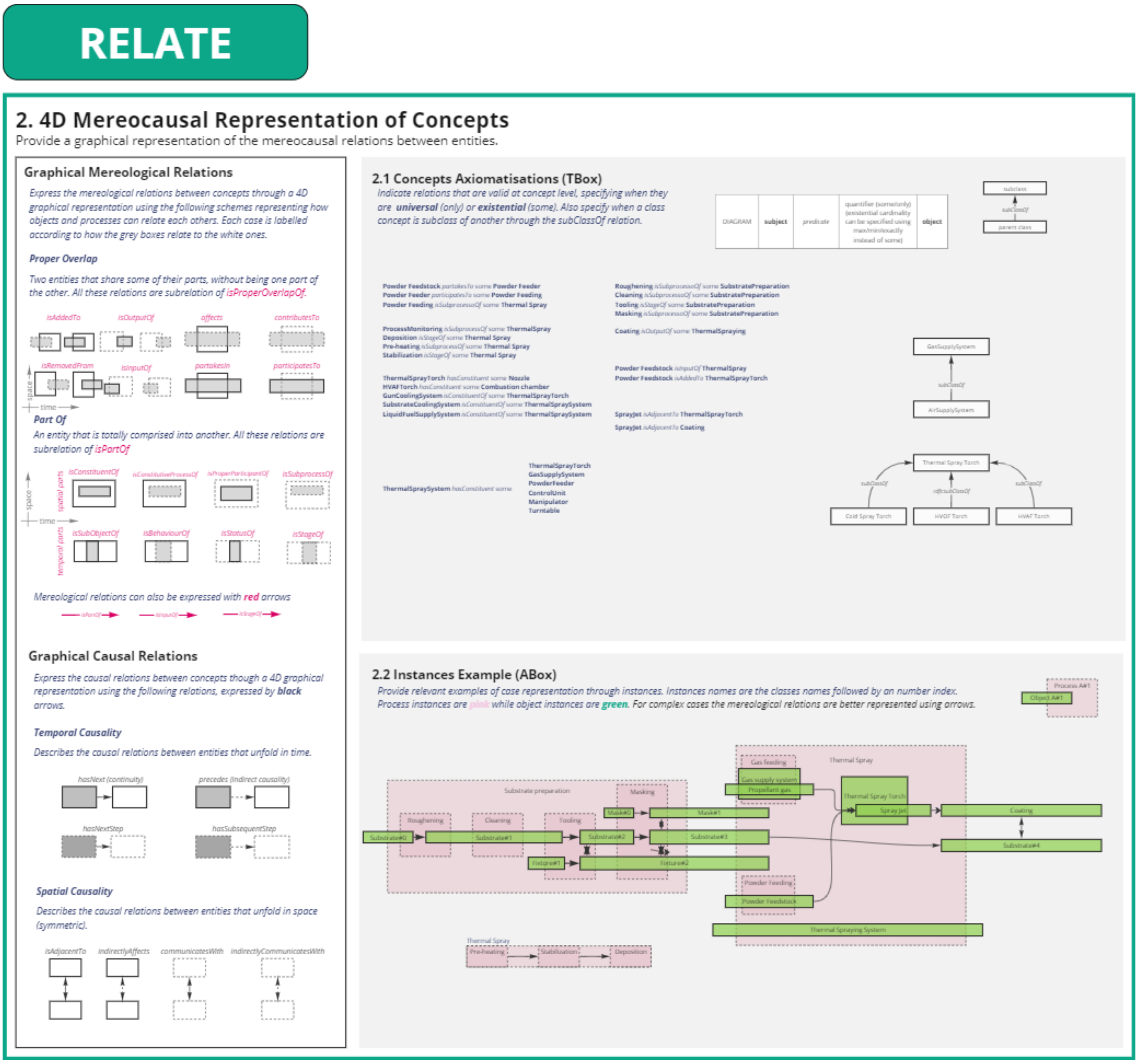

Figure 22 - Relate block, expressing the mereocausality relations between classes as axioms (*Subject/Predicate/Quantifier/Object*)

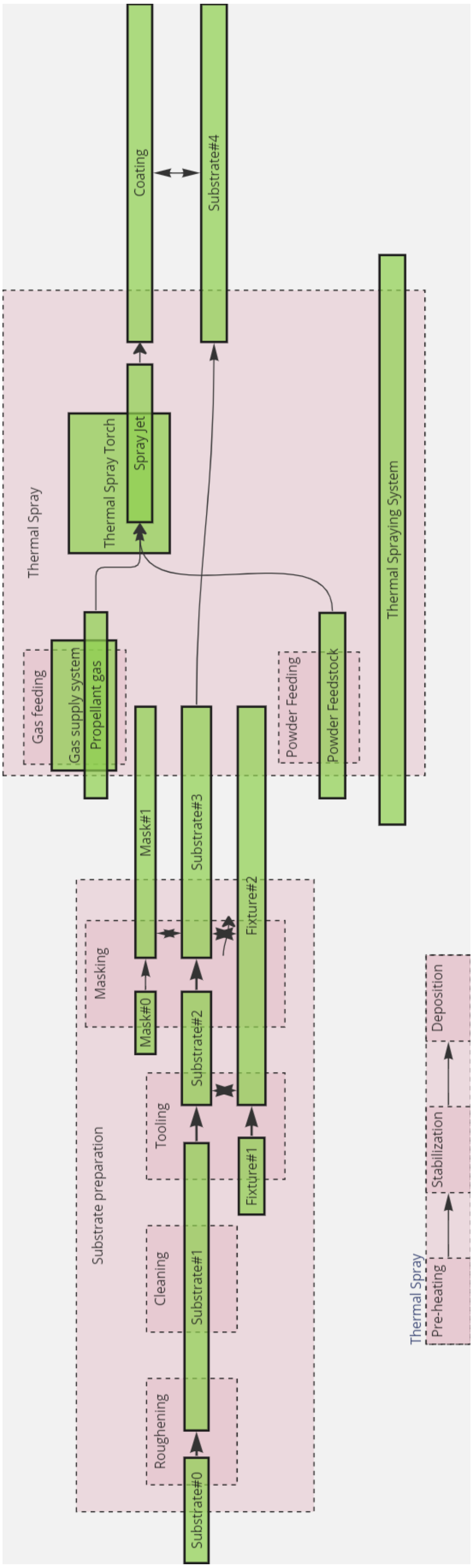

Figure 23 - User Case conceptualisation example

4.1.4 Properties Association

The third block has been populated by listing all the properties that are relevant for the thermal spraying process, and then connecting the properties to each respective entity. For each property a reference to the ISQ, to the unit of measurement and to the literature sources has been provided, as documentation.

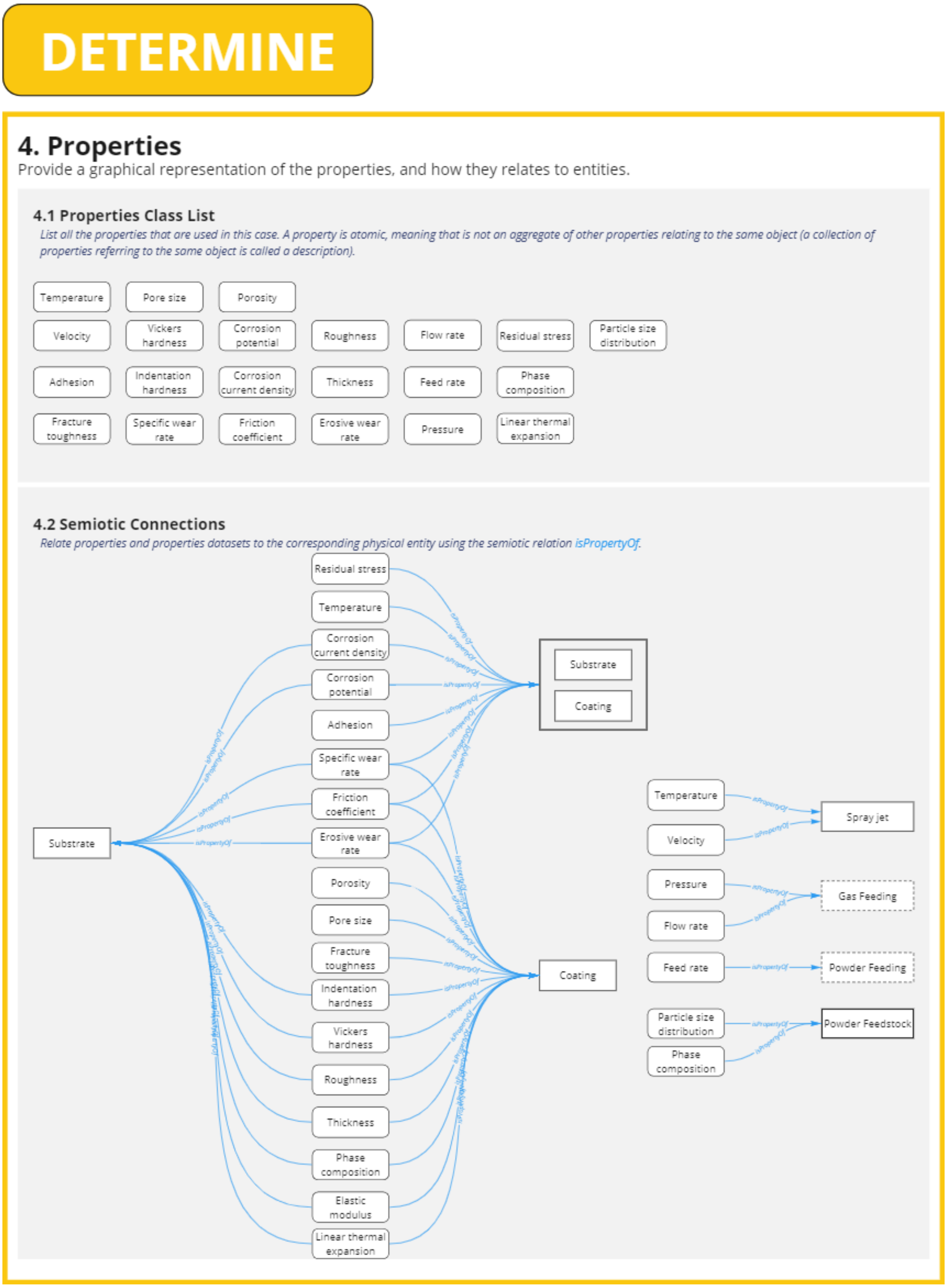

Figure 24 - Determine block, expressing the properties used to characterise each class entity

4.1.5 MODA and CHADA

The formalisation of MODA and CHADA has been provided by D1.2 and D1.3. The CoBRAIN ontology will make use of the EMMO conceptual tools populate the KBE with a representation of the MODA and CHADA workflows foreseen by the project during the T1.2.

An example of a simple simulation workflow represented using the CoBRAIN subset is shown in Figure 25, including the connection between the material and the model, the simulation input and output, the data structures, the individuals (i.e., the ABox) that stands for a specific simulation run, and the actual data serialisation.

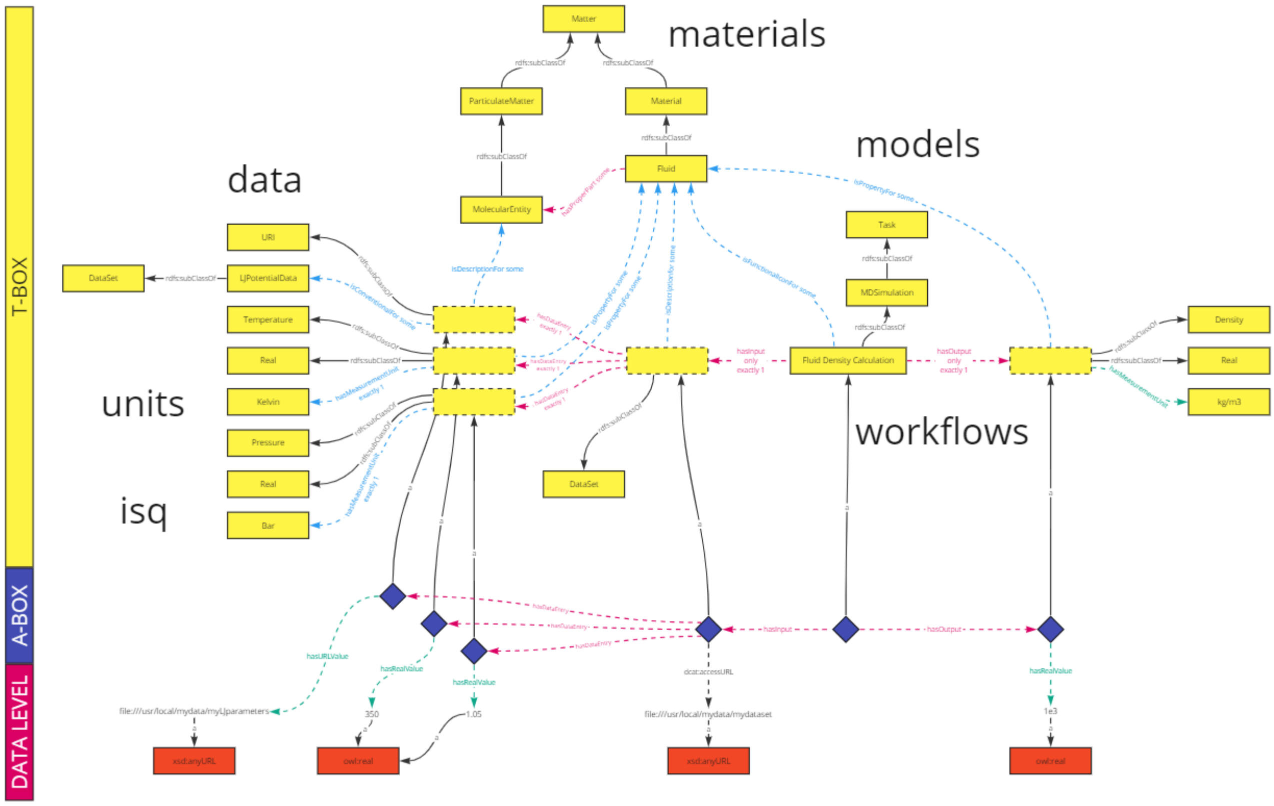

Figure 25 - Ontologisation of a simulation workflow

4.2 OWL 2 DL CoBRAIN Ontology

Following the conceptualisation expressed in the conceptualisation board, an OWL 2 DL ontology has been created, to be used as model in the graph database that will constitute the KBE. The CoBRAIN ontology is stored in GitHub, in the CoBRAIN organisation page https://github.com/cobrain-project (for now as private repository, that will be made public as soon as the final version will be achieved), with IRI https://www.cobrain-project.eu/thermalspraying.

The ontology has been developed using the Protégé tool for OWL 2 DL ontology development[11] as shown in Figure 26. The ontology provides a taxonomy of classes that can be used to represent the thermal spraying process, as shown in Figure 27, together with the subset of EMMO mereocausality and semiotic relationships, as shown in Figure 28. It provides also a taxonomy of classes for the representation of datatypes and properties, as shown in Figure 29.

The OWL 2 DL serialisation of the CoBRAIN ontology is provided as Annex I.

[11] https://protege.stanford.edu/

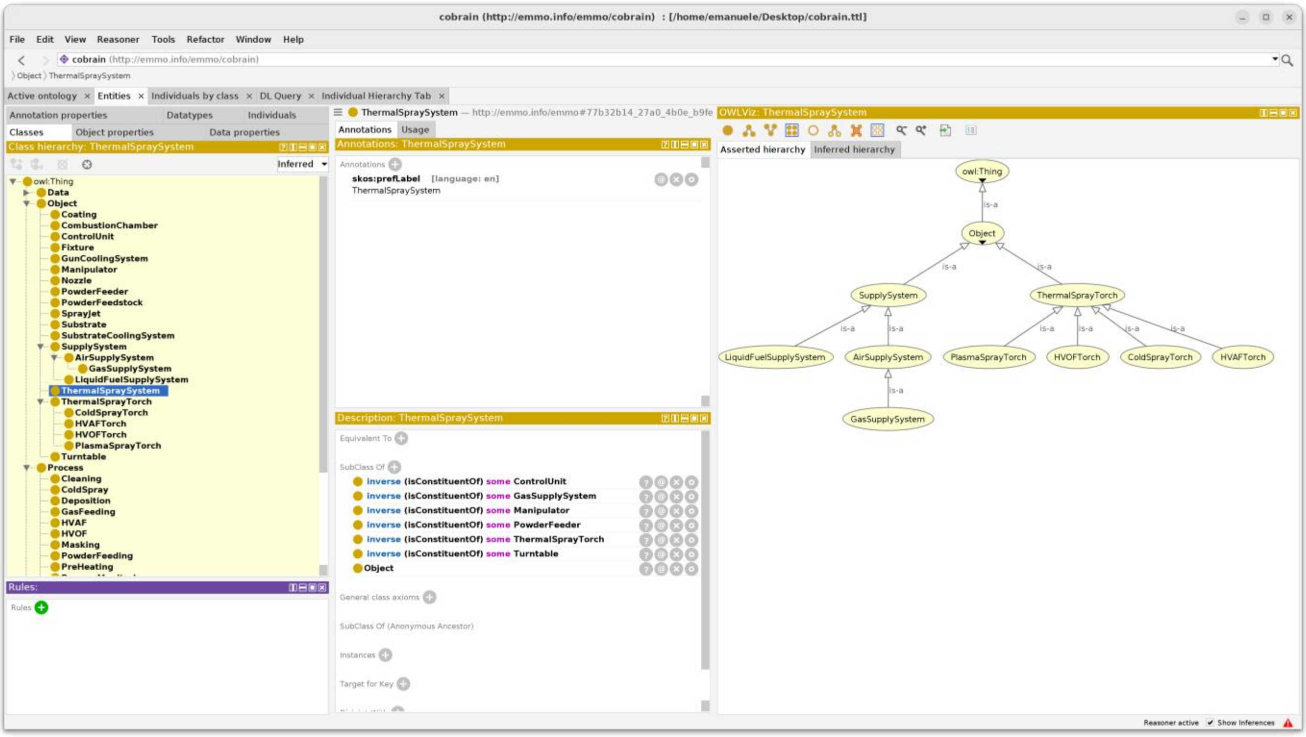

Figure 26 - CoBRAIN Ontology in Protégé

Figure 27 - CoBRAIN Ontology Object/Process Taxonomy

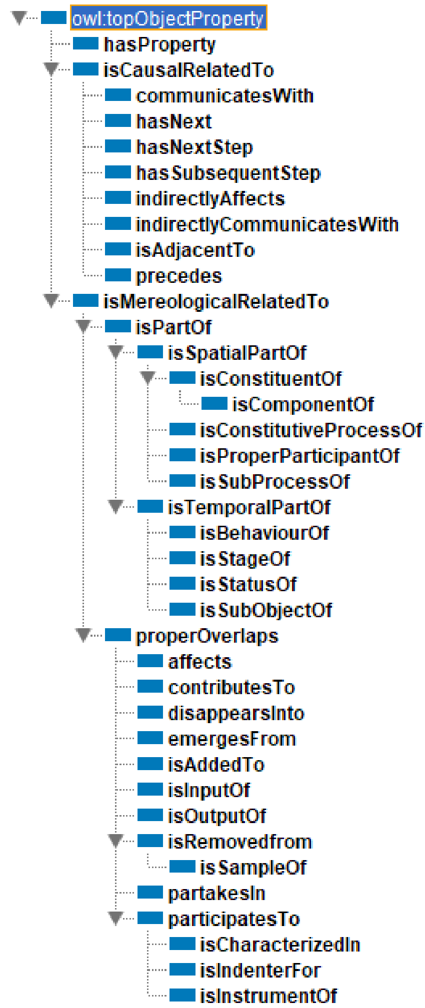

Figure 28 - CoBRAIN Ontology Object Property Hierarchy

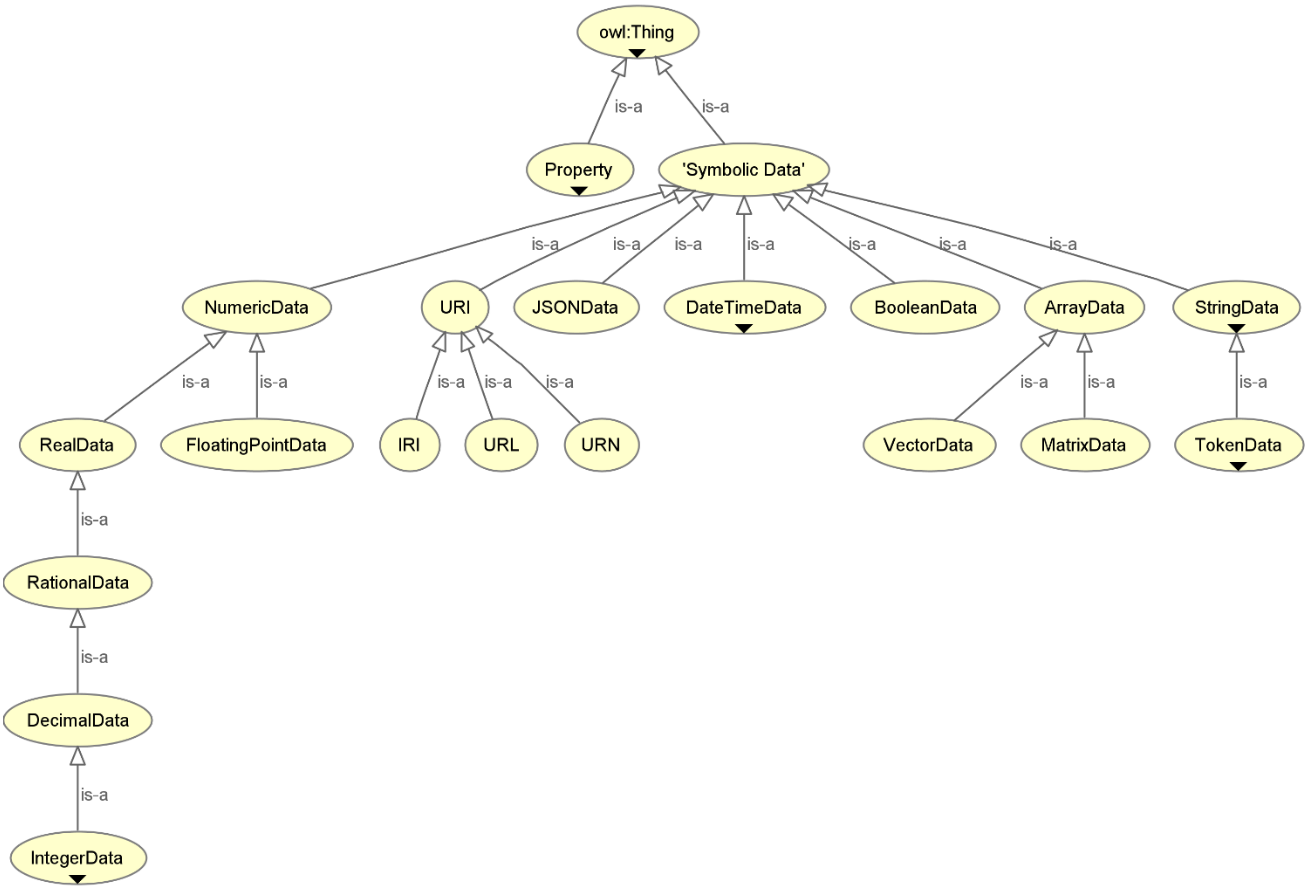

Figure 29 – CoBRAIN Ontology Property and Data Taxonomy

4.3 Data Mapping Example

While the mapping of the DMP datasets is foreseen in the second year of the project, within T1.4 activities, it can be useful to see how it can be realised using the CoBRAIN ontology conceptualisation.

For example, the DMP dataset for nanoindentation is shown in Figure 30, listing the data and metadata foreseen by this application. The Excel table collecting all the dataset entries is shown in Figure 31, where each row is representing a specific nanoindentation characterisation process. The mapping between the dataset Excel serialisation and the KBE is shown in Figure 32, where each column has been interpreted semantically according to the CoBRAIN ontology concepts and related to the other columns using the relations provided by the EMMO subset, using in a Subject/Predicate/Object schema.

Using this approach, it is possible for the end users to store the data using traditional, easy to use tools (such as Excel spreadsheets), without the need for training in ontology engineering or data management. The spreadsheet will be imported into the KME thanks to the related mapping.

Examples of state of the art software tools that can be used for KME creation and dataset mapping are GraphDB[12] and OntoRefine[13] respectively, that will be tested for use in the CoBRAIN project during the second year of the project.

[12] https://graphdb.ontotext.com/

[13] https://www.ontotext.com/products/ontotext-refine/

SHARED DATA and METADATA

Field	Description
Sample ID	String: Sample name and identification number of test.
Sample description	String: sample composition and production information.
Test definition	String: Type of test and instrument name (i.e. Nanoindentation-Pillar splitting, MTS G200).
SOP file name	String: indication of the file name containing parameters of measurement (i.e. acquisition rate, max load, loading rate, approach speed etc.) .
Measurement Date Time	dd/mm/aaaa hh:mm:ss
Indenters	String: type of the indenter (i.e. Berkovich); serial number; material of the indenter.
Curves	Indentation curve: Load applied [N] vs penetration depth [m].
P_C	**mN,** the value of the critical load, identified from Indentation curve: (Load applied [N] vs penetration depth).
K_{IC}	**MPa√m,** the value of the fracture toughness calculated from the value of the critical load.

LOCAL DATA

Field	Description
Sample ID	String: Sample name and identification number of test.
Measurement file	**.mss**, located in UNIROMA3's servers, contains all the information related to the measurement and the complete results.
Indentation Data	**.xls**, located in UNIROMA3's servers, contains data, exported from .mss, needed for fracture toughness calculation (i.e. applied load [mN] vs penetration depth [nm]).

Figure 30 - DMP Nanoindentation Dataset

METADATA													DATA		
Sample				Test					Indenter						
Sample ID	Composition	Production Information	Origin ID	Test ID	Test Type	Instrument ID	SOP File	DateTime	Type	S/N	Material	Indentation Curve	Pc	KIC
FCC0qB	[[Cu,Zn],[65,35]]	Some text about sample production	yQvzd7	h2baA2	PillarSplitting	MTSG200-1	file://emanuele@kant.unibo.it:22/home/emanuele/file3.txt	12/3/2023 11:54	Berkovich	XIUQ32	W	[[1,2,3],[1,2,3]]	12	34
TatORe	[[Cu,65],[Zn,35]]	Some other text about sample production	yQvzd7	ap6eUT	PillarSplitting	MTSG200-1	file://emanuele@kant.unibo.it:22/home/emanuele/file5.txt	14/3/2023 12:54:00 AM	Berkovich	XIUQ32	W	[[1,3,4],[2,1,5]]	5	3

Figure 31 - DMP Nanoindentation Excel Table

Subject	Predicate	Object	
ID	productInformation	Production Information	xsd:string
	isCharacterizedIn	Test ID	Characterization
	hasProperty	[a IndentationCurve ;	
		isOutputOf Test ID;	
		hasDataValue Indentation Curve .]	xsd:JSON
		[a CriticalLoad ;	
		isOutputOf Test ID;	
		hasDataValue PC .]	owl:real
		[a FractureToughness;	
		isOutputOf Test ID;	
		hasDataValue KIC .]	owl:real
		[a Composition ;	
		isOutputOf Test ID;	
		hasDataValue Composition .]	xsd:string
	a	Sample	
	isSampleOf	Origin ID	
Test ID	a	Test Type	Characterization
	hasInstrument	Instrument ID	Instrument
	hasSOPFile	SOP File	xsd:anyURI
	hasDateTime	Date Time	xsd:Datetime
InstrumentID	hasIndenter	[a Type ;	Indenter
		hasSN S/N ;	xsd:string
		hasMaterial Material .]	xsd:string

Figure 32 - DMP Nanoindentation Mapping

5 Conclusions – Next Actions

This deliverable presents an overview of the CoBRAIN Knowledge Management Environment, showing how it can act as Open Translation Environment, and its compatibility with the OntoTrans framework. It also presents the development of the CoBRAIN ontology (the TBox), starting from a subset of the EMMO environment, and how it can be used as conceptual framework for the representation of the knowledge generated by the CoBRAIN project.

The next steps of WP1 are related to T1.4, where the CoBRAIN ontology (TBox) will be used as model to represent the information provided by D1.2 and D1.3. The datasets expressed in the Data Management Plan will be mapped to the Knowledge Base as shown in the previous section, to connect the user cases representation to the actual metadata and data. A mapping will be provided for each dataset.

The CoBRAIN ontology will be further updated to include specific concepts (classes and relations) that will be required by each simulation, characterisation of experimental user case scenario, and according to the technical specifications that will be required by the specific graph databased implementation.

6 Attainment of Objectives

Table 3 - General project objectives related to WP1 and their status on M12.

Ref.[14]	General Objective	Status
O2.1	Knowledge base repository for the ontological representation of Thermal Spray	TBox completed. ABox and data linking at M24.

Table 4 - Specific objectives of WP1 and their status on M12.

Ref.[15]	Work Package Objective	Status
WP1.1	to Specify the complete MODA and CHADA to be used in the project	Done with D1.2 and D1.3 at M06.
WP1.2	to Create a set of ontological relations that connect and describe Modelling, Characterization and TS Processes	Done with D1.1 at M12 through the CoBRAIN ontology and the EMMO framework. To be expanded up to the end of the project M48 according to project needs.
WP1.3	to Create an OWL-DL ontological representation of the manufacturing processes	Done with D1.1 at M12.
WP1.4	to Store everything in a Knowledge Base repository exploiting commercially available RDF Triplestore	Foreseen by T1.4 at M24.

[14] Reference to the general project objectives stated from page 4 of Part B of the Annex 1 – Description of Action

[15] Reference to the specific objectives of the workpackage as listed in Part A of Annex 2 – Description of Action

7 Annex I

7.1 Turtle Serialization of the CoBRAIN Ontology

~/GitHub/ontology/cobrain.ttl

```
@prefix : <https://www.cobrain-project.eu/thermalspraying/> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix xml: <http://www.w3.org/XML/1998/namespace> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@base <https://www.cobrain-project.eu/thermalspraying/> .

<https://www.cobrain-project.eu/thermalspraying> rdf:type owl:Ontology ;
                                                  <http://purl.org/dc/terms/contributor> """Alvise Bianchin
Matres scrl
alvise.bianchin@matres.org""" ,
                                                  """Giovanni Bolelli
Università degli Studi di Modena e Reggio Emilia
giovanni.bolelli@unimore.it""" ;
                                                  <http://purl.org/dc/terms/creator> """Emanuele Ghedini
Alma Mater Studiorum - Università di Bologna
emanuele.ghedini@unibo.it""" ;
                                                  <http://purl.org/dc/terms/license> """This work is licensed under CC BY 4.0
https://creativecommons.org/licenses/by/4.0/""" ;
                                                  rdfs:comment """Work performed in the framework of CoBRAIN Project
Funded under European Commission Horizon Europe: Digital, Industry and Space
Grant agreement ID: 101092211
https://doi.org/10.3030/101092211""" .

#################################################################
#    Annotation properties
#################################################################

###  http://purl.org/dc/terms/contributor
<http://purl.org/dc/terms/contributor> rdf:type owl:AnnotationProperty .


###  http://purl.org/dc/terms/creator
<http://purl.org/dc/terms/creator> rdf:type owl:AnnotationProperty .


###  http://purl.org/dc/terms/license
<http://purl.org/dc/terms/license> rdf:type owl:AnnotationProperty .


###  http://www.w3.org/2004/02/skos/core#altLabel
<http://www.w3.org/2004/02/skos/core#altLabel> rdf:type owl:AnnotationProperty ;
                                               rdfs:subPropertyOf rdfs:label .


###  http://www.w3.org/2004/02/skos/core#prefLabel
<http://www.w3.org/2004/02/skos/core#prefLabel> rdf:type owl:AnnotationProperty ;
                                                rdfs:subPropertyOf rdfs:label .


###  https://www.cobrain-project.eu/thermalspraying/elucidation
:elucidation rdf:type owl:AnnotationProperty .
```

```
###  https://www.cobrain-project.eu/thermalspraying/productionInformation
:productionInformation rdf:type owl:AnnotationProperty ;
                       <http://www.w3.org/2004/02/skos/core#prefLabel> "
Production Information" .


#################################################################
#    Object Properties
#################################################################

###  https://www.cobrain-project.eu/thermalspraying/affects
:affects rdf:type owl:ObjectProperty ;
         rdfs:subPropertyOf :properOverlaps ;
         rdfs:domain :Process ;
         rdfs:range :Object .


###  https://www.cobrain-project.eu/thermalspraying/communicatesWith
:communicatesWith rdf:type owl:ObjectProperty ;
                  rdfs:subPropertyOf :isCausalRelatedTo .


###  https://www.cobrain-project.eu/thermalspraying/contributesTo
:contributesTo rdf:type owl:ObjectProperty ;
               rdfs:subPropertyOf :properOverlaps ;
               rdfs:domain :Process ;
               rdfs:range :Process .


###  https://www.cobrain-project.eu/thermalspraying/disappearsInto
:disappearsInto rdf:type owl:ObjectProperty ;
                rdfs:subPropertyOf :properOverlaps ;
                rdfs:domain :Process ;
                rdfs:range :Object .


###  https://www.cobrain-project.eu/thermalspraying/emergesFrom
:emergesFrom rdf:type owl:ObjectProperty ;
             rdfs:subPropertyOf :properOverlaps ;
             rdfs:domain :Process ;
             rdfs:range :Object .


###  https://www.cobrain-project.eu/thermalspraying/hasNext
:hasNext rdf:type owl:ObjectProperty ;
         rdfs:subPropertyOf :isCausalRelatedTo .


###  https://www.cobrain-project.eu/thermalspraying/hasNextStep
:hasNextStep rdf:type owl:ObjectProperty ;
             rdfs:subPropertyOf :isCausalRelatedTo .


###  https://www.cobrain-project.eu/thermalspraying/hasProperty
:hasProperty rdf:type owl:ObjectProperty ;
             rdfs:subPropertyOf owl:topObjectProperty ;
             rdfs:range :Property .
```

```
###  https://www.cobrain-project.eu/thermalspraying/hasSubsequentStep
:hasSubsequentStep rdf:type owl:ObjectProperty ;
                   rdfs:subPropertyOf :isCausalRelatedTo .


###  https://www.cobrain-project.eu/thermalspraying/indirectlyAffects
:indirectlyAffects rdf:type owl:ObjectProperty ;
                   rdfs:subPropertyOf :isCausalRelatedTo .


###  https://www.cobrain-project.eu/thermalspraying/indirectlyCommunicatesWith
:indirectlyCommunicatesWith rdf:type owl:ObjectProperty ;
                            rdfs:subPropertyOf :isCausalRelatedTo .


###  https://www.cobrain-project.eu/thermalspraying/isAddedTo
:isAddedTo rdf:type owl:ObjectProperty ;
           rdfs:subPropertyOf :properOverlaps ;
           rdfs:domain :Object ;
           rdfs:range :Object .


###  https://www.cobrain-project.eu/thermalspraying/isAdjacentTo
:isAdjacentTo rdf:type owl:ObjectProperty ;
              rdfs:subPropertyOf :isCausalRelatedTo .


###  https://www.cobrain-project.eu/thermalspraying/isBehaviourOf
:isBehaviourOf rdf:type owl:ObjectProperty ;
               rdfs:subPropertyOf :isTemporalPartOf ;
               rdfs:domain :Process ;
               rdfs:range :Object .


###  https://www.cobrain-project.eu/thermalspraying/isCausalRelatedTo
:isCausalRelatedTo rdf:type owl:ObjectProperty ;
                   rdfs:subPropertyOf owl:topObjectProperty ;
                   rdf:type owl:SymmetricProperty .


###  https://www.cobrain-project.eu/thermalspraying/isCharacterizedIn
:isCharacterizedIn rdf:type owl:ObjectProperty ;
                   rdfs:subPropertyOf :participatesTo ;
                   rdfs:range :Characterization .


###  https://www.cobrain-project.eu/thermalspraying/isComponentOf
:isComponentOf rdf:type owl:ObjectProperty ;
               rdfs:subPropertyOf :isConstituentOf ;
               rdfs:domain :Component ;
               rdfs:range :System .


###  https://www.cobrain-project.eu/thermalspraying/isConstituentOf
:isConstituentOf rdf:type owl:ObjectProperty ;
                 rdfs:subPropertyOf :isSpatialPartOf ;
                 rdfs:domain :Object ;
                 rdfs:range :Object .
```

```
###  https://www.cobrain-project.eu/thermalspraying/isConstitutiveProcessOf
:isConstitutiveProcessOf rdf:type owl:ObjectProperty ;
                         rdfs:subPropertyOf :isSpatialPartOf ;
                         rdfs:domain :Process ;
                         rdfs:range :Object .


###  https://www.cobrain-project.eu/thermalspraying/isIndenterFor
:isIndenterFor rdf:type owl:ObjectProperty ;
               rdfs:subPropertyOf :participatesTo ;
               rdfs:domain :Indenter ;
               rdfs:range :Nanoindentation .


###  https://www.cobrain-project.eu/thermalspraying/isInputOf
:isInputOf rdf:type owl:ObjectProperty ;
           rdfs:subPropertyOf :properOverlaps ;
           rdfs:range :Process .


###  https://www.cobrain-project.eu/thermalspraying/isInstrumentOf
:isInstrumentOf rdf:type owl:ObjectProperty ;
                rdfs:subPropertyOf :participatesTo .


###  https://www.cobrain-project.eu/thermalspraying/isMereologicalRelatedTo
:isMereologicalRelatedTo rdf:type owl:ObjectProperty ;
                         rdfs:subPropertyOf owl:topObjectProperty .


###  https://www.cobrain-project.eu/thermalspraying/isOutputOf
:isOutputOf rdf:type owl:ObjectProperty ;
            rdfs:subPropertyOf :properOverlaps ;
            rdfs:range :Process .


###  https://www.cobrain-project.eu/thermalspraying/isPartOf
:isPartOf rdf:type owl:ObjectProperty ;
          rdfs:subPropertyOf :isMereologicalRelatedTo .


###  https://www.cobrain-project.eu/thermalspraying/isProperParticipantOf
:isProperParticipantOf rdf:type owl:ObjectProperty ;
                       rdfs:subPropertyOf :isSpatialPartOf ;
                       rdfs:domain :Object ;
                       rdfs:range :Process .


###  https://www.cobrain-project.eu/thermalspraying/isRemovedfrom
:isRemovedfrom rdf:type owl:ObjectProperty ;
               rdfs:subPropertyOf :properOverlaps ;
               rdfs:domain :Object ;
               rdfs:range :Object .


###  https://www.cobrain-project.eu/thermalspraying/isSampleOf
:isSampleOf rdf:type owl:ObjectProperty ;
            rdfs:subPropertyOf :isRemovedfrom ;
            rdfs:domain :Sample .
```

```


###  https://www.cobrain-project.eu/thermalspraying/isSpatialPartOf
:isSpatialPartOf rdf:type owl:ObjectProperty ;
                 rdfs:subPropertyOf :isPartOf .


###  https://www.cobrain-project.eu/thermalspraying/isStageOf
:isStageOf rdf:type owl:ObjectProperty ;
           rdfs:subPropertyOf :isTemporalPartOf ;
           rdfs:domain :Process ;
           rdfs:range :Process .


###  https://www.cobrain-project.eu/thermalspraying/isStatusOf
:isStatusOf rdf:type owl:ObjectProperty ;
            rdfs:subPropertyOf :isTemporalPartOf ;
            rdfs:domain :Object ;
            rdfs:range :Process .


###  https://www.cobrain-project.eu/thermalspraying/isSubObjectOf
:isSubObjectOf rdf:type owl:ObjectProperty ;
               rdfs:subPropertyOf :isTemporalPartOf ;
               rdfs:domain :Object ;
               rdfs:range :Object .


###  https://www.cobrain-project.eu/thermalspraying/isSubProcessOf
:isSubProcessOf rdf:type owl:ObjectProperty ;
                rdfs:subPropertyOf :isSpatialPartOf ;
                rdfs:domain :Process ;
                rdfs:range :Process .


###  https://www.cobrain-project.eu/thermalspraying/isTemporalPartOf
:isTemporalPartOf rdf:type owl:ObjectProperty ;
                  rdfs:subPropertyOf :isPartOf .


###  https://www.cobrain-project.eu/thermalspraying/partakesIn
:partakesIn rdf:type owl:ObjectProperty ;
            rdfs:subPropertyOf :properOverlaps ;
            rdfs:domain :Object ;
            rdfs:range :Object .


###  https://www.cobrain-project.eu/thermalspraying/participatesTo
:participatesTo rdf:type owl:ObjectProperty ;
                rdfs:subPropertyOf :properOverlaps ;
                rdfs:domain :Object ;
                rdfs:range :Process .


###  https://www.cobrain-project.eu/thermalspraying/precedes
:precedes rdf:type owl:ObjectProperty ;
          rdfs:subPropertyOf :isCausalRelatedTo .


###  https://www.cobrain-project.eu/thermalspraying/properOverlaps
```

```
:properOverlaps rdf:type owl:ObjectProperty ;
                rdfs:subPropertyOf :isMereologicalRelatedTo .


#################################################################
#    Data properties
#################################################################

###  https://www.cobrain-project.eu/thermalspraying/hasDataValue
:hasDataValue rdf:type owl:DatatypeProperty ;
              rdfs:subPropertyOf owl:topDataProperty ;
              rdf:type owl:FunctionalProperty ;
              rdfs:domain :Property .


###  https://www.cobrain-project.eu/thermalspraying/hasDatetime
:hasDatetime rdf:type owl:DatatypeProperty ;
             rdfs:subPropertyOf owl:topDataProperty ;
             rdfs:range xsd:dateTime .


###  https://www.cobrain-project.eu/thermalspraying/hasSOPFile
:hasSOPFile rdf:type owl:DatatypeProperty ;
            rdfs:subPropertyOf owl:topDataProperty ;
            rdfs:range xsd:anyURI .


###  https://www.cobrain-project.eu/thermalspraying/hasSerialNumber
:hasSerialNumber rdf:type owl:DatatypeProperty .


#################################################################
#    Classes
#################################################################

###  https://www.cobrain-project.eu/thermalspraying/Adhesion
:Adhesion rdf:type owl:Class ;
          rdfs:subClassOf :Property ;
          rdfs:seeAlso "ASTM C633-13 (2017)" ,
                       """ISO 4618:2023, 3.7
phenomenon of attachment at the interface between a solid surface and another material caused by molecular forces""" ;
          <http://www.w3.org/2004/02/skos/core#prefLabel> "Adhesion" ;
          :elucidation """(ASTM D907) \"The state in which two surfaces are held together by interphase forces which may consist of chemical forces or interlocking action, or both\"
Tensile adhesion is obtained by a pull-off test.""" .

[ rdf:type owl:Axiom ;
   owl:annotatedSource :Adhesion ;
   owl:annotatedProperty rdfs:seeAlso ;
   owl:annotatedTarget """ISO 4618:2023, 3.7
phenomenon of attachment at the interface between a solid surface and another material caused by molecular forces""" ;
   rdfs:isDefinedBy "https://www.iso.org/obp/ui/#iso:std:iso:4618:ed-3:v1:en:term:3.7"
 ] .


###  https://www.cobrain-project.eu/thermalspraying/AirSupplysystem
:AirSupplysystem rdf:type owl:Class ;
```

```
                 rdfs:subClassOf :GasSupplySystem ;
                 rdfs:comment "This system is designed to provide a consistent, safe, and high-quality supply of compressed air to the thermal spray system. The system can be pressure- and/or volume flow-controlled. Compressed air is usually produced on-site with a suitably sized compressor." ;
                 rdfs:seeAlso "D.E. Crawmer (2013), Process Control and Control Equipment, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
                 <http://www.w3.org/2004/02/skos/core#prefLabel> "Air Supply System" ;
                 :elucidation "The air supply system feeds and regulates the flow of air to the thermal spray system, including as process gas, as torch cooling medium, and as substrate cooling medium" .


###  https://www.cobrain-project.eu/thermalspraying/ArrayData
:ArrayData rdf:type owl:Class ;
           rdfs:subClassOf :SymbolicData .


###  https://www.cobrain-project.eu/thermalspraying/BooleanData
:BooleanData rdf:type owl:Class ;
             rdfs:subClassOf :SymbolicData .


###  https://www.cobrain-project.eu/thermalspraying/ByteData
:ByteData rdf:type owl:Class ;
          rdfs:subClassOf :ShortData .


###  https://www.cobrain-project.eu/thermalspraying/Characterization
:Characterization rdf:type owl:Class ;
                  rdfs:subClassOf :Process .


###  https://www.cobrain-project.eu/thermalspraying/Cleaning
:Cleaning rdf:type owl:Class ;
          rdfs:subClassOf :SubstratePreparation ;
          rdfs:comment """This is the first step for the substrate preparation.
After removing all contaminants, parts should be protected from airborne debris and fingerprints and should be handled with clean fixtures and materials.""" ;
          rdfs:isDefinedBy "Anon. (2013), Introduction to Coating Design and Processing, in: R.C. Tucker jr. (Ed.), ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ,
                           "EN 13507:2018: Thermal Spraying - Pre-treatment of surfaces of metallic parts and components for thermal spraying." ;
          rdfs:seeAlso "Fauchais, Pierre L.; Heberlein, Joachim VR; Boulos, Maher I. Thermal spray fundamentals: from powder to part. Springer Science & Business Media, 2014." ,
                       "J. Knapp, D. Lemen (2013), Precoating Operations, in: R.C. Tucker jr. (Ed.), ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
          <http://www.w3.org/2004/02/skos/core#prefLabel> "Cleaning" ;
          :elucidation "The process removes all contaminants, such as scale, oil, grease, and paint, from the surface to be roughened and coated." .


###  https://www.cobrain-project.eu/thermalspraying/Coating
:Coating rdf:type owl:Class ;
         rdfs:subClassOf :Object ;
         rdfs:comment "Definition adapted from ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
         rdfs:isDefinedBy "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
```

```
         <http://www.w3.org/2004/02/skos/core#altLabel> "Deposit" ,
                                                        "Layer" ;
         <http://www.w3.org/2004/02/skos/core#prefLabel> "Coating" ;
         :elucidation "A layer of material built up onto the substrate by a thermal spray process" .


###  https://www.cobrain-project.eu/thermalspraying/ColdSpray
:ColdSpray rdf:type owl:Class ;
           rdfs:subClassOf :Spraying ;
           rdfs:comment """There are three variants of cold spraying:
- Low-pressure cold spray utilizes compressed air at pressures up to 10 bar and temperatures up to 600 °C. The powder is injected radially in the divergent part of the nozzle, using a pressureless powder feeder.
- High-pressure cold-spray utilizes nitrogen or helium at pressures up to 6 MPa and temperatures up to 1100 °C. The powder is injected axially in the cold spray torch, upstream of the nozzle, using a pressurized powder feeder.
- Medium-pressure cold spray operates with compressed air at intermediate pressure levels, usually in the range of 7 - 35 bar, with temperatures up to 550 °C - 600 °C. The powder is injected radially in the convergent part of the nozzle using a presureless powder feeder.""" ;
           rdfs:isDefinedBy "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
           rdfs:seeAlso "Gartner F, Stoltenhoff T, Schmidt T, Kreye H (2006) The cold spray process and its potential  for industrial applications. J Therm Spray Technol 15(2):223–232" ,
                        "J. Karthikeyan (2013), Cold Spray Process, in: R.C. Tucker jr. (Ed.), ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
           <http://www.w3.org/2004/02/skos/core#altLabel> " ColdGasDynamicSpraying" ,
                                                          "ColdGasSpraying" ,
                                                          "KineticSpraying" ;
           <http://www.w3.org/2004/02/skos/core#prefLabel> "Cold Spraying" ;
           :elucidation "A thermal spray process utilizing a supersonic jet of produced by the expansion of a compressed through a converging/diverging nozzle gas to accelerate, at or near room temperature, powder particles to high velocities. The solid particles traveling at speeds often above 500 m/s plastically deform and consolidate on impact with their substrate to create a coating." .


###  https://www.cobrain-project.eu/thermalspraying/ColdSprayTorch
:ColdSprayTorch rdf:type owl:Class ;
                rdfs:subClassOf :SprayTorch ;
                rdfs:comment """The torch has no combustion chamber.
The gas is pre-heated with electrical resistance systems that are located in the torch itself and/or in external heating units.
Nozzles are convergent/divergent; they are usually interchangeable and vary in shape, size, and material, to achieve specific spray patterns and avoid clogging.
Cold Spray torches can either have a water-cooled nozzle or (especially in low-pressure models) no nozzle cooling system.""" ;
                rdfs:isDefinedBy "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
                rdfs:seeAlso "J. Karthikeyan (2013), Cold Spray Process, in: R.C. Tucker jr. (Ed.), ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
                <http://www.w3.org/2004/02/skos/core#altLabel> "Cold Spray Gun" ;
                <http://www.w3.org/2004/02/skos/core#prefLabel> "Cold Spray Torch" ;
                :elucidation "A thermal spray torch specifically designed to perform the Cold Spray process" .


###  https://www.cobrain-project.eu/thermalspraying/CombustionChamber
:CombustionChamber rdf:type owl:Class ;
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                   rdfs:subClassOf :TorchComponent ;
                   rdfs:comment """Fuel and comburent can be pre-mixed before entering the combustion chamber, as in most gas-fuelled HVOF and HVAF torch types, or they can be mixed in the combustion chamber, as in most liquid-fuelled HVOF torches.
Sometimes, the convergent part of the nozzle can also act as a combustion chamber.""" ;
                   rdfs:seeAlso "D.E. Crawmer (2013), Thermal Spray Processes, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
                   <http://www.w3.org/2004/02/skos/core#prefLabel> "Combustion Chamber" ;
                   :elucidation "The combustion chamber is the location within a HVOF or HVAF torch where a confined fuel-comburent combustion takes place at pressures above ambient pressure." .


###  https://www.cobrain-project.eu/thermalspraying/Component
:Component rdf:type owl:Class ;
           rdfs:subClassOf :Object .


###  https://www.cobrain-project.eu/thermalspraying/Composition
:Composition rdf:type owl:Class ;
             rdfs:subClassOf :Property ;
             <http://www.w3.org/2004/02/skos/core#prefLabel> "Composition" .


###  https://www.cobrain-project.eu/thermalspraying/ControlSystem
:ControlSystem rdf:type owl:Class ;
               rdfs:subClassOf :System ;
               <http://www.w3.org/2004/02/skos/core#prefLabel> "Control System" .


###  https://www.cobrain-project.eu/thermalspraying/ControlUnit
:ControlUnit rdf:type owl:Class ;
             rdfs:subClassOf :ControlSystem ,
                             :ThermalSprayingComponent ;
             rdfs:comment """The control unit is the main user interface to control the process and ensures safety, control and repeatability.
It can feature analogue and/or digital controls and can feature various degrees of automation. It can optionally record and store the measured quantities.
It can operate on open- or closed-loop principles.""" ;
             rdfs:seeAlso "D.E. Crawmer (2013), Process Control and Control Equipment, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
             <http://www.w3.org/2004/02/skos/core#altLabel> "Command Panel" ,
                                                             "Command Unit" ,
                                                             "Control Panel" ;
             <http://www.w3.org/2004/02/skos/core#prefLabel> "Control Unit" ;
             :elucidation "The control unit is a system that controls the operation of the thermal spray system, specifically managing gas flows, powder feed, torch startup/shutdown, turntable and manipulator/robot movements, gun cooling system." .


###  https://www.cobrain-project.eu/thermalspraying/CoolingSystem
:CoolingSystem rdf:type owl:Class ;
               rdfs:subClassOf :System ;
               <http://www.w3.org/2004/02/skos/core#prefLabel> "Cooling System" .


###  https://www.cobrain-project.eu/thermalspraying/CorrosionCurrentDensity
:CorrosionCurrentDensity rdf:type owl:Class ;
```

```
                          rdfs:subClassOf :Property ;
                          rdfs:seeAlso "Pierre R. Roberge (2000), Handbook of Corrosion Engineering. McGraw-Hill, New York. D.J. De Renzo (1985), CORROSION RESISTANT MATERIALS HANDBOOK, Fourth Edition. NOYES DATA CORPORATION Park Ridge, New Jersey, U.S.A." ;
                          <http://www.w3.org/2004/02/skos/core#prefLabel> "Corrosion Current Density" ;
                          :elucidation "The current corrosion density value represents the rate at which a metal or alloy is corroding in a specific environment. It is a measure of the amount of metal ions that are being released from the material due to the corrosion process." .


###  https://www.cobrain-project.eu/thermalspraying/CorrosionPotential
:CorrosionPotential rdf:type owl:Class ;
                    rdfs:subClassOf :Property ;
                    rdfs:seeAlso "Pierre R. Roberge (2000), Handbook of Corrosion Engineering. McGraw-Hill, New York. D.J. De Renzo (1985), CORROSION RESISTANT MATERIALS HANDBOOK, Fourth Edition. NOYES DATA CORPORATION Park Ridge, New Jersey, U.S.A." ;
                    <http://www.w3.org/2004/02/skos/core#prefLabel> "Corrosion Potential" ;
                    :elucidation "The corrosion potential value represents the tendency of a metal or alloy to corrode in a specific environment. It is a measure of the electrochemical potential difference between the metal and its environment, which is the driving force for the corrosion process." .


###  https://www.cobrain-project.eu/thermalspraying/CriticalLoad
:CriticalLoad rdf:type owl:Class ;
              rdfs:subClassOf :Property ;
              <http://www.w3.org/2004/02/skos/core#prefLabel> "Critical Load" .


###  https://www.cobrain-project.eu/thermalspraying/DateTimeData
:DateTimeData rdf:type owl:Class ;
              rdfs:subClassOf :SymbolicData .


###  https://www.cobrain-project.eu/thermalspraying/DateTimeStampData
:DateTimeStampData rdf:type owl:Class ;
                   rdfs:subClassOf :DateTimeData .


###  https://www.cobrain-project.eu/thermalspraying/DecimalData
:DecimalData rdf:type owl:Class ;
             rdfs:subClassOf :RationalData .


###  https://www.cobrain-project.eu/thermalspraying/Deposition
:Deposition rdf:type owl:Class ;
            rdfs:subClassOf :SprayingStage ;
            rdfs:comment """During this stage, the torch is moved in front of the substrates with a specified kinematics and for a specified number of cycles by using the coordinated motion of the turntable and the manipulator or robot.
The substrate can be cooled during the deposition stage to prevent excessive rise in temperatures that would result in high residual stress levels being generated both during and after the deposition process.""" ;
            rdfs:seeAlso "Anon. (2013), Introduction to Coating Design and Processing, in: R.C. Tucker jr. (Ed.), ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
            <http://www.w3.org/2004/02/skos/core#altLabel> "Build-up" ,
                                                            "Coating" ,
                                                            "Spraying" ;
            <http://www.w3.org/2004/02/skos/core#prefLabel> "Deposition" ;
```

```
            :elucidation "Deposition is the stage of the thermal spray process during which the coating is built up onto the substrate." .


###  https://www.cobrain-project.eu/thermalspraying/Device
:Device rdf:type owl:Class ;
        rdfs:subClassOf :Object .


###  https://www.cobrain-project.eu/thermalspraying/Division
:Division rdf:type owl:Class ;
          rdfs:subClassOf :NormalizedStringData ,
                          :TokenData .


###  https://www.cobrain-project.eu/thermalspraying/ElasticModulus
:ElasticModulus rdf:type owl:Class ;
                rdfs:subClassOf :Property ;
                rdfs:isDefinedBy "ISO 14577 (Instrumented indentation test)" ,
                                 "ISO 80000-4:2019" ;
                rdfs:seeAlso "F. Cardarelli (2008), Materials Handbook: A Concise Desktop Reference, second edition. Springer, London. G.T. Murray (1997), Handbook of Materials Selection for Engineering Applications. CRC Press." ;
                <http://www.w3.org/2004/02/skos/core#prefLabel> "Elastic Modulus" ;
                :elucidation "The proportionality coefficient between the stress applied to a material and the resulting strain within the linear reversible deformation regime." .


###  https://www.cobrain-project.eu/thermalspraying/Equals
:Equals rdf:type owl:Class ;
        rdfs:subClassOf :NormalizedStringData ,
                        :TokenData .


###  https://www.cobrain-project.eu/thermalspraying/ErosiveWearRate
:ErosiveWearRate rdf:type owl:Class ;
                 rdfs:subClassOf :WearRate ;
                 rdfs:seeAlso """ASTM G76-18: Erosion Test by Solid Particle Impingement Using Gas Jet
ASTM G211-14(2020): Elevated Temperature Erosion Test by Solid Particle Impingement Using Gas Jet""" ;
                 <http://www.w3.org/2004/02/skos/core#prefLabel> "Erosive Wear Rate" ;
                 :elucidation """The erosive wear rate (or erosion rate) is a measure of the loss of material from a surface due to erosion by solid particles carried by a compressible (gas) or incompressible (water) fluid flow.
The erosive wear rate is expressed as the volume of material removed per unit mass of impinging solid particles.""" .


###  https://www.cobrain-project.eu/thermalspraying/FIB
:FIB rdf:type owl:Class ;
     rdfs:subClassOf :Characterization ;
     <http://www.w3.org/2004/02/skos/core#prefLabel> "Focused Ion Beam" .


###  https://www.cobrain-project.eu/thermalspraying/FeedRate
:FeedRate rdf:type owl:Class ;
          rdfs:subClassOf :Property ;
          rdfs:isDefinedBy "ISO 80000-4:2019" ;
```

```
          rdfs:seeAlso "Glossary of Terms, in: R.C. Tucker Jr. (Ed.), ASM Handbook Vol. 5A, ASM International, Materials Park, OH, USA, 2013, pp. 351-381." ;
          <http://www.w3.org/2004/02/skos/core#prefLabel> "Feed Rate" ;
          :elucidation "The mass of material thatpasses through a given section of a conduit per unit time." .


###  https://www.cobrain-project.eu/thermalspraying/Fixture
:Fixture rdf:type owl:Class ;
         rdfs:subClassOf :HoldingSystem ,
                         :ThermalSprayingComponent ;
         rdfs:comment """The fixture must be designed to hold the substrates in a proper configuration so that, in combination with the motion imparted by the turntable and the manipulator, the thermal spray jet is perpendicular to the substrate surface for as long as possible, and should also allow to achieve the desired relative linear velocity and trajectories.
Shadow masks can be integrated in the fixture.
Fixtures are usually permanent but may need periodic regeneration to remove deposits that build up in areas of the fixture exposed to the thermal spray jet.""" ;
         rdfs:seeAlso "J. Knapp, D. Lemen (2013), Precoating Operations, in: R.C. Tucker jr. (Ed.), ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
         <http://www.w3.org/2004/02/skos/core#altLabel> "Tool" ,
                                                        "Tooling" ;
         <http://www.w3.org/2004/02/skos/core#prefLabel> "Fixture" ;
         :elucidation "The fixture is a suitably designed system to hold one or more substrates allowing their mounting on a turntable with a suitable geometrical configuration with respect to the thermal spray torch and the manipulator." .


###  https://www.cobrain-project.eu/thermalspraying/FloatingPointData
:FloatingPointData rdf:type owl:Class ;
                   rdfs:subClassOf :NumericData .


###  https://www.cobrain-project.eu/thermalspraying/FlowRate
:FlowRate rdf:type owl:Class ;
          rdfs:subClassOf :Property ;
          rdfs:isDefinedBy "ISO 80000-4:2019" ;
          rdfs:seeAlso "Glossary of Terms, in: R.C. Tucker Jr. (Ed.), ASM Handbook Vol. 5A, ASM International, Materials Park, OH, USA, 2013, pp. 351-381." ;
          <http://www.w3.org/2004/02/skos/core#prefLabel> "Flow Rate" ;
          :elucidation "The volume of a gas passing across the section of a conduit per unit time" .


###  https://www.cobrain-project.eu/thermalspraying/FractureToughness
:FractureToughness rdf:type owl:Class ;
                   rdfs:subClassOf :Property ;
                   rdfs:seeAlso "F. Cardarelli (2008), Materials Handbook: A Concise Desktop Reference, second edition. Springer, London. G.T. Murray (1997), Handbook of Materials Selection for Engineering Applications. CRC Press." ;
                   <http://www.w3.org/2004/02/skos/core#prefLabel> "Fracture Toughness" ;
                   :elucidation "Toughness is the ability of a material to resist fracture or failure when subjected to stress, shock, or impact. It is a property of a material that combines its strength and its ability to absorb energy without breaking." .


###  https://www.cobrain-project.eu/thermalspraying/FrictionCoefficient
```

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:FrictionCoefficient rdf:type owl:Class ;
                     rdfs:subClassOf :Property ;
                     rdfs:isDefinedBy "ISO 80000-4:2019" ;
                     rdfs:seeAlso """ASTM G99-17: Pin-on-Disc Sliding Test
ASTM G133-05(2016): Linearly Reciprocating Ball-on-Flat Sliding Test
ASTM G77-17: Block-on-Ring Sliding Test""" ,
                                  "Gwidon W. Stachowiak (2006), WEAR–MATERIALS, MECHANISMSAND PRACTICE, JohnWiley&SonsLtd, The Atrium, Southern Gate, Chichester, West Sussex, England" ;
                     <http://www.w3.org/2004/02/skos/core#prefLabel> "Friction Coefficient" ;
                     :elucidation """Proportionality factor between the magnitude of the tangential friction force applied to contacting bodies to maintain (kinetic friction coefficient) or initiate (static friction coefficient) relative motion, and the magnitude of the normal contact force between the bodies.
The friction coefficient is a dimensionless value that measures the resistance to relative motion, caused by dissipative effects such as asperity-level adhesion, abrasion, (visco)elastic hysteresis, third-body effects.""" .


###  https://www.cobrain-project.eu/thermalspraying/G200NanoIndenter
:G200NanoIndenter rdf:type owl:Class ;
                  rdfs:subClassOf :NanoIndenter ;
                  <http://www.w3.org/2004/02/skos/core#prefLabel> "Nano Indenter G200" .


###  https://www.cobrain-project.eu/thermalspraying/GasFeeding
:GasFeeding rdf:type owl:Class ;
            rdfs:subClassOf :SprayingSubProcess ;
            <http://www.w3.org/2004/02/skos/core#prefLabel> "Gas Feeding" .


###  https://www.cobrain-project.eu/thermalspraying/GasFuelledHVOFTorch
:GasFuelledHVOFTorch rdf:type owl:Class ;
                     rdfs:subClassOf :HVOFTorch ;
                     <http://www.w3.org/2004/02/skos/core#prefLabel> "Gas-Fuelled HVOF torch" .


###  https://www.cobrain-project.eu/thermalspraying/GasSupplySystem
:GasSupplySystem rdf:type owl:Class ;
                 rdfs:subClassOf :SupplySystem ;
                 rdfs:comment "This system is designed to provide consistent, safe, and high-quality supply of gases to the thermal spray system. Gases other than air are usually taken from compressed gas bottles, although other sources are possible (e.g. in-situ hydrogen generators). The flow can be pressure- and/or volume-flow controlled." ;
                 rdfs:seeAlso "D.E. Crawmer (2013), Process Control and Control Equipment, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
                 <http://www.w3.org/2004/02/skos/core#prefLabel> "Gas Supply System" ;
                 :elucidation "The gas supply system feeds and regulates the flow of the various process gases to the thermal spray system" .


###  https://www.cobrain-project.eu/thermalspraying/Gradient
:Gradient rdf:type owl:Class ;
          rdfs:subClassOf :NormalizedStringData ,
                          :TokenData .


###  https://www.cobrain-project.eu/thermalspraying/GunCoolingSystem
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:GunCoolingSystem rdf:type owl:Class ;
                  rdfs:subClassOf :CoolingSystem ;
                  rdfs:comment """The gun cooling system can use either liquids (deionized water), gases (compressed air), or a mixture or both.
The system can feature flow meters and temperature sensors to monitor the flow rate of cooling medium and its inlet and outlet temperature, thereby allowing a quantification of the thermal power lost by the torch to the cooling system.""" ;
                  rdfs:seeAlso "D.E. Crawmer (2013), Process Control and Control Equipment, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
                  <http://www.w3.org/2004/02/skos/core#altLabel> "Cooling Circuit" ;
                  <http://www.w3.org/2004/02/skos/core#prefLabel> "Gun Cooling System" ;
                  :elucidation "A system that delivers a liquid or gaseous cooling fluid to the thermal spray torch to prevent overheating of critical parts" .


###  https://www.cobrain-project.eu/thermalspraying/HVAF
:HVAF rdf:type owl:Class ;
      rdfs:subClassOf :ThermalSpraying ;
      rdfs:comment """HVAF (High Velocity Air Fuel) is a thermal spray process similar to HVOF but using compressed air instead of pure oxygen as the comburent. Fuels are typically gaseous (propane, propylene); powder injection is typically axial in the combustion chamber. Nozzles may feature a secondary air-fuel injection. Fuel mixtures, e.g. propane+hydrogen, can sometimes be employed.
Compressed air is also used to cool the torch before being injected into the combustion chamber, thus achieving regenerative pre-heating.""" ;
      rdfs:isDefinedBy "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
      rdfs:seeAlso "D.E. Crawmer (2013), Thermal Spray Processes, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ,
                   "Fauchais, Pierre L.; Heberlein, Joachim VR; Boulos, Maher I. Thermal spray fundamentals: from powder to part. Springer Science & Business Media, 2014." ;
      <http://www.w3.org/2004/02/skos/core#altLabel> "HVAF Spraying" ,
                                                     "High Velocity Air Fuel" ,
                                                     "High Velocity Air Fuel Spraying" ;
      :elucidation "A thermal spray process that involves accelerating and heating a feedstock material in powder form by feeding it into a stream of exhaust gases originating from the confined combustion of air and fuel(s) at high pressure and the subsequent expansion of the combustion products through a nozzle." .


###  https://www.cobrain-project.eu/thermalspraying/HVAFTorch
:HVAFTorch rdf:type owl:Class ;
           rdfs:subClassOf :ThermalSprayTorch ;
           rdfs:comment """HVAF torches can usually be fit with multiple, interchangeable, and separate combustion chambers and nozzles, offering more hardware variety in a single device than do HVOF torches. Often, the combustion chamber ends with a converging/diverging nozzle and a separate, secondary nozzle is installed downstream of the chamber-integrated nozzle.
Process gas flows are usually regulated by adjusting their inlet pressure, whilst volume flow rates can be optionally measured but are not directly controlled.""" ;
           rdfs:isDefinedBy "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
           rdfs:seeAlso "D.E. Crawmer (2013), Thermal Spray Processes, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
           <http://www.w3.org/2004/02/skos/core#altLabel> "HVAF Gun" ;
           <http://www.w3.org/2004/02/skos/core#prefLabel> "HVAF Torch" ;
           :elucidation "A thermal spray torch specifically designed to perform the HVAF process" .
```

```
###  https://www.cobrain-project.eu/thermalspraying/HVOF
:HVOF rdf:type owl:Class ;
      rdfs:subClassOf :ThermalSpraying ;
      rdfs:comment """Fuels can be liquid (e.g. kerosene), gaesous (e.g. hydrogen, propane, prolpylene, ethene, ecc.)
Powders can be injected axially in the combustion chamber or radially downstream of the combustion chamber, which affects their heating and acceleration history
Expansion nozzles can be converging or converging/diverging (De Laval type) and can have a straight barrel downstream""" ;
      rdfs:isDefinedBy "EN 1395-2:2007: Thermal Spraying - Acceptance inspection of thermal spraying equipment - Part 2: Flame spraying including HVOF" ,
                       "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
      rdfs:seeAlso "D.E. Crawmer (2013), Thermal Spray Processes, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ,
                   "Fauchais, Pierre L.; Heberlein, Joachim VR; Boulos, Maher I. Thermal spray fundamentals: from powder to part. Springer Science & Business Media, 2014." ;
      <http://www.w3.org/2004/02/skos/core#altLabel> "HVOF Spraying" ,
                                                     "High Velocity Oxygen Fuel" ,
                                                     "High Velocity Oxygen Fuel Spraying" ;
      <http://www.w3.org/2004/02/skos/core#prefLabel> "HVOF" ;
      :elucidation "A thermal spray process that involves accelerating and heating a feedstock material in powder form by feeding it into a stream of exhaust gases originating from the confined combustion of oxygen and fuel(s) at high pressure and the subsequent expansion of the combustion products through a nozzle." .


###  https://www.cobrain-project.eu/thermalspraying/HVOFTorch
:HVOFTorch rdf:type owl:Class ;
           rdfs:subClassOf :ThermalSprayTorch ;
           rdfs:comment """HVOF torches are available in multiple variants that differ in construction details such as presence/absence of a distinct combustion chamber, type of nozzle, presence or absence of interchangeable barrels after the nozzle, powder injection location, fuel type, which result in different particle velocity/temperature combinations:

- Gas-fuelled HVOF torch with hybrid air/water cooling: no separate combustion chamber, the powder is injected axially in the convergent nozzle section and the pre-mixed oxygen-fuel flow is delivered co-axially, with compressed air flowing along the convergent nozzle wall for cooling. The divergent part of the nozzle is water-cooled. The nozzle has fixed geometry and is not replaceable.

- Gas-fuelled HVOF torch with single-piece combustion chamber, convergent nozzle, and cylindrical barrel. The powder is injected axially in the combustion chamber and the entire torch is water-cooled

- Gas-fuelled HVOF torch with combustion chamber at 90° with respect to the convergent-straight nozzle and axial powder injection at the nozzle inlet.

- HVOF torch with atomization of liquid fuel in a combustion chamber where combustion with oxygen is triggered by a spark plug; the chamber ends with a convergent-divergent nozzle followed by an interchangeable straight barrel; powder is injected radially at the barrel inlet.

Process gases are usually fed at constant pressure with a volume flow rate-control system.""" ;
           rdfs:isDefinedBy "EN 1395-2:2007: Thermal Spraying - Acceptance inspection of thermal spraying equipment - Part 2: Flame spraying including HVOF" ,
                            "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
```

```
            rdfs:seeAlso "D.E. Crawmer (2013), Thermal Spray Processes, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
            <http://www.w3.org/2004/02/skos/core#altLabel> "HVOF Gun" ;
            <http://www.w3.org/2004/02/skos/core#prefLabel> "HVOF Torch" ;
            :elucidation "A thermal spray torch specifically designed to perform the HVOF process" .


###  https://www.cobrain-project.eu/thermalspraying/HighPressureColdSpraying
:HighPressureColdSpraying rdf:type owl:Class ;
                          rdfs:subClassOf :ColdSpray ;
                          <http://www.w3.org/2004/02/skos/core#prefLabel> "High Pressure Cold Spraying" .


###  https://www.cobrain-project.eu/thermalspraying/HighSpeed3DMapping
:HighSpeed3DMapping rdf:type owl:Class ;
                    rdfs:subClassOf :Nanoindentation ;
                    <http://www.w3.org/2004/02/skos/core#prefLabel> "High-Speed 3D Mapping" .


###  https://www.cobrain-project.eu/thermalspraying/HoldingSystem
:HoldingSystem rdf:type owl:Class ;
               rdfs:subClassOf :System ;
               <http://www.w3.org/2004/02/skos/core#prefLabel> "Holding System" .


###  https://www.cobrain-project.eu/thermalspraying/IRI
:IRI rdf:type owl:Class ;
     rdfs:subClassOf :URI .


###  https://www.cobrain-project.eu/thermalspraying/IndentationCurve
:IndentationCurve rdf:type owl:Class ;
                  rdfs:subClassOf :Property ;
                  <http://www.w3.org/2004/02/skos/core#prefLabel> "Indentation Curve" .


###  https://www.cobrain-project.eu/thermalspraying/IndentationHardness
:IndentationHardness rdf:type owl:Class ;
                     rdfs:subClassOf :Property ;
                     rdfs:seeAlso """SO 14577-1:2015
ISO 14577-2:2015
ISO 14577-3:2015
ISO 14577-4:2016""" ;
                     <http://www.w3.org/2004/02/skos/core#prefLabel> "Indentation Hardness" ;
                     :elucidation """Hardness is the resistance of a material to permanent penetration by another material.
The indentation hardness (HIT) is specifically defined as the average contact pressure between the indenter and the indented material, i.e. HIT = Fmax/Ap, were Fmax = maximum applied load and Ap = contact area projected into the plane of the sample surface (\"projected contact area\").
It is obtained by a depth-sensing indentation measure, where the applied load (F) and indenter penetration (h) are recorded continuously during penetration and retraction.
Fmax is directly obtained by the load recording; Ap is obtained by processing the load-penetration curve according to the Oliver-Pharr procedure.
A Vickers or Berkovich indenter can be used interchangeably.
Indentation hardness is specifically told into:
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- Macro-hardness: 2 N ≤ Fmax ≤ 30 kN
- Micro-hardness: Fmax < 2 N; h > 0.2 µm
- Nano-hardness: h ≤ 0.2 µm""" .


###  https://www.cobrain-project.eu/thermalspraying/Indenter
:Indenter rdf:type owl:Class ;
          rdfs:subClassOf :NanoIndenterComponent ;
          <http://www.w3.org/2004/02/skos/core#prefLabel> "Indenter" .


###  https://www.cobrain-project.eu/thermalspraying/IntData
:IntData rdf:type owl:Class ;
         rdfs:subClassOf :LongData .


###  https://www.cobrain-project.eu/thermalspraying/IntegerData
:IntegerData rdf:type owl:Class ;
             rdfs:subClassOf :DecimalData .


###  https://www.cobrain-project.eu/thermalspraying/JSONData
:JSONData rdf:type owl:Class ;
          rdfs:subClassOf :SymbolicData .


###  https://www.cobrain-project.eu/thermalspraying/LanguageData
:LanguageData rdf:type owl:Class ;
              rdfs:subClassOf :NameData .


###  https://www.cobrain-project.eu/thermalspraying/Laplacian
:Laplacian rdf:type owl:Class ;
           rdfs:subClassOf :NCNameData .


###  https://www.cobrain-project.eu/thermalspraying/LinearThermalExpansionCoefficient
:LinearThermalExpansionCoefficient rdf:type owl:Class ;
                                   rdfs:subClassOf :Property ;
                                   rdfs:isDefinedBy "ISO 80000-5:2019" ;
                                   <http://www.w3.org/2004/02/skos/core#prefLabel> "Linear Thermal Expansion Coefficient" ;
                                   :elucidation "Relative change of length of a material with temperature." .


###  https://www.cobrain-project.eu/thermalspraying/LiquidFuelSupplySystem
:LiquidFuelSupplySystem rdf:type owl:Class ;
                        rdfs:subClassOf :SupplySystem ;
                        rdfs:comment "The system is typically based on a volumetric pump. Fuels such as kerosene or paraffin are taken from tanks. This system is usually equipped only in thermal spray system intended to operate with a liquid-fuelled HVOF torch." ;
                        rdfs:seeAlso "D.E. Crawmer (2013), Process Control and Control Equipment, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
                        <http://www.w3.org/2004/02/skos/core#altLabel> "Fuel Pump" ;
                        <http://www.w3.org/2004/02/skos/core#prefLabel> "Liquid Fuel Supply System" ;
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                        :elucidation "The liquid fuel supply system feeds and regulated the flow of liquid fuels to a thermal spray system" .


###  https://www.cobrain-project.eu/thermalspraying/LiquidFuelledHVOFTorch
:LiquidFuelledHVOFTorch rdf:type owl:Class ;
                        rdfs:subClassOf :HVOFTorch ;
                        <http://www.w3.org/2004/02/skos/core#prefLabel> "Liquid-Fuelled HVOF torch" .


###  https://www.cobrain-project.eu/thermalspraying/LongData
:LongData rdf:type owl:Class ;
          rdfs:subClassOf :IntegerData .


###  https://www.cobrain-project.eu/thermalspraying/LowPressureColdSpraying
:LowPressureColdSpraying rdf:type owl:Class ;
                         rdfs:subClassOf :ColdSpray ;
                         <http://www.w3.org/2004/02/skos/core#prefLabel> "Low Pressure Cold Spraying" .


###  https://www.cobrain-project.eu/thermalspraying/Manipulator
:Manipulator rdf:type owl:Class ;
             rdfs:subClassOf :Device ;
             rdfs:comment """Definition adapted from EN 1395-6:2007: Thermal spraying - Acceptance inspection of thermal spraying equipment - Part 6: Manipulator systems.

Typically, two types of manipulators can be employed:
- X-Y or X-Y-Z manipulators that perform linear movements along the respective axes
- Industrial robots, often with 5 or 6 degrees of freedom.

Robots are needed to coat geometrically complex substrates and to achieve higher linear velocities, whilst X-Y or X-Y-Z manipulators are suitable for simple planar or cylindrical substrates.
The manipulator can optionally be synchronized with the turntable to add one more controlled degree of freedom and increase the ability to follow geometrically complex substrates.""" ;
             rdfs:isDefinedBy "EN 1395-6:2007: Thermal spraying - Acceptance inspection of thermal spraying equipment - Part 6: Manipulator systems." ;
             rdfs:seeAlso "Anon. (2013), Introduction to Coating Design and Processing, in: R.C. Tucker jr. (Ed.), ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ,
                          "D.E. Crawmer (2013), Process Control and Control Equipment, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
             <http://www.w3.org/2004/02/skos/core#altLabel> "Axes Control" ,
                                                            "Robot" ,
                                                            "Translator" ;
             <http://www.w3.org/2004/02/skos/core#prefLabel> "Manipulator" ;
             :elucidation "Manipulators are employed to move the thermal spray torch with respect to the substrate or, more infrequently, to move the substrate with respect to a stationary thermal spray torch." .


###  https://www.cobrain-project.eu/thermalspraying/Masking
:Masking rdf:type owl:Class ;
         rdfs:subClassOf :SubstratePreparation ;
         rdfs:comment """This process is necessary to prevent deposit formation on areas where it is not wanted. It also improves the uniformity of the deposit when coating limited areas.
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Three types of masks are used depending on the number of parts to be coated.
Three types of mask can be employed.
A contact mask consists of a tape wrapped onto areas where the substrate must be protected. The tape is withdrawn after grit blasting and, to get rid of residual glue, the area where it covered the surface must be cleaned with a solvent. Masking tapes can be made of: glass fabric plus adhesive or aluminium foil laminated to glass fabric with silicone plus adhesive or similar combinations.
A shadow mask consists of a metal sheet, sometimes being an integral part of the tool, which is placed in front of the area not to be coated and in physical proximity to the surface, typically two to three coating thicknesses away.
A paint-on mask is a paint or slurry that is applied onto the area to be protected and dried or cured.
Masks can be applied before or after grit-blasting because, in some cases, they are required to protect both against grit-blasting and against coating deposition. Tapes and paints are removed and scrapped after the thermal spray process. Shadow masks are used multiple times and can be regenerated by removing the excess material deposited onto them e.g. by grit-blasting or chemical stripping.""" ;
         rdfs:isDefinedBy "EN 13507:2018: Thermal Spraying - Pre-treatment of surfaces of metallic parts and components for thermal spraying." ,
                          "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
         rdfs:seeAlso "Anon. (2013), Introduction to Coating Design and Processing, in: R.C. Tucker jr. (Ed.), ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ,
                      "J. Knapp, D. Lemen (2013), Precoating Operations, in: R.C. Tucker jr. (Ed.), ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
         <http://www.w3.org/2004/02/skos/core#altLabel> "Fixturing" ;
         <http://www.w3.org/2004/02/skos/core#prefLabel> "Masking" ;
         :elucidation "The process consists of applying a physical protection to prevent deposit adhesion to areas of the substrate not to be coated" .


###  https://www.cobrain-project.eu/thermalspraying/MassFlowFeeder
:MassFlowFeeder rdf:type owl:Class ;
                rdfs:subClassOf :PowderFeeder ;
                <http://www.w3.org/2004/02/skos/core#prefLabel> "Mass Flow Feeder" .


###  https://www.cobrain-project.eu/thermalspraying/MatrixData
:MatrixData rdf:type owl:Class ;
            rdfs:subClassOf :ArrayData .


###  https://www.cobrain-project.eu/thermalspraying/MediumPressureColdSpraying
:MediumPressureColdSpraying rdf:type owl:Class ;
                            rdfs:subClassOf :ColdSpray ;
                            <http://www.w3.org/2004/02/skos/core#prefLabel> "
Medium Pressure Cold Spraying" .


###  https://www.cobrain-project.eu/thermalspraying/Minus
:Minus rdf:type owl:Class ;
       rdfs:subClassOf :NMTOKENData ,
                       :NormalizedStringData ,
                       :TokenData .


###  https://www.cobrain-project.eu/thermalspraying/Multiplication
:Multiplication rdf:type owl:Class ;
                rdfs:subClassOf :NormalizedStringData ,
                                :TokenData .

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###  https://www.cobrain-project.eu/thermalspraying/NCNameData
:NCNameData rdf:type owl:Class ;
            rdfs:subClassOf :NameData ,
                            :NormalizedStringData ,
                            :TokenData .


###  https://www.cobrain-project.eu/thermalspraying/NMTOKENData
:NMTOKENData rdf:type owl:Class ;
             rdfs:subClassOf :StringData .


###  https://www.cobrain-project.eu/thermalspraying/NameData
:NameData rdf:type owl:Class ;
          rdfs:subClassOf :NMTOKENData .


###  https://www.cobrain-project.eu/thermalspraying/NanoIndenter
:NanoIndenter rdf:type owl:Class ;
              rdfs:subClassOf :Device ;
              <http://www.w3.org/2004/02/skos/core#prefLabel> "Nano Indenter" ;
              :elucidation "The Nano Indenter G200 indentation testing system, designed for nanoscale measurements during characterization and development of a wide range of materials." .


###  https://www.cobrain-project.eu/thermalspraying/NanoIndenterComponent
:NanoIndenterComponent rdf:type owl:Class ;
                       rdfs:subClassOf :Component ;
                       <http://www.w3.org/2004/02/skos/core#prefLabel> "Nano Indenter Component" .


###  https://www.cobrain-project.eu/thermalspraying/Nanoindentation
:Nanoindentation rdf:type owl:Class ;
                 rdfs:subClassOf :Characterization ;
                 <http://www.w3.org/2004/02/skos/core#prefLabel> "Nanoindentation" .


###  https://www.cobrain-project.eu/thermalspraying/NegativeIntegerData
:NegativeIntegerData rdf:type owl:Class ;
                     rdfs:subClassOf :NonPositiveIntegerData .


###  https://www.cobrain-project.eu/thermalspraying/NonNegativeIntegerData
:NonNegativeIntegerData rdf:type owl:Class ;
                        rdfs:subClassOf :IntegerData .


###  https://www.cobrain-project.eu/thermalspraying/NonPositiveIntegerData
:NonPositiveIntegerData rdf:type owl:Class ;
                        rdfs:subClassOf :IntegerData .


###  https://www.cobrain-project.eu/thermalspraying/NormalizedStringData
:NormalizedStringData rdf:type owl:Class ;
                      rdfs:subClassOf :StringData .
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###  https://www.cobrain-project.eu/thermalspraying/Nozzle
:Nozzle rdf:type owl:Class ;
        rdfs:subClassOf :TorchComponent ;
        rdfs:comment """Definition adapted from ISO 14917:2017: Thermal Spraying - Terminology, classification.
The geometry of the nozzle is responsible for shaping and accelerating the gas flow into a high-velocity stream entraining the particles.""" ;
        rdfs:isDefinedBy "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
        <http://www.w3.org/2004/02/skos/core#altLabel> "Spray Nozzle" ;
        <http://www.w3.org/2004/02/skos/core#prefLabel> "Nozzle" ;
        :elucidation "The nozzle is the part of a thermal spray gun that contains the outlet opening for the spray jet" .


###  https://www.cobrain-project.eu/thermalspraying/NumericData
:NumericData rdf:type owl:Class ;
             rdfs:subClassOf :SymbolicData .


###  https://www.cobrain-project.eu/thermalspraying/Object
:Object rdf:type owl:Class ;
        rdfs:comment "EMMO Object Concept" .


###  https://www.cobrain-project.eu/thermalspraying/ParticleSizeDistribution
:ParticleSizeDistribution rdf:type owl:Class ;
                          rdfs:subClassOf :Property ;
                          rdfs:isDefinedBy "ISO 13320:2020 - Particle size analysis – Laser diffraction method" ,
                                           "ISO 9276-1" ,
                                           "ISO 9276-2" ;
                          <http://www.w3.org/2004/02/skos/core#prefLabel> "Particle Size Distribution" ;
                          :elucidation """This term designates the distribution of sizes of the particles composing a powder.
The size is expressed as equivalent diameter, i.e. the diameter of a sphere of equivalent volume to the actual particle.
The distribution is expressed as a volume distribution, i.e. the fraction of the overall volume of the powder comprised within each size range. A particle size distribution is understood as a volume distribution unless otherwise specified.
Alternatively, it can be expressed as a number distribution, i.e. the fraction of the overall number of particles comprised within each size range. It should be expressly indicated whether the distribution is expressed as a number distribution. Usually, a number distribution results in an over-representation of the finer size ranges.
It is measured by laser scattering, sieving, or image analysis on optical or SEM micrographs of a powder sample.
The distribution is summarized by the 10th, 50th and 90th quantiles or by average and standard deviation.""" .


###  https://www.cobrain-project.eu/thermalspraying/PhaseComposition
:PhaseComposition rdf:type owl:Class ;
                  rdfs:subClassOf :Property ;
                  rdfs:seeAlso """EN 13925-1:2003
EN 13925-2:2003
EN 13925-3:2005""" ;
                  <http://www.w3.org/2004/02/skos/core#prefLabel> "Phase Composition" ;
                  :elucidation """Phase composition refers to the type and relative amount of distinct phases composing a sample.
Phase composition is measured by X-Ray Diffraction (XRD).
The pattern obtained by diffraction of a monochromatic beam of X-rays from a sample allows qualitative identification of its crystalline phases by (computer-
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assisted) matching to reference databases of diffraction patterns like the ICDD JCPDF-2 or JCPDF-4 databases.
Fitting of the experimental pattern with suitable mathematical functions and integration of peaks' areas allows quantitative assessment of the relative mass fraction of phases by suitable techniques such as the external standard method, internal standard method, or the reference intensity ratio method.""" .


###  https://www.cobrain-project.eu/thermalspraying/PillarSplitting
:PillarSplitting rdf:type owl:Class ;
                 rdfs:subClassOf :Nanoindentation ;
                 <http://www.w3.org/2004/02/skos/core#prefLabel> "Pillar Splitting" .


###  https://www.cobrain-project.eu/thermalspraying/Plus
:Plus rdf:type owl:Class ;
      rdfs:subClassOf :NormalizedStringData ,
                      :TokenData .


###  https://www.cobrain-project.eu/thermalspraying/PoreSize
:PoreSize rdf:type owl:Class ;
          rdfs:subClassOf :Property ;
          rdfs:isDefinedBy "ISO 15901-1:2016 (mercury intrusion porosimetry)" ;
          <http://www.w3.org/2004/02/skos/core#prefLabel> "Pore Size" ;
          :elucidation """Pore size is the equivalent diameter of a pore, i.e. the diameter of a sphere with a volume equivalent to that of the pore.
The pore size in a material can be conveyed either through a complete distribution curve or through an average value. It is measured either by image analysis on optical or scanning electron micrographs, or by mercury intrusion porosimetry.""" .


###  https://www.cobrain-project.eu/thermalspraying/Porosity
:Porosity rdf:type owl:Class ;
          rdfs:subClassOf :Property ;
          rdfs:isDefinedBy "ASTM E2109-01(2021) - Porosity of thermal spray coatings by image analysis" ,
                           "ISO 15901-1:2016 - Mercury intrusion porosimetry" ;
          rdfs:seeAlso "F. Cardarelli (2008), Materials Handbook: A Concise Desktop Reference, second edition. Springer, London. G.T. Murray (1997), Handbook of Materials Selection for Engineering Applications. CRC Press." ;
          <http://www.w3.org/2004/02/skos/core#prefLabel> "Porosity" ;
          :elucidation "Porosity refers to the volume percentage of void space in a material. It is defined as the ratio of the volume of pores or voids in a material to the total volume of the material. . It is measured either by image analysis on optical or scanning electron micrographs, or by mercury intrusion porosimetry." .


###  https://www.cobrain-project.eu/thermalspraying/PositiveIntegerData
:PositiveIntegerData rdf:type owl:Class ;
                     rdfs:subClassOf :NonNegativeIntegerData .


###  https://www.cobrain-project.eu/thermalspraying/PowderFeeder
:PowderFeeder rdf:type owl:Class ;
              rdfs:subClassOf :SupplySystem ;
              owl:disjointUnionOf ( :MassFlowFeeder
                                    :VolumeFlowFeeder
                                  ) ,
                                  ( :PressurelessFeeder
                                    :PressurizedFeeder
```

```
                                  ) ;
              rdfs:comment """The definition is adapted from ISO 14917:2017: Thermal Spraying - Terminology, classification.

There are various types of powder feeders that can be distinguished into:
- Pressurized/pressureless feeders - the former type is needed when powder must be fed into a high-pressure region of a thermal spray jet.
- Volume flow controlled/mass flow controlled feeders. The former typically have simpler construction with systems such as rotating grooved discs or endless screws to feed meters volumes of material. The latter are usually based on an electronic balance with an output-based, closed-loop control and can be based on principles such as fluidized bed systems.

The power is usually uptaken with a flow of carrier gas then trnasports it through a tube toward the torch.""" ;
              rdfs:isDefinedBy "EN 1395-7:2007: Thermal Spraying - Acceptance inspection of thermal spraying equipment - Part 7: Powder feed systems" ,
                               "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
              rdfs:seeAlso "D.E. Crawmer (2013), Process Control and Control Equipment, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ,
                           "N. Sanpo, J. Wang, C.C. Berndt (2013), Feedstock Material Considerations for Thermal Spray, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
              <http://www.w3.org/2004/02/skos/core#prefLabel> "Powder Feeder" ;
              :elucidation "The powder feeder is a system for a controlled supply of powder feedstock to a thermal spray torch" .


###  https://www.cobrain-project.eu/thermalspraying/PowderFeeding
:PowderFeeding rdf:type owl:Class ;
               rdfs:subClassOf :SprayingSubProcess ;
               rdfs:comment "Powder feeding is done using either gravimetric or volumetric powder feeders. The feed rate is usually measured as a mass flow rate. The powder is usually carried with a flow of inert gas (nitrogen, argon)." ;
               rdfs:seeAlso "D.E. Crawmer (2013), Process Control and Control Equipment, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
               <http://www.w3.org/2004/02/skos/core#prefLabel> "Powder Feeding" ;
               :elucidation "Powder feeding is the process of supplying the powder feedstock to a thermal spray torch at a controlled rate." .


###  https://www.cobrain-project.eu/thermalspraying/PowderFeedstock
:PowderFeedstock rdf:type owl:Class ;
                 rdfs:subClassOf :ThermalSprayingComponent ;
                 rdfs:comment "Particle sizes are usually between 5 and 100 microns in size, and can be made from a variety of materials, such as metals, ceramics, polymers, and composites. The exact particle size distribution is an important process parameter and mist be tailored to the specific thermal spray process, the type of material, and the desired outcome/intended application." ;
                 rdfs:isDefinedBy "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
                 rdfs:seeAlso "N. Sanpo, J. Wang, C.C. Berndt (2013), Feedstock Material Considerations for Thermal Spray, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
                 <http://www.w3.org/2004/02/skos/core#altLabel> "Feedstock" ,
                                                                "Powder" ;
                 <http://www.w3.org/2004/02/skos/core#prefLabel> "Powder Feedstock" ;
                 :elucidation "Powder feedstock is a material in powder form used produce a coating on a substrate by feeding into a thermal spray torch" .


###  https://www.cobrain-project.eu/thermalspraying/PreHeating
```

```
:PreHeating rdf:type owl:Class ;
            rdfs:subClassOf :SprayingStage ;
            rdfs:comment """Pre-heating can be achieved either by using a separate heating system or, more frequently, by performing one or more passes of the torch onto the substrate without powder feed to increase the substrate temperature using the heat of the gas jet itself.
Pre-heating serves multiple purposes: it removed adsorbates and condensates (e.g. moisture, volatile organic compounds, etc.); it improves the wettability between the deposited material and the substrate; it prevents excessive temperature gradients across the coating/substrate system during the thermal spray process, which might otherwise result in transverse cracking of the coating due to excessive tensile stresses accumulated in its outer layers.""" ;
            rdfs:seeAlso "J. Knapp, D. Lemen (2013), Precoating Operations, in: R.C. Tucker jr. (Ed.), ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
            <http://www.w3.org/2004/02/skos/core#altLabel> "Heating" ;
            <http://www.w3.org/2004/02/skos/core#prefLabel> "Pre-Heating" ;
            :elucidation "Pre-heating is a sub-process of thermal spray whereby the temperature of the substrate is increased above room temperature shortly before deposition so that the substrate temperature is higher than room temperature when deposition begins." .


###  https://www.cobrain-project.eu/thermalspraying/Pressure
:Pressure rdf:type owl:Class ;
          rdfs:subClassOf :Property ;
          rdfs:isDefinedBy "ISO 80000-4:2019" ;
          <http://www.w3.org/2004/02/skos/core#prefLabel> "Pressure" ;
          :elucidation "Quotient of the component of a force normal to a surface and its area" .


###  https://www.cobrain-project.eu/thermalspraying/PressurelessFeeder
:PressurelessFeeder rdf:type owl:Class ;
                    rdfs:subClassOf :PowderFeeder ;
                    <http://www.w3.org/2004/02/skos/core#prefLabel> "Pressureless Feeder" .


###  https://www.cobrain-project.eu/thermalspraying/PressurizedFeeder
:PressurizedFeeder rdf:type owl:Class ;
                   rdfs:subClassOf :PowderFeeder ;
                   <http://www.w3.org/2004/02/skos/core#prefLabel> "Pressurized Feeder" .


###  https://www.cobrain-project.eu/thermalspraying/Process
:Process rdf:type owl:Class ;
         rdfs:comment "EMMO Process Concept" .


###  https://www.cobrain-project.eu/thermalspraying/ProcessMonitoring
:ProcessMonitoring rdf:type owl:Class ;
                   rdfs:subClassOf :SprayingSubProcess ;
                   rdfs:comment """Process monitoring includes both parameters directly measured by the control unit, and measures from additional sensors such as pyrometers/thermocameras for substrate temperature, in-flight process diagnostics for particle velocities/temperatures, etc.
These can be or not be integrated into a single monitoring system.""" ;
                   rdfs:seeAlso "D.E. Crawmer (2013), Process Control and Control Equipment, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
                   <http://www.w3.org/2004/02/skos/core#altLabel> "Process Control" ;
```

```
                   <http://www.w3.org/2004/02/skos/core#prefLabel> "Process Monitoring" ;
                   :elucidation "Measuring and controlling key parameters of the thermal spray process in real-time, such as gas flow rates, powder feed rate, substrate temperature, robot movements, etc." .


###  https://www.cobrain-project.eu/thermalspraying/Property
:Property rdf:type owl:Class ;
          rdfs:comment "EMMO Property Concept" .


###  https://www.cobrain-project.eu/thermalspraying/RationalData
:RationalData rdf:type owl:Class ;
              rdfs:subClassOf :RealData .


###  https://www.cobrain-project.eu/thermalspraying/RealData
:RealData rdf:type owl:Class ;
          rdfs:subClassOf :NumericData .


###  https://www.cobrain-project.eu/thermalspraying/ResidualStress
:ResidualStress rdf:type owl:Class ;
                rdfs:subClassOf :Property ;
                rdfs:isDefinedBy "EN 15305:2018 - Residual stress measurement by XRD" ;
                rdfs:seeAlso "NPL Good Practice Guide 143: Residual stress measurement by FIB+DIC" ,
                             """V. Hauk, Structural and Residual Stress Analysis by Nondestructive Methods. Evaluation - Application - Assessment, Elsevier, 1997
https://doi.org/10.1016/B978-0-444-82476-9.X5000-2""" ;
                <http://www.w3.org/2004/02/skos/core#prefLabel> "Residual Stress" ;
                :elucidation """A self-equilibrated system of stresses (with resulting strains) existing in a part in the absence of any externally applied action. These are usually the consequence of technological processes carried out on a part, such as machining; thermal, thermochemical or mechanical treatments; coating deposition; etc.
Residual stresses can be measured non-destructively by X-ray diffraction or (less frequently) neutron diffraction, Raman spectroscopy, photoluminescence piezospectroscopy, or they can be measured destructively by hole-drilling.
Micro-scale measurements of residual stresses  are carried out by Focused Ion Beam (FIB) milling coupled with Digital Image Correlation (DIC).""" .


###  https://www.cobrain-project.eu/thermalspraying/RobotManipulator
:RobotManipulator rdf:type owl:Class ;
                  rdfs:subClassOf :Manipulator ;
                  <http://www.w3.org/2004/02/skos/core#prefLabel> "Robot Manipulator" .


###  https://www.cobrain-project.eu/thermalspraying/Roughening
:Roughening rdf:type owl:Class ;
            rdfs:subClassOf :SubstratePreparation ;
            rdfs:comment "The substrate roughening in most cases is achieved by grit blasting: a compressed air stream containing abrasive particles is directed, through a nozzle, toward the part to be treated. It is also possible to use water jets with pressures, or to machine with suitably profiled tools (e.g. dove-tail profiles). Grit blasting or water jet roughening also induces compressive stress in the first tenths of mm below the substrate-roughened surface." ;
            rdfs:isDefinedBy "EN 13507:2018: Thermal Spraying - Pre-treatment of surfaces of metallic parts and components for thermal spraying." ,
```

```
                             "J. Knapp, D. Lemen (2013), Precoating Operations, in: R.C. Tucker jr. (Ed.), ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
            rdfs:seeAlso "Anon. (2013), Introduction to Coating Design and Processing, in: R.C. Tucker jr. (Ed.), ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
            <http://www.w3.org/2004/02/skos/core#altLabel> "GritBlasting" ,
                                                           "SandBlasting" ;
            <http://www.w3.org/2004/02/skos/core#prefLabel> "Roughening" ;
            :elucidation "Roughening the surface to provide asperities or irregularities to enhance coating adhesion and provide a larger effective surface." .


###  https://www.cobrain-project.eu/thermalspraying/Roughness
:Roughness rdf:type owl:Class ;
           rdfs:subClassOf :Property ;
           rdfs:isDefinedBy "ISO 21920-2:2021 (profile surface texture)" ,
                            "ISO 25178-2:2021 (areal surface texture)" ;
           <http://www.w3.org/2004/02/skos/core#prefLabel> "Roughness" ;
           :elucidation """Deviation of the detected profile/surface of an object (mechanical/electromagnetic/auxiliary profile/surface, depending on whether it is detected through mechanical interaction, electromagnetic interactions including optical methods, or other methods including atomic force microscopy/scanning tunnelling microscopy) from the reference line/surface after removal of (1) the smallest lateral scale components caused by noise in the acquisition system, (2) the macro-scale form, by suitable fitting e.g. to polynomial or spline functions, and (3) the large-scale lateral component (waviness) with a suitable filtering operation (e.g. Gaussian or robust Gaussian filters).
The roughness of a profile/surface can be conveyed by calculating one or more of a series of scalar parameters on the basis of a data matrix containing the complete roughness profile/surface.""" .


###  https://www.cobrain-project.eu/thermalspraying/Sample
:Sample rdf:type owl:Class ;
        rdfs:subClassOf :Object ,
                        [ rdf:type owl:Restriction ;
                          owl:onProperty :isSampleOf ;
                          owl:someValuesFrom owl:Thing
                        ] .


###  https://www.cobrain-project.eu/thermalspraying/ShortData
:ShortData rdf:type owl:Class ;
           rdfs:subClassOf :IntData .


###  https://www.cobrain-project.eu/thermalspraying/SpecificWearRate
:SpecificWearRate rdf:type owl:Class ;
                  rdfs:subClassOf :WearRate ;
                  rdfs:seeAlso """ASTM G99-17: Pin-on-Disc Sliding Test
ASTM G133-05(2016): Linearly Reciprocating Ball-on-Flat Sliding Test
ASTM G77-17: Block-on-Ring Sliding Test
ASTM G65-16(2021): Dry Sand/Rubber Wheel Abrasion Test
ASTM D4060-19: Taber Abrasion Test""" ;
                  <http://www.w3.org/2004/02/skos/core#prefLabel> "Specific Wear Rate" ;
                  :elucidation """The specific wear rate is a measure of the loss of material from a surface due to mechanical wear. It represents the specific rate (i.e. rate per unit load) at which a material loses mass when subjected to wear.
It can be measured for sliding, rolling/sliding, and abrasive wear processes.""" .

```

```
###  https://www.cobrain-project.eu/thermalspraying/SprayJet
:SprayJet rdf:type owl:Class ;
          rdfs:subClassOf :ThermalSprayingComponent ;
          rdfs:comment """The definition is taken from ISO 14917:2017: Thermal Spraying - Terminology, classification.
The characteristics of the particles in the spray jet, i.e. their velocity and their temperature, depend on the process parameters, the thermophysical properties of the particles themselves and their size distribution. The velocity and temperature of the particles, on the other hand, are the key features that determine the properties of the coating (porosity, adhesive and cohesive strength, etc.).""" ;
          rdfs:isDefinedBy "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
          <http://www.w3.org/2004/02/skos/core#altLabel> "Particle Jet" ,
                                                         "Particle Stream" ,
                                                         "Spray Stream" ;
          <http://www.w3.org/2004/02/skos/core#prefLabel> "Spray Jet" ;
          :elucidation "The stream of particles emerging from the thermal spray torch." .


###  https://www.cobrain-project.eu/thermalspraying/SprayTorch
:SprayTorch rdf:type owl:Class ;
            rdfs:subClassOf :Device ;
            rdfs:isDefinedBy "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
            rdfs:seeAlso "D.E. Crawmer (2013), Thermal Spray Processes, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
            <http://www.w3.org/2004/02/skos/core#altLabel> "Gun" ,
                                                           "Spraying Gun" ,
                                                           "Torch" ;
            <http://www.w3.org/2004/02/skos/core#prefLabel> "Spray Torch" .


###  https://www.cobrain-project.eu/thermalspraying/Spraying
:Spraying rdf:type owl:Class ;
          rdfs:subClassOf :Process ,
                          [ rdf:type owl:Restriction ;
                            owl:onProperty [ owl:inverseOf :isStageOf
                                           ] ;
                            owl:someValuesFrom :SprayingStage
                          ] ,
                          [ rdf:type owl:Restriction ;
                            owl:onProperty [ owl:inverseOf :isSubProcessOf
                                           ] ;
                            owl:someValuesFrom :Spraying
                          ] ;
          <http://www.w3.org/2004/02/skos/core#prefLabel> "Spraying Process" .


###  https://www.cobrain-project.eu/thermalspraying/SprayingStage
:SprayingStage rdf:type owl:Class ;
               rdfs:subClassOf :Process ,
                               [ rdf:type owl:Restriction ;
                                 owl:onProperty :isStageOf ;
                                 owl:someValuesFrom :Spraying
                               ] ;
               <http://www.w3.org/2004/02/skos/core#prefLabel> "Spraying Stage" .


###  https://www.cobrain-project.eu/thermalspraying/SprayingSubProcess
```

```
:SprayingSubProcess rdf:type owl:Class ;
                    rdfs:subClassOf :Process ,
                                    [ rdf:type owl:Restriction ;
                                      owl:onProperty :isSubProcessOf ;
                                      owl:someValuesFrom :Spraying
                                    ] ;
                    <http://www.w3.org/2004/02/skos/core#prefLabel> "Spraying Sub Process" .


###  https://www.cobrain-project.eu/thermalspraying/Stabilization
:Stabilization rdf:type owl:Class ;
               rdfs:subClassOf :SprayingStage ;
               rdfs:comment "Powder feeders usually take a brief time, from some tens of seconds to a few minutes, to deliver a constant feed rate upon first startup. The powder feeding must be allowed to stabilize before the torch is moved onto the substrate to avoid irregularities and poor deposit quality which would happen if the feed rate is not constant. The stabilization stage also allows to prevent issues that might arise from feeder malfunction, as this would be detected during the stabilization period and the substrate would not be compromised by an irregular deposition from a malfunctioning feeder." ;
               <http://www.w3.org/2004/02/skos/core#prefLabel> "Stabilization" ;
               :elucidation "Stabilization is a sub-process of thermal spray during which the powder feed rate is made to stabilize while the torch is not depositing material onto the substrate" .


###  https://www.cobrain-project.eu/thermalspraying/StringData
:StringData rdf:type owl:Class ;
            rdfs:subClassOf :SymbolicData .


###  https://www.cobrain-project.eu/thermalspraying/Substrate
:Substrate rdf:type owl:Class ;
           rdfs:subClassOf :ThermalSprayingComponent ;
           rdfs:comment "Definition adapted from ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
           rdfs:isDefinedBy "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
           <http://www.w3.org/2004/02/skos/core#altLabel> "Component" ,
                                                          "Part" ,
                                                          "Workpiece" ;
           <http://www.w3.org/2004/02/skos/core#prefLabel> "Substrate" ;
           :elucidation "The object to be coated (entirely or in part) in a thermal spray process" .


###  https://www.cobrain-project.eu/thermalspraying/SubstrateCoolingSystem
:SubstrateCoolingSystem rdf:type owl:Class ;
                        rdfs:subClassOf :CoolingSystem ;
                        rdfs:comment """Compressed air is the most typical coolant, but CO2, liquid nitrogen, or even liquid Ar can also be used in special cases.
The system can be stationary, i.e. fixed nozzles deliver the cooling jet to the substrate surface, and/or movable, i.e. nozzles are installed on the manipulator and move together with the thermal spray torch to cool the substrate surface immediately before and/or after the passage of the thermal spray jet.
In addition to cooling, the jet also serves the purpose of limiting the amount of overspray particles attaching to the surface of the growing deposit layer.""" ;
                        <http://www.w3.org/2004/02/skos/core#altLabel> "Cooling Jets" ;
                        <http://www.w3.org/2004/02/skos/core#prefLabel> " Substrate Cooling System" ;
                        :elucidation "A system that delivers a stream of coolant to the substrate surface" .
```

```
###  https://www.cobrain-project.eu/thermalspraying/SubstratePreparation
:SubstratePreparation rdf:type owl:Class ;
                      rdfs:subClassOf :Process ;
                      rdfs:comment """The sequence of operations during substrate preparation can vary.
Cleaning can be done before and/or after roughening, the latter also exerting a cleaning action. Masking is optional and not necessary in every case, and it can be done before or after roughening, before or after tooling, or the tool itself can include a shadow mask.""" ;
                      rdfs:isDefinedBy "EN 13507:2018: Thermal Spraying - Pre-treatment of surfaces of metallic parts and components for thermal spraying" ;
                      rdfs:seeAlso "Fauchais, Pierre L.; Heberlein, Joachim VR; Boulos, Maher I. Thermal spray fundamentals: from powder to part. Springer Science & Business Media, 2014." ,
                                   "J. Knapp, D. Lemen (2013), Precoating Operations, in: R.C. Tucker jr. (Ed.), ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
                      <http://www.w3.org/2004/02/skos/core#prefLabel> "Substrate Preparation" ;
                      :elucidation "The purpose of substrate preparation is to allow deposition on selected substrate areas and ensure adequate adhesion of the sprayed material. This process comprises the sub-processes of cleaning, roughening, masking, and tooling." .


###  https://www.cobrain-project.eu/thermalspraying/SupplySystem
:SupplySystem rdf:type owl:Class ;
              rdfs:subClassOf :System ;
              <http://www.w3.org/2004/02/skos/core#prefLabel> "Supply System" .


###  https://www.cobrain-project.eu/thermalspraying/SymbolicData
:SymbolicData rdf:type owl:Class ;
              <http://www.w3.org/2004/02/skos/core#prefLabel> "Symbolic Data"@en .


###  https://www.cobrain-project.eu/thermalspraying/System
:System rdf:type owl:Class ;
        rdfs:subClassOf :Object ,
                        [ rdf:type owl:Restriction ;
                          owl:onProperty [ owl:inverseOf :isConstituentOf
                                         ] ;
                          owl:someValuesFrom :Component
                        ] ;
        <http://www.w3.org/2004/02/skos/core#prefLabel> "System" .


###  https://www.cobrain-project.eu/thermalspraying/Temperature
:Temperature rdf:type owl:Class ;
             rdfs:subClassOf :Property ;
             rdfs:seeAlso "ISO 80000-5:2019" ;
             <http://www.w3.org/2004/02/skos/core#prefLabel> "Temperature" ;
             :elucidation "Partial derivative of internal energy of a system with respect to entropy at constant volume and constant number of particles in the system." .


###  https://www.cobrain-project.eu/thermalspraying/ThermalSpraySystem
:ThermalSpraySystem rdf:type owl:Class ;
                    rdfs:subClassOf :System ;
```

```
                   <http://www.w3.org/2004/02/skos/core#prefLabel> "Thermal Spray System" .


###  https://www.cobrain-project.eu/thermalspraying/ThermalSprayTorch
:ThermalSprayTorch rdf:type owl:Class ;
                   rdfs:subClassOf :SprayTorch ;
                   rdfs:comment """Definition taken with slight adaptation from ISO 14917:2017: Thermal Spraying - Terminology, classification.
The torch can be operated manually or automatically, and the process parameters, such as the gas flow rates and powder feed rate, can be adjusted to control the properties of the resulting coating.
The combustion-based torch design typically consists of a combustion chamber, a powder injector, and a nozzle. Other types of torches can differ slightly in their main constituents but all encompass a nozzle from which the gas flow emerges.""" ;
                   rdfs:isDefinedBy "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
                   rdfs:seeAlso "D.E. Crawmer (2013), Thermal Spray Processes, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
                   <http://www.w3.org/2004/02/skos/core#prefLabel> "Thermal Spray Torch" ;
                   :elucidation "The unit with which the feedstock is heated to the plastic or molten state, accelerated and projected onto the prepared substrate surface." .


###  https://www.cobrain-project.eu/thermalspraying/ThermalSpraying
:ThermalSpraying rdf:type owl:Class ;
                 rdfs:subClassOf :Spraying ;
                 rdfs:comment """Thermal spraying is distinguished by cladding processes by the lack of substrate melting during the process.
The feedstock material may be in the form of powder, ceramic rod, wire, or molten materials.
The definition is adapted from ISO 14917:2017""" ;
                 rdfs:isDefinedBy "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
                 rdfs:seeAlso "D.E. Crawmer (2013), Thermal Spray Processes, in: R.C. Tucker jr. (Ed.),ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ,
                              "Hermanek FJ (2001) Thermal spray terminology and company origins. ASM International, Materials Park, OH" ;
                 <http://www.w3.org/2004/02/skos/core#prefLabel> "Thermal Spraying" ;
                 :elucidation "Thermal spray comprises a group of coating processes in which finely divided materials are heated to a molten, semi-molten or plastic condition and propelled onto solid substrate surface by means of a Thermal Spray Torch, forming a coating." .

[ rdf:type owl:Axiom ;
   owl:annotatedSource :ThermalSpraying ;
   owl:annotatedProperty rdfs:isDefinedBy ;
   owl:annotatedTarget "ISO 14917:2017: Thermal Spraying - Terminology, classification." ;
   rdfs:comment "https://www.iso.org/obp/ui/#iso:std:iso:14917:ed-2:v1:en:term:3.1"^^xsd:anyURI
 ] .


###  https://www.cobrain-project.eu/thermalspraying/ThermalSprayingComponent
:ThermalSprayingComponent rdf:type owl:Class ;
                          rdfs:subClassOf :Component ;
                          <http://www.w3.org/2004/02/skos/core#prefLabel> " Thermal Spraying System Component"@en .

```

```
###  https://www.cobrain-project.eu/thermalspraying/Thickness
:Thickness rdf:type owl:Class ;
           rdfs:subClassOf :Property ;
           rdfs:isDefinedBy "ISO 80000-3:2019" ;
           <http://www.w3.org/2004/02/skos/core#prefLabel> "Thickness" ;
           :elucidation "Minimum length of a straight line segment between two parallel planes enclosing an object" .


###  https://www.cobrain-project.eu/thermalspraying/TokenData
:TokenData rdf:type owl:Class ;
           rdfs:subClassOf :StringData .


###  https://www.cobrain-project.eu/thermalspraying/Tooling
:Tooling rdf:type owl:Class ;
         rdfs:subClassOf :SubstratePreparation ;
         rdfs:comment """The tool must be suitable for coupling with the turntable and, together with the turntable and the manipulators/robot, must ensure suitable part configuration and motion with respect to the thermal spray torch.
The sample holder (\"tool\") might include shadow masks. In this case, the process of tooling also coincides with masking.""" ;
         rdfs:seeAlso "J. Knapp, D. Lemen (2013), Precoating Operations, in: R.C. Tucker jr. (Ed.), ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
         <http://www.w3.org/2004/02/skos/core#prefLabel> "Tooling" ;
         :elucidation "Substrates are attached to a suitable sample holder e.g. through screws or springs." .


###  https://www.cobrain-project.eu/thermalspraying/TorchComponent
:TorchComponent rdf:type owl:Class ;
                rdfs:subClassOf :Component ;
                <http://www.w3.org/2004/02/skos/core#prefLabel> "Torch Component" .


###  https://www.cobrain-project.eu/thermalspraying/Turntable
:Turntable rdf:type owl:Class ;
           rdfs:subClassOf :Device ;
           rdfs:comment """Turntables can feature simple continuous rotation or be synchronized with the manipulator.
Turntables can also be used to coat planar substrates of limited lateral width to achieve higher relative torch/substrate linear velocities than woukd be possible through the linear motion of the manipulator in front of a stationary substrate.""" ;
           rdfs:isDefinedBy "EN 1395-6:2007: Thermal spraying - Acceptance inspection of thermal spraying equipment - Part 6: Manipulator systems." ;
           rdfs:seeAlso "Anon. (2013), Introduction to Coating Design and Processing, in: R.C. Tucker jr. (Ed.), ASM Handbook Vol. 5A: Thermal Spray Technology, ASM International, Materials Park, OH, USA." ;
           <http://www.w3.org/2004/02/skos/core#altLabel> "Mandrel" ;
           <http://www.w3.org/2004/02/skos/core#prefLabel> "Turntable" ;
           :elucidation "The turntable is a rotating device in a thermal spray system onto which the tool holding the substrate(s) is mounted." .


###  https://www.cobrain-project.eu/thermalspraying/URI
:URI rdf:type owl:Class ;
     rdfs:subClassOf :SymbolicData .
```

```
###  https://www.cobrain-project.eu/thermalspraying/URL
:URL rdf:type owl:Class ;
     rdfs:subClassOf :URI .


###  https://www.cobrain-project.eu/thermalspraying/URN
:URN rdf:type owl:Class ;
     rdfs:subClassOf :URI .


###  https://www.cobrain-project.eu/thermalspraying/UnsignedByteData
:UnsignedByteData rdf:type owl:Class ;
                  rdfs:subClassOf :ShortData ,
                                  :UnsignedShortData .


###  https://www.cobrain-project.eu/thermalspraying/UnsignedIntData
:UnsignedIntData rdf:type owl:Class ;
                 rdfs:subClassOf :LongData ,
                                 :UnsignedLongData .


###  https://www.cobrain-project.eu/thermalspraying/UnsignedLongData
:UnsignedLongData rdf:type owl:Class ;
                  rdfs:subClassOf :NonNegativeIntegerData .


###  https://www.cobrain-project.eu/thermalspraying/UnsignedShortData
:UnsignedShortData rdf:type owl:Class ;
                   rdfs:subClassOf :IntData ,
                                   :UnsignedIntData .


###  https://www.cobrain-project.eu/thermalspraying/VectorData
:VectorData rdf:type owl:Class ;
            rdfs:subClassOf :ArrayData .


###  https://www.cobrain-project.eu/thermalspraying/Velocity
:Velocity rdf:type owl:Class ;
          rdfs:subClassOf :Property ;
          rdfs:isDefinedBy "ISO 80000-3:2019" ;
          <http://www.w3.org/2004/02/skos/core#prefLabel> "Velocity" ;
          :elucidation "Vector quantity corresponding to the rate of change of position" .


###  https://www.cobrain-project.eu/thermalspraying/VickersHardness
:VickersHardness rdf:type owl:Class ;
                 rdfs:subClassOf :Property ;
                 rdfs:seeAlso """ISO 6507-1:2018
ISO 6507-2:2018
ISO 6507-3:2018
ISO 6507-4:2018
ISO 4516:2002""" ;
                 <http://www.w3.org/2004/02/skos/core#prefLabel> "Vickers Hardness" ;
                 :elucidation """Hardness is the resistance of a material to permanent penetration by another material.
Vickers microhardness is specifically defined as the ratio between the maximum load (F, expressed in kgf) applied onto a Vickers indenter and the lateral
```

```
surface area (Ar) of the residual impression left in the indented material after complete unloading (in mm2). The latter is computed from the length of the diagonals of the residual impression, measured with an optical microscope.
Vickers hardness is specifically told into:
- Vickers hardness: F ≥ 49.03 N (5 kgf)
- Low-force Vickers hardness: 1.961 N (200 gf) ≤ F < 49.03 N (5 kgf)
- Vickers micro-hardness: 0.009807 N (1 gf) ≤ F < 1.961 N (200 gf)""" .


###  https://www.cobrain-project.eu/thermalspraying/VolumeFlowFeeder
:VolumeFlowFeeder rdf:type owl:Class ;
                  rdfs:subClassOf :PowderFeeder ;
                  <http://www.w3.org/2004/02/skos/core#prefLabel> "Volume Flow Feeder" .


###  https://www.cobrain-project.eu/thermalspraying/WearRate
:WearRate rdf:type owl:Class ;
          rdfs:subClassOf :Property ;
          <http://www.w3.org/2004/02/skos/core#prefLabel> "Wear Rate" .


###  https://www.cobrain-project.eu/thermalspraying/XYManipulator
:XYManipulator rdf:type owl:Class ;
               rdfs:subClassOf :Manipulator ;
               <http://www.w3.org/2004/02/skos/core#prefLabel> "X-Y Manipulator" .


###  https://www.cobrain-project.eu/thermalspraying/XYZManipulator
:XYZManipulator rdf:type owl:Class ;
                rdfs:subClassOf :Manipulator ;
                <http://www.w3.org/2004/02/skos/core#prefLabel> "X-Y-Z Manipulator" .


#################################################################
#    Individuals
#################################################################

###  https://www.cobrain-project.eu/thermalspraying/MTSG200-1
:MTSG200-1 rdf:type owl:NamedIndividual ,
                    :G200NanoIndenter ;
           <http://www.w3.org/2004/02/skos/core#prefLabel> "MTS G200 UR3" ;
           :elucidation "The MTS G200 system available at the University of Rome laboratory." .


###  Generated by the OWL API (version 4.5.26.2023-07-17T20:34:13Z) https://github.com/owlcs/owlapi
```