International Journal of Database Theory and Application
Vol.7, No.6 (2014), pp.175-190
http://dx.doi.org/10.14257/ijdta.2014.7.6.16

STSM: An Infrastructure for Unifying Steel Knowledge and Discovering New Knowledge

Xiaoming Zhang, Pengtao Lv* and Jianxia Wang

School of Information Science and Engineering, Hebei University of Science and Technology, Shijiazhuang, 050018, China

*zhangxiaom@hebust.edu.cn, *lvpengtao1988@outlook.com, Wang_jianxia@126.com*

Abstract

There are rich data resources in materials science, but these data resources are heterogeneous in level of system, structure, syntax, and semantics. Therefore, a domain ontology is necessary and helpful for the integration of these heterogeneous data resources, and it is also one of the main tasks of materials informatics. In this paper, we propose a steel semantic model (named STSM) based on ontology and logic rules for the representation of the steel knowledge. STSM is developed with the consideration of the features of materials data and the developed process is presented. Then, we describe the content and organization of STSM which covers the basic knowledge in steel domain. Further, domain axioms and logic rules are designed to enhance the reasoning ability of STSM. STSM is built and tested in protégé, and an experimental prototype based on Jena is also developed to demonstrate the effectiveness of STSM.

Keywords: *domain ontology; steel knowledge; domain axioms; rules; reasoning*

1. Introduction

Materials data resources are playing an important role in science development and there are more and more materials information available on the web. However, these resources have different kinds of formats, and they are lack of unified standard [1], which may lead to difficulties in finding materials information. Most of the time, materials researchers have to go to different web sites or knowledge bases to query knowledge of interest, which is inconvenient. Moreover, the existing materials query patterns which can support reasoning are very few. Reasoning is very important for materials researchers, because it can reveal the implicit materials information to researchers by imitating human intelligence [2]. Therefore a materials domain ontology which can support reasoning should be constructed to integrate heterogeneous materials data resources and find new knowledge or implicit knowledge from existing knowledge bases [3-6]. This paper chooses steel domain as the research object, and the steel semantic model is constructed to integrate steel knowledge. Moreover, the steel semantic model includes domain axioms, and the rules are also designed. This paper makes the following contributions.

(1) We describe the development process of steel domain ontology based on the Methontology method [7] which provides guidelines for constructing domain ontologies.

* Corresponding author

ISSN: 2005-4270 IJDTA

(2) We develop the steel semantic model STSM. STSM covers comprehensive and shared knowledge in steel materials domain, so it can be used to integrate heterogeneous materials data resources in semantic level.

(3) The axioms and rules are designed in STSM, and they can be used to reclassify and find new knowledge from existing knowledge bases. Furthermore, we discuss the application of axioms and rules in steel domain.

The remainder of paper is organized as follows. Section 2 introduces the related work. Section 3 describes the problem definition and important concept definitions. Section 4 gives development steps, content and organization of STSM. Section 5 shows the design and application of axioms and rules in steel domain. Section 6 concludes the paper and gives future work.

2. Related Work

In recent years, relatively mature domain ontologies have been established in environment [8], biology and medicine [9-22], chemistry [23-26], art [27] and other domains [28] with the rapid development of semantic web technology, and they have been applied to their respective domain. However, materials domain may have few relatively mature ontologies [29-31]. In materials domain ontologies, Ashino establishes a more comprehensive materials ontology [1], and it can cover completely materials knowledge and be used for exchanging data. MatONTO [32] is mainly used to study information integration about inorganic materials, which can support rules and be used to discover new compounds. MatOWL [33] explores the transformation from MatML to MatOWL and the population of instance data from MatML to MatOWL. The Steel ontology in ONTORULE [2, 30, 34, 35] includes less concepts, which focuses on the reasoning applied in engineering. These materials domain ontologies promote the development of materials data integration, but some of them lack of domain axioms and rules or have fewer concepts. Moreover, the reasoning ability is limited. Therefore we try to construct a steel semantic model which includes more comprehensive domain concepts and supports axioms and rules, so that materials researchers can discover new materials knowledge by axiom-based or rule-based reasoning.

3. Problem Description and Concept Definition

3.1. Problem Description

Immeasurable amounts of steel materials data are accumulated by different kinds of institutions, and lots of them are open. However, these open data resources are heterogeneous in level of system, structure, syntax, semantic. Most of existing materials domain ontologies are not specially designed for steel knowledge, so they may not summarize the comprehensive steel knowledge. In addition, some of existing materials ontologies may not support axioms or rule-based inferences. Therefore it is necessary to create a steel semantic model for integrating the heterogeneous data resources and finding new knowledge from existing knowledge bases. The following goals are expected to be achieved in this paper.

(1) A relatively comprehensive steel semantic model (we will extend to the field of metallic materials domain in the future) should be established, and it can cover the basic concepts of steel domain and the relationships between these concepts.

(2) The steel semantic model should include axioms. We can achieve reclassification by axioms. For example, the concepts which meet the axiom about dual-phase steel will be reclassified as subclasses of dual-phase steel.

(3) The rules are also designed in steel semantic model. Some inferences are too cumbersome to be represented by axioms, and it is necessary to use rule-based reasoning. We can find hidden materials knowledge by logic rules.

(4) The steel semantic model is constructed with comprehensive concepts and relationships from existing steel knowledge. We also refer to other related materials semantic model, so it can be compatible with other major materials ontologies, which makes it easy to map with other materials ontologies.

3.2. Conception Definition

It is necessary to explain the following definition for convenient expression in the next subsections.

Definition 1. Ontology. Ontology includes a series of finite terminologies and relationship between terminologies [36,37,38]. Ontology $\boldsymbol{O}$ can be represented as a quintuple: $\boldsymbol{O} = (\boldsymbol{C}, \boldsymbol{I}, \boldsymbol{P}, \boldsymbol{A})$, where $\boldsymbol{C}$ represents the concept set. $\boldsymbol{I}$ represents individual set, and $\boldsymbol{i}$ represents instance($\boldsymbol{i} \in \boldsymbol{I}$). $\boldsymbol{P}$ represents property set, and $\boldsymbol{P} = \boldsymbol{P_o} \cup \boldsymbol{P_d} \cup \boldsymbol{P_a}$, where $\boldsymbol{P_o}$ represents object property set and it is used to represent relationship between two instances($\boldsymbol{i1}$, $\boldsymbol{i2} \in \boldsymbol{I}$); $\boldsymbol{P_d}$ represents data property set and it is used to represent relationship between instance and data value; $\boldsymbol{P_a}$ represents annotation property set. $\boldsymbol{A}$ means axioms set.

Definition 2. STO. Based on Definition 1, we give the definition of the steel ontology STO: $\boldsymbol{STO} = (\boldsymbol{C_{st}}, \boldsymbol{P_{st}}, \boldsymbol{I_{st}}, \boldsymbol{A_{st}})$. $\boldsymbol{C_{st}}$ means concept set of steel domain, which covers the basic terminologies in steel domain; $\boldsymbol{P_{st}}$ represents property set of steel domain; $\boldsymbol{I_{st}}$ represents individual set of steel domain; $\boldsymbol{A_{st}}$ represents axioms set, and $\boldsymbol{A_{st}} = \boldsymbol{A_r} \cup \boldsymbol{A_d}$, where $\boldsymbol{A_r}$ represents restrictive axioms set and $\boldsymbol{A_d}$ represents defined axioms set which consists of domain axioms.

It should be pointed out that the rules in steel semantic model are implemented by Jena Rule, so they are not parts of STO. Therefore steel semantic model STSM is defined as follows.

Definition 3. STSM. $\boldsymbol{STSM} = \boldsymbol{STO} \cup \boldsymbol{R_{st}}$, where $\boldsymbol{R_{st}}$ means rules set. Further, $\boldsymbol{R_{st}} = \boldsymbol{R_c} \cup \boldsymbol{R_p}$, where $\boldsymbol{R_c}$ represents classification rules set and $\boldsymbol{R_p}$ represents prediction rules set.

Some important concepts such as $\boldsymbol{A_d}$ and $\boldsymbol{A_r}$ in above definitions should be explained in more detail. The defined axioms $\boldsymbol{A_d}$ is presented in the form of necessary and sufficient condition, and it is an equivalent relation. The part of the left side of the equation is defined concept which is always the abbreviation of complicated description. Correspondingly, the part of the right side of the equation is made up of atomic terms or properties from $\boldsymbol{O}$. The restrictive axioms [39] $\boldsymbol{A_r}$ is used to describe various restrictive condition of concepts, and it includes value restrictive and cardinality constraint [40]. The value restrictive is used to restrict domain and range of attribute, and cardinality constraint is used to limit the number of attribute value.

Further, classification rules $\boldsymbol{R_c}$ is used to reclassify according to different standards. For example, if a steel material's tensile strength is greater than 1400Mpa and $\boldsymbol{G_r}$ content is greater than 10.5%, then it is a *super high strength stainless steel*. The prediction rules $\boldsymbol{R_p}$ can predict unknown phenomenon or properties by relevant historical data and existing data.

4. Design of STSM

4.1. The Development Process of STSM

With the consideration of the feature of materials knowledge, we develop STSM based on the guidelines of methontology method [7,41]. According to the proposed methods, STSM has been developed. Table 1 gives the development steps of STSM, and Figure 1 describes the development process of STSM in the form of graph in detail.

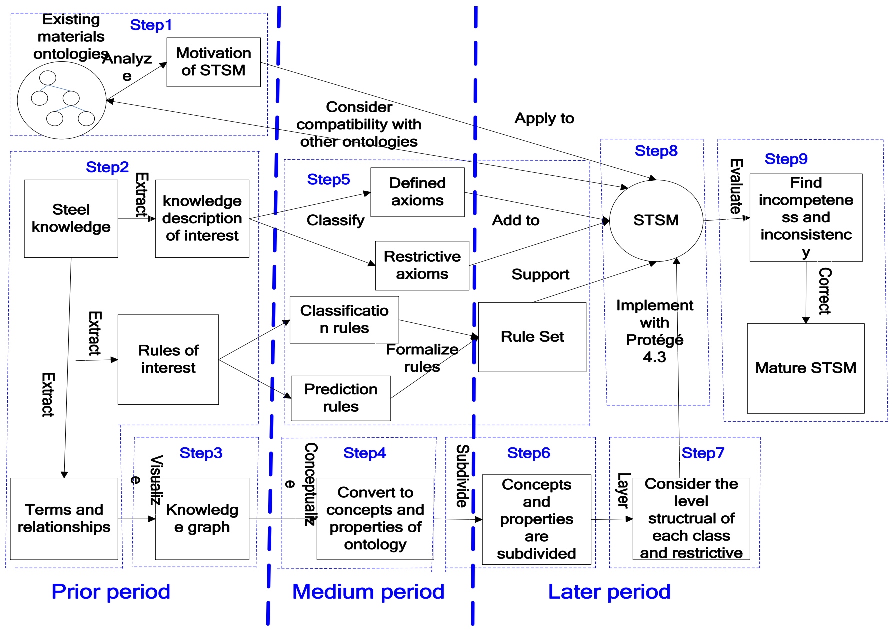


Figure 1. Development Process of STSM

Table 1. Development Step of STSM

Steps	Description
Step1	The existing materials ontologies are analyzed and the motivation of STSM is confirmed.
Step2	The steel materials knowledge is analyzed and terminologies and relationships are found.
Step3	The terminologies and relationships are represented in the form of graph
Step4	The terminologies and relationships from topological graph are converted into concepts and properties from STSM
Step5	Relevant axioms and rules are made.
Step6	STSM can be subdivided into several major classes, and we should consider relationships between different classes.
Step7	The hierarchies in each major class should be considered, and corresponding cardinality constrains and value limitations should be made.
Step8	Implementation stage. OWL ontology is generated with Protege4.3
Step9	Evaluation stage. The inconsistency and incompleteness are evaluated through the relevant technology with the participation of domain experts

In step 2, the knowledge topological graph of steel materials is generated as Figure 2 by analyzing steel materials knowledge. In Figure 2, the rounded rectangles represent materials properties such as basic data, heat treatment, chemical composition, mechanical property, processing property etc. Rectangles represent specific properties in detail. Ellipses mean steel classification which includes structural steel, machine parts steel, tool and mould steel, heat resisting steel and stainless steel.

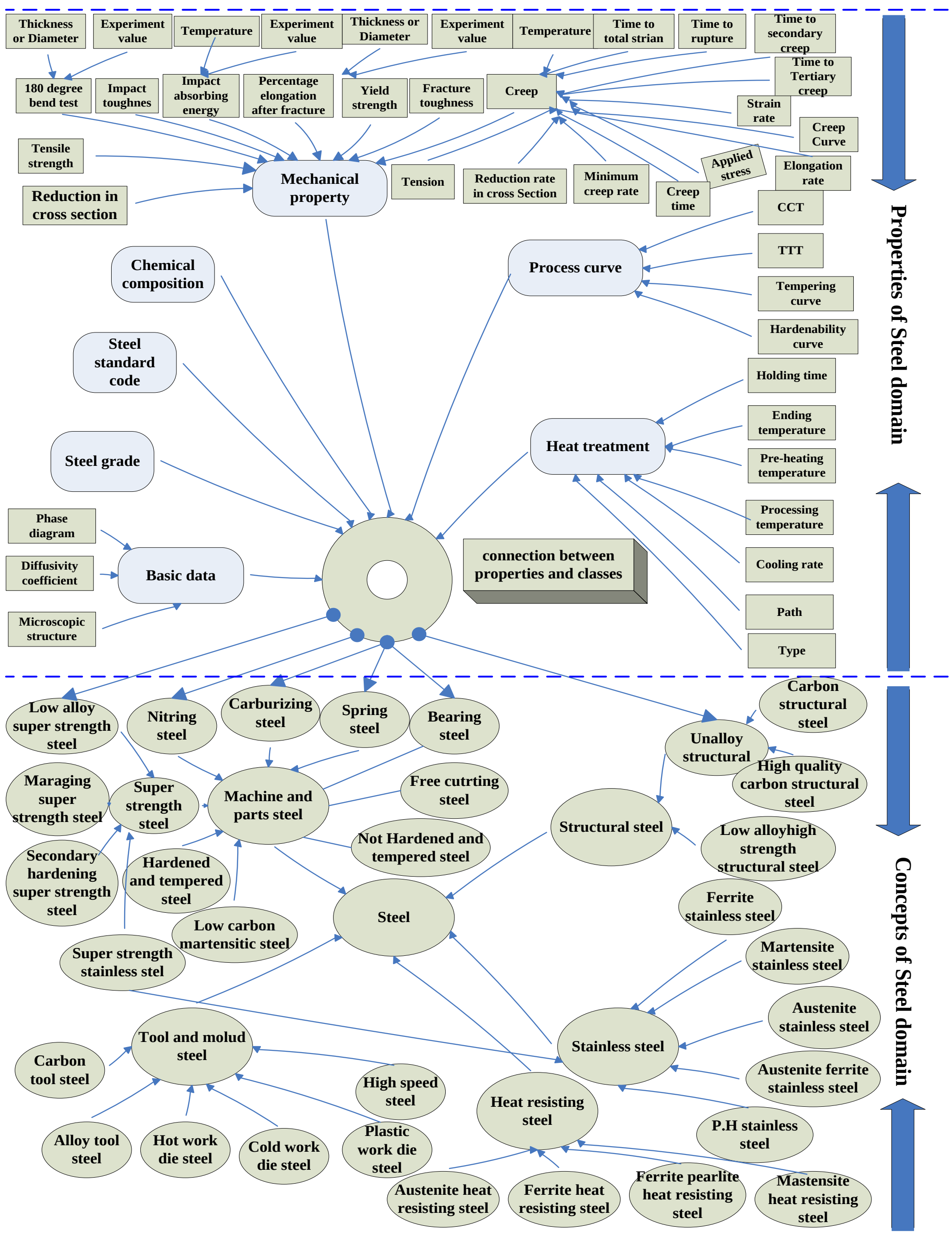


Figure 2. Knowledge Topological Graph of Steel Materials

4.2. Content and organization of STSM

Currently, STSM includes steel ontology STO and rules set $\boldsymbol{R_{st}}$. Now STSM has 476 concepts, 46 object properties and 24 data properties, and it can cover the basic knowledge of steel materials. Figure 3 shows organization structure of STSM. Obviously, STO is the core in STSM and it supports rules. In detail, concept set $\boldsymbol{C_{st}}$ includes 4 basic classes, and they are *Element* (it includes basic chemical elements), *Property* (it includes basic materials properties), *Steel* (it is classified into different categories according to different standards) and *Unit*. Specially, *Property* and *Steel* are key classes in STSM and introduced in the following.

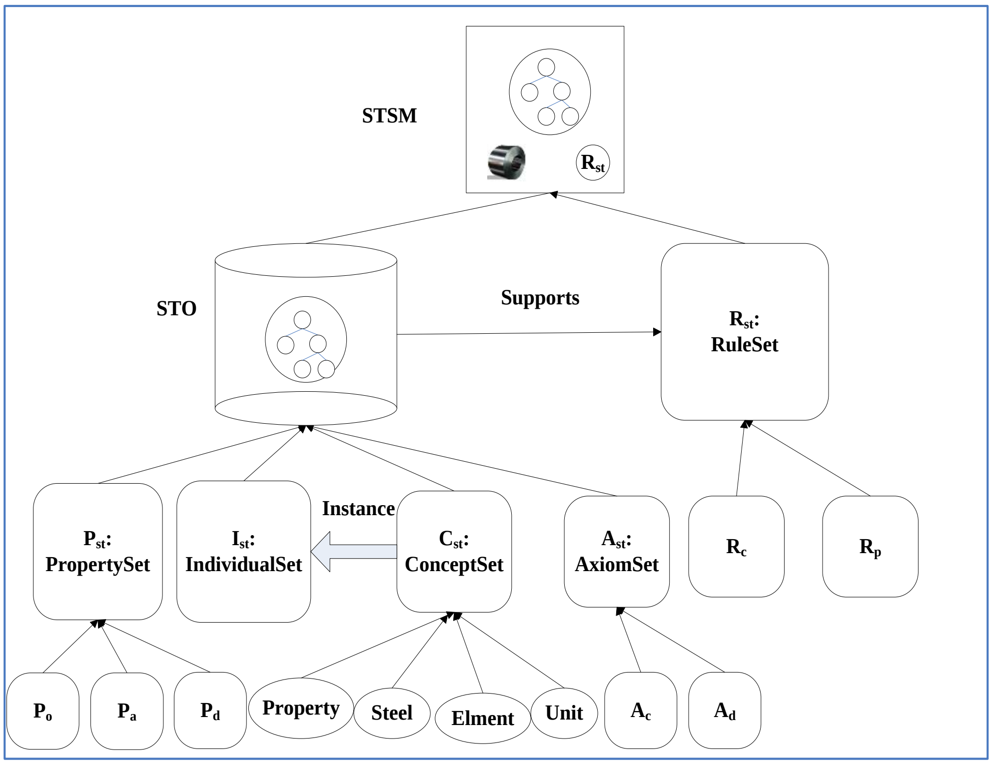


Figure 3. Organization Structure of STSM

Property class is mainly based on the properties of steel materials, and main properties in steel are represented in the form of ontology languages. With the help of the subclasses of *Property*, the properties of steel materials are represented clearly. Figure 4 gives the organization structure of *Property*. The subclasses of *Property* consist of basic data, chemical composition, mechanical property, process curve, heat treatment and physical quantity. Basic data includes microstructure, diffusivity coefficient and phase diagram, and they can also be subdivided. For example, microstructure can subdivided into 2D micro structure and 3D micro structure. The mechanical property includes yield strength, fracture toughness, 180 degree bend test, tensile strength etc. The process curve includes TTT, CCT, tempering curve, harden ability curve. The physical quantity includes time, diameter, and temperature etc.

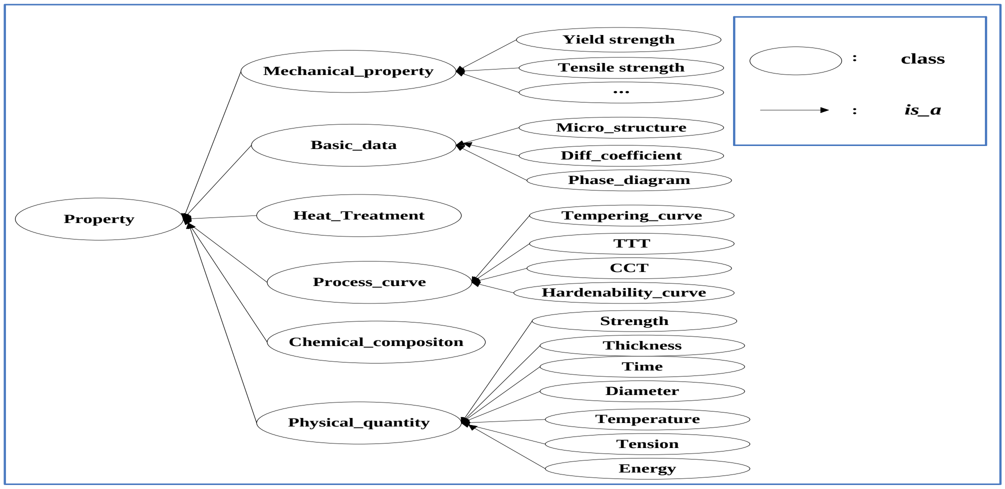


Figure 4. Organization Structure of Property

Furthermore, *Steel* is also the core class in the STSM. The steel domain has different classification methods according to different principles. For example, the *Steel* can be classified according to application, organization structure and different standards (For example, the steel serial number standard from America is used to classify in steel domain). So different classification principles should be considered in *Steel*, and the *Steel* is classified according to application of steel in this paper, and other classification methods are given in the form of axioms or rules. The Figure 5 shows organization structure of *Steel* according to application of steel. *Steel* has subclasses such as structure steel, machine parts steel, tool and mould steel, stainless steel and heat resisting steel. Structural steel can be also classified into unalloy structural steel and low alloy structural steel. Machine parts steel includes spring steel, bearing steel, carburizing steel, hardened and tempered steel and so on. Similarly, tool and mould steel, heat resisting steel and stainless steel have also different subclasses.

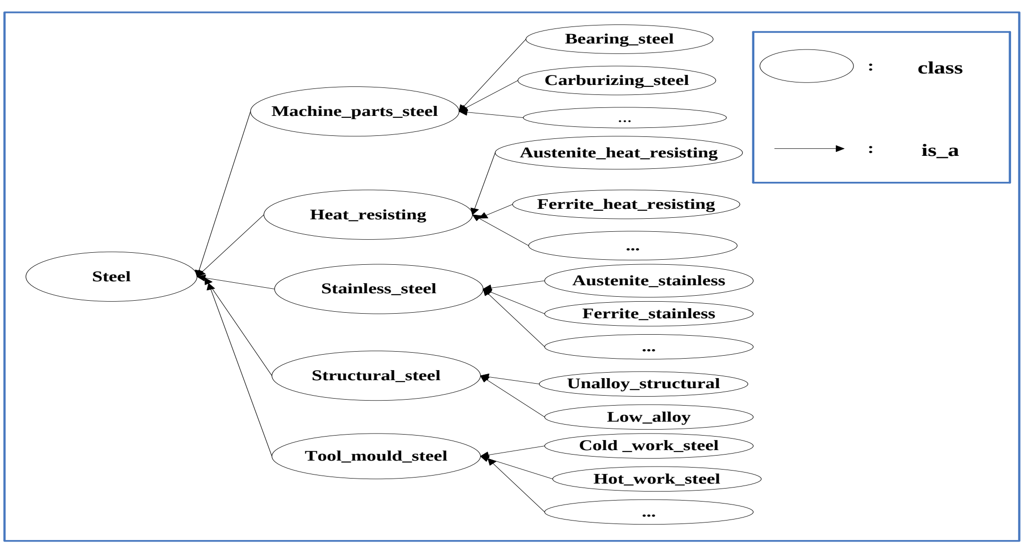


Figure 5. Organization Structure of Steel

Table 2 presents the important classes of STO along with their direct parent class, and through this table we can clearly see the hierarchical structure of the core concepts and relationships between them in steel materials. For example, the direct children of *mechanical property* include fracture toughness, impact toughness, creep etc, and it has also direct parent class *property*. Likewise, the direct parent class of high quality carbon structural steel and carbon structural steel is unalloy structural steel which has structural steel as its direct parent class. Table 2 may not show the relationships between these important concepts, so Figure 6 complements the relationships.

Table 2. The Classes and their Direct Parent Classes in Steel Domain (part)

The important classes of STO	Direct parent classes
diffusivity	Property
Microscopic_structural	Property
Heat_Treatment	Property
Mechanical_property	Property
180-degree_bend_test	Mechanical_property
Creep	Mechanical_property
Fracture_toughness	Mechanical_property
Impact_toughness	Mechanical_property
Tensile_strength	Mechanical_property
Yield_strength	Mechanical_property
Structural_steel	Steel
Low_alloy_high_strengh_structural_steel	Structural_steel
Unalloy_structural_steel	Structural_steel
Carbon_structural_steel	Unalloy_structural_steel
High-quality_Carbon_structural_steel	Unalloy_structural_steel
Machine_parts_with_steel	Steel
Bearing_steel	Machine_parts_with_steel

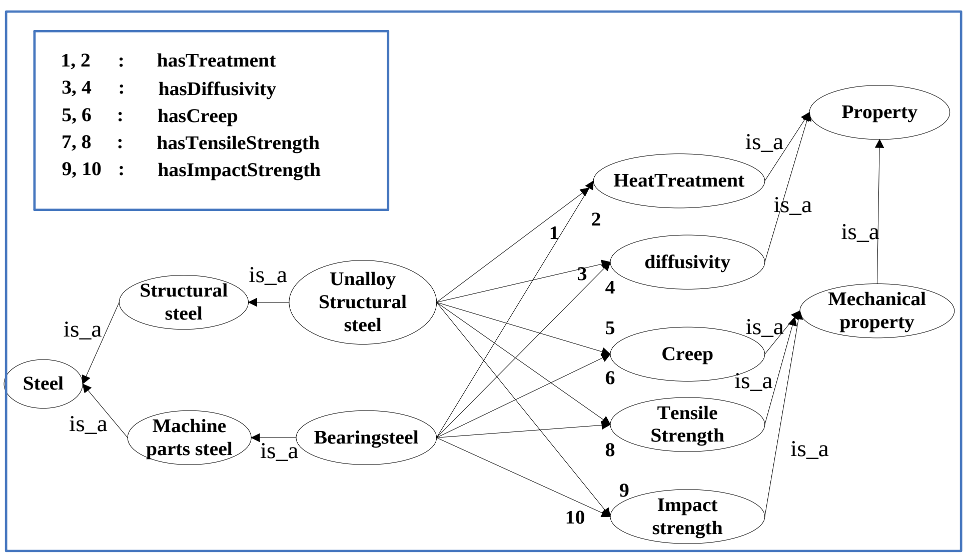


Figure 6. Relationships between Important Concepts (Part)

5. Design of Axioms and Rules in STSM

5.1. Design of Axioms

In STSM, the restrictive axioms $\boldsymbol{A_r}$ appears frequently in STSM, and it can be used to organize the relationships between these classes, and limit the domain and range of the object properties or data properties. The defined axioms $\boldsymbol{A_d}$ in the STSM is used to define concepts. For example, the Ferrite steel is a steel whose basic organizations includes ferrite, and these concepts and individuals which meet the definition will belong to the defined concept. We try to design axioms according to the following two aspects [42, 43]. Firstly, there is no classification about microstructure in the STSM, so axioms can be designed to classify steel according to microstructure. Secondly, different classification standards and guidelines should be considered to support international generality.

We have implemented the axioms for steel microstructure, other axioms are being designed. Some of the implemented defined axioms are given as follows.

Axiom 1. Axioms for Ferrite steel.
Ferrite_steel ≡ Steel u 9hasBasicOrganization.Ferrite.

Axiom 2. Axioms for Dual-phase steel.
Dual-phase_steel ≡ Steel u ≥2 hasBasicOrganization.BasicOrganization.

Axiom 3. Axioms for Austenite steel.
Austenite_steel ≡ Steel u 9hasBasicOrganization.Austenite.

Axiom 4. Axioms for Martensite steel.
Martensite_steel ≡ Steel u 9hasBasicOrganization.Marstensite.

Ferrite_steel on the left of the equation in Axiom 1 is the defined concept, and the right part is made up of atomic concept steel and anonymous class, which means that *Ferrite steel* is a kind of steel that includes at least a ferrite organization. As shown in Figure 7, *Ferrite steel* has not sub-concepts before reasoning in the protégé 4.3. However, the results are revealed as Figure 8 after reasoning with Pellet [44,45], and *Ferrite steel* has 6 sub-concepts as shown in Table 3.

Thus, we know that these materials belong to *Ferrite steel*. Furthermore, the axiom 3 shows the definition of *Austenite steel*, and *Austenite steel* is the materials that at least a basic organization which is austenite. The axioms of *Ferrite steel* and *Austenite steel* are similar with the axioms of *Martensite steel* and *Dual-phase steel*. It's worth noting that we have designed above axioms and more axioms are being designed.

Table 3. The Sub-concepts of Ferrite Steel in STSM (inferred)

Parent of concept	Concept in STSM
Ferrite steel	Austenite_ferrite_stainless_steel
Ferrite steel	F+P (Ferrite and Pearlite) not_hardened_and _tempered_steel
Ferrite steel	Ferrite_heat_resisting_steel
Ferrite steel	Ferrite_pearlite_heat_resisting_steel
Ferrite steel	Ferrite_stainless_steel
Ferrite steel	Low_alloy_high_strength_structral_steel

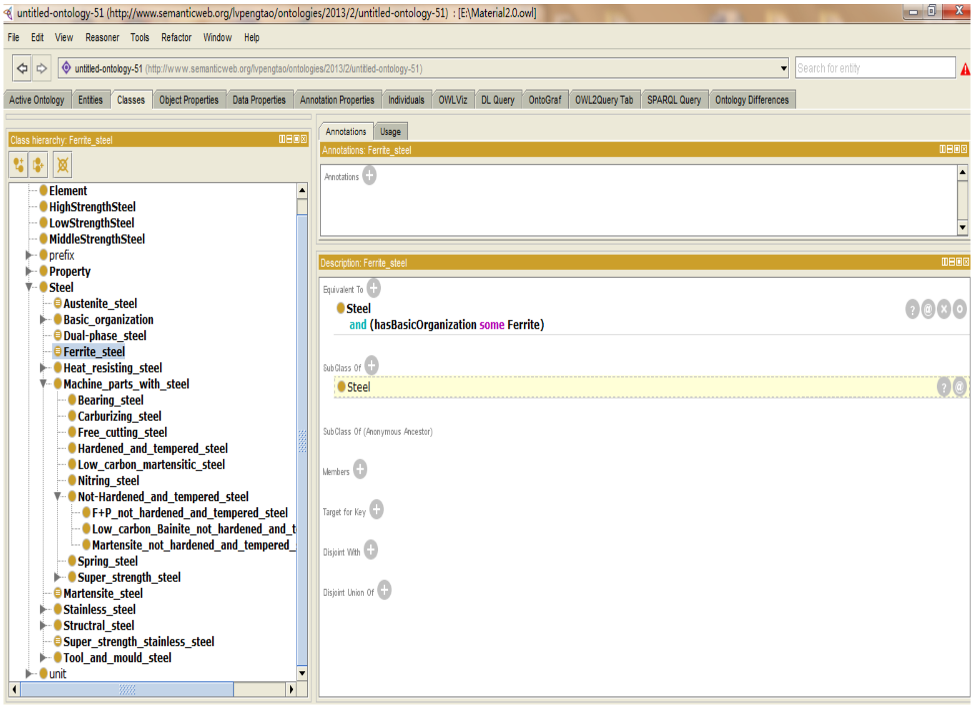


Figure 7. The Interface before Reasoning in Protégé 4.3

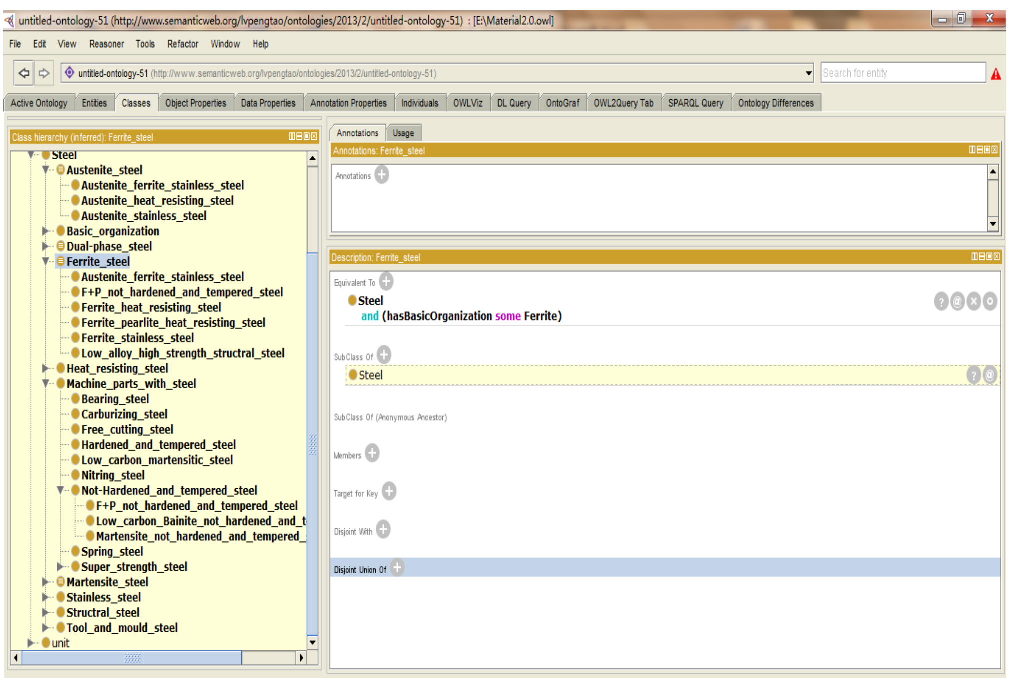


Figure 8. The Interface After Reasoning in Protégé 4.3

5.2. Design of Rules

Axioms have some limitations in representing knowledge. For example, high strength steel is the steel whose tensile strength is greater than 1400Mpa, and it would be difficult to be represented in axioms, because constraints in axioms always recognize a specific value and do not recognize value range. In other words, the axioms can identify 1400Mpa, but do not recognize the range which is greater than 1400Mpa. Hence, we should introduce rules [46,47,48] to STSM, which can represent knowledge that can not be represented by axioms. By making rules conforming to certain syntax and structure, new knowledge can be discovered by reasoning. The key issue of rule design is to find appropriate rules which are accepted by domain experts. This paper designs rules as follows, but they are not limited in these aspects, and more and more rules will be found with further research.

(1) Tensile strength. Steel will be classified into high strength steel or low strength steel according to tensile strength.

(2) Content of total alloy element. Alloy steel will be classified into high alloy steel, middle alloy steel and low alloy steel according to content of total alloy element.

(3) Stainless and corrosion-resisting steel. Stainless and corrosion-resisting steel is the steel whose Gr content is greater than 10.5%.

(4) Super strength stainless. If a kind of steel includes element Gr whose content value is greater than 10.5% and has tensile strength which is greater than 1400Mpa, then it is super strength stainless steel.

(5) The materials property may be predicted by relevant materials properties parameters.

In STSM, the first 4 rules belong to classification rules $\boldsymbol{R_c}$, and the last rules belong to prediction rules $\boldsymbol{R_p}$.

There are many rule languages, such as OWL [49], SWRL [50], RIF [2], Jena Rule [51], and the Jena Rule is used in STSM. Table 4 shows the rules of tensile strength. High strength steel is the steel whose tensile strength is greater than 1400Mpa, and low strength steel is the steel whose tensile strength is less than 700Mpa, and middle strength steel have tensile strength between 700Mpa and 1400Mpa. Table 5 gives the rules in super high strength stainless steel, and it means that super high strength stainless steel is that steel whose tensile strength is greater than 1400Mpa and Gr content is greater than 10.5%.

Table 4. Rules for Tensile Strength

Name	Rule
HighStrengthSteel	[HighStrengthSteel: (?x matowl :hasTensileStrength ?y) (?y matowl :hasUnit Mpa) （?y matowl :hasMinValue ?z) greaterThan(?z, 1400) ->(?x rdf:type matowl:HighStrengthSteel)]
LowStrengthSteel	[LowStrengthSteel: (?x matowl :hasTensileStrength ?y) (?y matowl :hasUnit Mpa) (?y matowl :hasMinValue ?z) lessThan(?z, 700) -> (?x rdf:type Matowl:LowStrengthSteel)]
MiddleStrengthSteel	[MiddleStrengthSteel: (?x matowl :hasTensileStrength ?y) (?y matowl :hasUnit Mpa) （?y matowl :hasMinValue ?z) lessThan(?z, 1400) greaterThan(?z, 700) ->(?x rdf:type matowl:LowStrengthSteel)]

Table 5. Rules in Super High Strength Stainless Steel

Name	Rule
SuperStrength StainlessSteel	[SuperStrengthStainlessSteel: (?x matowl :hasTensileStrength ?y) (?y matowl :hasMinValue ?z) greaterThan(?z, 1400) (?x matowl :hasChemicalCompostion?w) (?w matowl :hasElement matowl：Gr) (?w matowl :hasContentRatio ?f) greaterThan(?f, 0.105) ->(?x rdf:type matowl: SuperStrengthStainlessSteel)]

We develop the experimental prototype with Netbeans 7.3 and Jena for testing the rules. In Figure 9, the steel ontology tree is shown, and the rules can be selected. For example, we select the rule for low strength steel which is shown in Figure 9, and query condition “rdf: type” and “LowStrength” should also be selected, which means that we want to query the steel whose types are low strength steel. The corresponding SPARQL statement of the above query condition is **SPARQL 1**. Lastly, the desired query results are acquired in Figure 9. According to query results, we conclude that Q275, Q255, Q235, Q215 and Q195 belong to low strength steel, but their types are not low strength steel if we don’t choose any rules in the rule list.

SPARQL 1. SPARQL for low strength steel.

```
SELECT ?x WHERE{
    ?x rdf:type matowl:LowStrengthSteel}
```

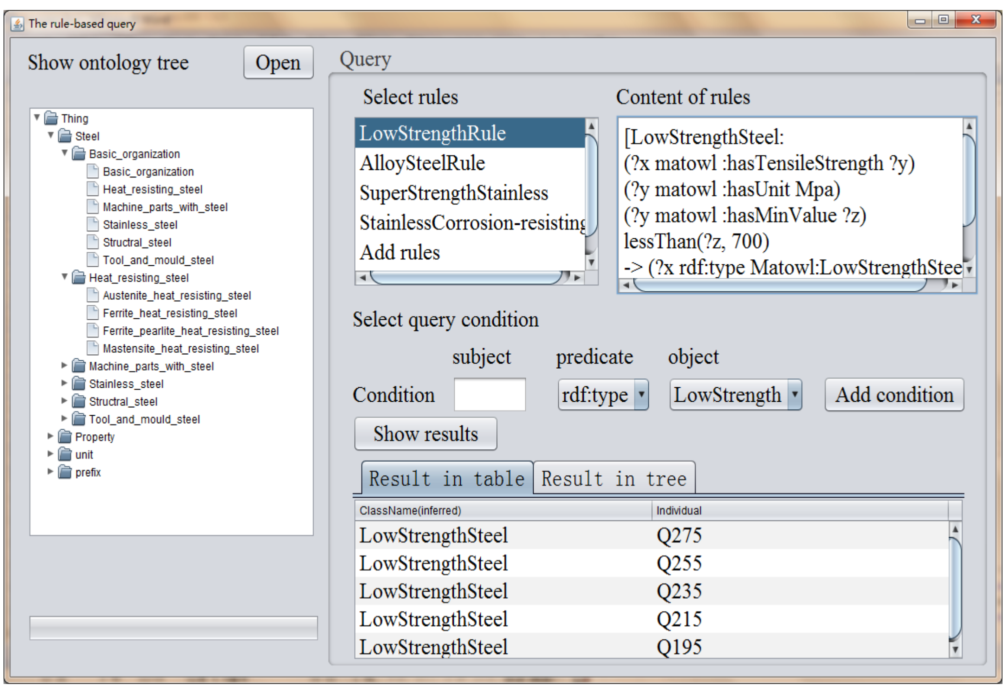


Figure 9. Query Results

6. Conclusion and Future Work

This paper discusses the construction process of a steel semantic model STSM with the consideration of the feature of materials knowledge. STSM covers the basic steel knowledge and can be used to integrate heterogeneous materials data. Further, we have developed some of the domain axioms and logic rules in STSM, which is sure to be helpful for discovering hidden materials knowledge by automatic reasoning. In future, STSM will be extended to the metal materials domain, so it can provide richer axioms and rules by elaborate analysis of materials domain knowledge. Besides, on the basis of STSM, we will populate the STSM with materials data from open data source to form a richer materials knowledge base.

Acknowledgements

This work is supported in National Natural Science Foundation of China (No. 51271033), Hebei Natural Science Foundation (No. F2013208107), Science Foundation Project of Hebei Education Department (No. QN20131138, No. ZD2014027), and the Research Foundation for the Doctoral Program of Hebei University of Science and Technology (No. QD201036).

References

[1] T. Ashino, “Materials Ontology: An infrastructure for exchanging materials information and knowledge”, Data Science Journal, vol. 9, **(2010)**, pp. 54-61.

[2] L. Polo and D. Berrueta, First steel industry internal demonstrators, EU-IST Integrated Project ONTORULE, **(2009)**.

[3] C. Wu, G. Cheng and J. Qiang, Metal Material Science, Metallurgical Industry Press, Beijing, **(2009)**.

[4] Y. Ma, six hundred kinds of heat treatment process methods, Chemicla Industry Press, Shanghai, **(2008)**.

[5] Q. Dai, Metal Material Science, Chemicla Industry Press, Beijing, **(2005)**.

[6] B. Ma and J. Wang, Practical heat treatment technology and application, Chemicla Industry Press, **(2009)**.

[7] M. Fernández-López, A. Gómez-Pérez and N. Juristo, “Methontology: from ontological art towards ontological engineering”, AAAI Technical Report SS-97-06, **(1997)**.

[8] T. Myers. and I. Atkinson, “Eco-informatics modeling via semantic inference”, Information Systems, vol. 38, no. 38, **(2013)**, pp. 16-32.

[9] L. M. Schriml, C. Arze, S. Nadendla, Y. W. Chang and M. Mazaitis, “Disease Ontology: a backbone for disease semantic integration”, Nucleic acids research, vol. 40, **(2012)**, pp. 940-946.

[10] V. Bertaud-Gounot, R. Duvauferrier and A. Burgun, “Ontology and medical diagnosis”, Informatics for Health and Social Care, vol. 37, **(2012)**, pp. 51-61.

[11] T. J. Bright, E. Yoko Furuya, G. J. Kuperman, J. J. Cimino and S. Bakken, “Development and evaluation of an ontology for guiding appropriate antibiotic prescribing”, Journal of Biomedical Informatics, vol. 45, no. 1, **(2012)**, pp. 120-128.

[12] F. Zeshan and R. Mohamad, “Medical Ontology in the Dynamic Healthcare Environment”, Procedia Computer Science, **(2012)**, vol. 10, pp. 340-348.

[13] E. E. Matos, F. Campos, R. Braga and D. Palazzi, “CelOWS: An ontology based framework for the provision of semantic web services related to biological models”, Journal of Biomedical Informatics, vol. 43, no, 1, **(2010)**, pp. 125-136

[14] A. Gupta, C. Condit and X. Qian, “BioDB: An ontology-enhanced information system for heterogeneous biological information”, Data & Knowledge Engineering, vol. 69, no. 11, **(2010)**, pp. 1084-1102.

[15] M. Ashburner, C. A. Ball and J. A. Blake, “Gene Ontology: tool for the unification of biology”, Nature genetics, vol. 25, **(2000)**, pp.25-29.

[16] C. E. Gillies, M.-R. Siadat, N. V. Patel and G. D. Wilson, “A simulation to analyze feature selection methods utilizing gene ontology for gene expression classification”, Journal of Biomedical Informatics, vol. 46, no. 6, **(2013)**, pp. 1044-1059.

[17] Y. Xu, M. Guo, W. Shi, X. Liu and C. Wang, “A novel insight into Gene Ontology semantic similarity”, Genomics, vol. 101, no. 6, **(2013)**, pp. 368-375.

[18] S. Khan, A . R. Baig and W. Shahzad, "A novel ant colony optimization based single path hierarchical classification algorithm for predicting gene ontology", Applied Soft Computing, vol. 16, **(2014)**, pp.

[19] C. J. Mungall, M. Bada, T. Z. Berardini, J. Deegan, A. Ireland, M. A. Harris, D. P. Hill and J. Lomax, "Cross-product extensions of the Gene Ontology", Journal of Biomedical Informatics, vol. 44, no. 1, **(2011)**, pp. 80-86.

[20] V. K. Khodiyar, D. P. Hill, D. Howe, T. Z. Berardini, S. Tweedie and P. J. Talmud, "The representation of heart development in the gene ontology", Developmental Biology, vol. 354, no. 1, **(2011)**, pp. 9-17.

[21] G. Macintyre, J. Bailey, D. Gustafsson, I. Haviv and A. kowalczyk, "Using Gene Ontology annotations in exploratory microarray clustering to understand cancer etiology", Pattern Recognition Letters, vol. 31, no. 14, **(2010)**, pp. 2138-2146.

[22] M. Ashburner, C. A. Ball, J . A. Blake, D. Botstein, H. Butler and J. Michael Cherry, "Gene Ontology: tool for the unification of biology", Nature genetics, **(2000)**, pp. 25-29.

[23] J. Hastings, L. Chepelev, E. Willighagen, N. Adams, C. Steinbeck and M. Dumontier, "The chemical information ontology: provenance and disambiguation for chemical data on the biological semantic web", PLoS One, vol. 6, **(2011)**.

[24] J. Morbach, A. Yang and W. Marquardt, "OntoCAPE—A large-scale ontology for chemical process engineering", Engineering Applications of Artificial Intelligence, vol. 20, no. 2, **(2007)**, pp. 147-161.

[25] A. Kokossis, E. Gao and A. Kourakis, "On the dynamic management of chemical engineering knowledge using an ontology-based approach", Engineering Applications of Artificial Intelligence, vol. 21, **(2006)**, pp. 1997-2002.

[26] H. J. Feldman, M. Dumontier, S. Ling, N. Haider and C. W.V. Hogue, "CO: A chemical ontology for identification of functional groups and semantic comparison of small molecules", FEBS Letters, vol. 579, no. 21, **(2005)**, pp. 4685-4691.

[27] J. Hunter, and S. Odat, "Building a Semantic Knowledge-Base for Painting Conservators", the 7th IEEEInternational Conference, **(2011)**.

[28] T. Pizzuti, G. Mirabelli, M . A. Sanz-Bob and F. Gomez-Gonzalez, "Food Track &Trace ontology for helping the food traceability control", Journal of Food Engineering, vol. 120, **(2014)**, pp. 17-30.

[29] X. Wang, T. N. Wong, Z.-P. Fan, "Ontology-based supply chain decision support for steel manufacturers in China", Expert Systems with Applications, vol. 40, no. 18, **(2013)**, pp. 7519-7533.

[30] P. Valledor, D. Diaz, D. Berrueta, L. Polo, E. Rubiera and A. Mosca, Ontology for the Steel Domain, EU-IST Integrated Project ONTORULE, **(2009)**.

[31] X. Cheng, C. Hu and Y. Li, "A Semantic-Driven Knowledge Representation Model for the Materials Engineering Application", Data Science Journal, vol. 13, **(2014)**, pp. 26-44.

[32] K. Cheung, J. Drennan and J. Hunter, "Towards an Ontology for Data-driven Discovery of New Materials", AAAI Spring Symposium: Semantic Scientific Knowledge Integration, **(2008)**.

[33] X. Zhang, C. Hu and H. Li, "Semantic Query On Materials Data Based on Mapping MatML to An OWL Ontology", Data Science Journal, vol. 13, **(2009)**.

[34] G. Gonzalez-Moriyon, L. Polo and C. Tejo-Alonso, Final steel industry public demonstrators, EU-IST Integrated Project ONTORULE **(2009)**.

[35] J. de Bruijn, P. Bonnard, H. Citeau and S. Dehors, Combinations of rules and ontologies: State-of-the-art survey of issues, EU-IST Integrated Project ONTORULE, **(2009)**.

[36] G. Antoniou and F. V. Harmelen, A Semantic Web Primer, MIT press, Cambridge, **(2008)**.

[37] A. Yuan, X. Hu and I. Song, "Learning to discover complex mappings from web forms to ontologies", Proceedings of the 21st ACM international conference on Information and knowledge management, **(2012)**.

[38] F. Baader, D. L. McGuinness, D. Nardi and P. F. Patel-Schneider, The description logic handbook: theory, implementation and applications, Cambridge university press, Cambridge, **(2003)**.

[39] R. Lin, F. Liu, C. Dai and L. Yao, "The application of restrictive axioms in OWL ontology model. Computer Engineering", Computer Engineering, **(2006)**, pp. 193-194.

[40] B. C. Grau , I. Horrocks, B. Motik, B. Parsia, P. Patel-Schneider and U.Satteler, "OWL 2: The next step for OWL", Web Semantics: Science, Services and Agents on the World Wide Web, vol. 6, no. 4, **(2008)**, pp. 309-322.

[41] N. F. Noy and D. L. McGuinness, "Ontology development 101: A guide to creating your first ontology", Stanford knowledge systems laboratory technical report KSL-01-05 and Stanford medical informatics technical report SMI-2001-0880, **(2001)**.

[42] F. Baader, M. Knechtel, and R. Peñaloza, "Context-dependent views to axioms and consequences of Semantic Web ontologies", Web Semantics: Science, Services and Agents on the World Wide Web, vol. 12–13, **(2012)**, pp. 22-40.

[43] T. R. Gruber, "A translation approach to portable ontology specifications", Knowledge acquisition, vol. 5, **(1993)**, pp. 199-220.

[44] G. Meditskos and N. Bassiliades, "DLEJena: A practical forward-chaining OWL 2 RL reasoner combining Jena and Pellet", Web Semantics: Science, Services and Agents on the World Wide Web, vol. 8, no. 1, **(2010)** pp. 89-94.

[45] E. Sirin, B. Parsia, B. C. Grau, A. Kalyanpur and Y. Katz, "Pellet: A practical owl-dl reasoner", Web Semantic: Science, Services and Agents on the World Wide Web, vol. 5, **(2007)**, pp. 51-53.

[46] M. B. Shen, Z. Yao, Wu, Y. Zhang and W. Yi, "Ontology-based association rules retrieval using protege tools", Data Mining Workshops, the 6th IEEE International Conference, **(2006)**.

[47] C. Golbreich, "Combining rule and ontology reasoners for the semantic web", Rules and Rule Markup Languages for the Semantic Web, Springer Berlin Heidelberg, vol. 3791, **(2004)**, pp. 6-22.

[48] S. Park, J. Kang, and W. Kim, "A framework for ontology based rule acquisition from web documents", Web Reasoning and Rule Systems, Springer, **(2007)**, pp. 229-238.

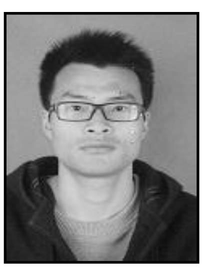
[49] S. Bechhofer, "OWL: Web ontology language", Encyclopedia of Database Systems, Springer, **(2009)**.

[50] SWRL:A semantic web rule language combining OWL and RuleML. http://www.w3.org/Submission/SWRL/ W3C Member submission. LastVisited, **(2013)**.

[51] J. J. Carroll, I. Dickinson, C. Dollin, D. Reynolds, A. Seaborne, and K. Wilkinson, "Jena: implementing the semantic web recommendations", Proceedings of the 13th international World Wide Web conference on Alternate track papers & posters, New York, **(2004)**.

Authors

Xiaoming Zhang, was born in 1975, received the PhD degree in computer application from University of Science and Technology Beijing of China in 2009, and the Master degree in computer application from Hebei University of China in 2002. Now, he is an associate professor in the School of Information Science and Engineering at Hebei University of Science and Technology, China. His main research interests include Semantic Web and domain-specific information integration.



Pengtao Lv, was born in 1988, received the bachelor's degree in computer science from Hebei University of Science and Technology, China. Now, he is studying for a master's degree in computer application in the same school. His main research interests lie in Semantic Web and domain-specific information integration.

Jianxia, Wang, was born in 1970, received the Master degree in Measurement Technology and Instrument from Yanshan University of China in 2003. Now, she is a professor in the School of Information Science and Engineering at Hebei University of Science and Technology, China. Her main research interests include Network and Database, Pattern recognition.

