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AN ATTEMPT AT FORMULATION OF ONTOLOGY FOR TECHNOLOGICAL KNOWLEDGE COMPRISED IN TECHNICAL STANDARDS

PRÓBA SFORMUŁOWANIA ONTOLOGII WIEDZY TECHNOLOGICZNEJ ZAWARTEJ W NORMACH TECHNICZNYCH ODLEWÓW

The principal function of technical standards is to facilitate exchange of information between various entities taking part in economic activities. Technical standards mainly comprise the basic knowledge from a specific field of technology. A condition for effective use of this knowledge is putting it in some order and creating mechanisms, which will enable searching for and finding of information. Ordering of knowledge is the task of ontology in the sense of information science. The authors' intention has been building of an ontology, which would enable access to a detailed knowledge comprised in the content of a standard and not only to a symbol used to designate this standard. This should enable designing of a knowledge exploration system solving the technological problems based on the data and rules recorded in numerous standards. The ontology will make basis for further development and extension of foundry knowledge using the results of scientific studies and practical experience. This article presents a concept and principles of ontology formulation for the needs of collecting the technological knowledge. In formulation of ontology the RDF (Resource Description Framework) language, used also as a tool for information representation in the resources of global network (WWW), is utilised. Some examples are given of how to record the knowledge comprised in ASTM standards according to the designed ontology along with examples of the rules used in search for information.
Keywords: ontology, product development

Zasadniczą funkcją norm technicznych jest usprawnienie przepływu informacji pomiędzy uczestnikami wymiany gospodarczej. Normy techniczne zawierają jednak także podstawową wiedzę z określonej dziedziny techniki. Warunkiem efektywnego wykorzystania tej wiedzy jest jej uporządkowanie i stworzenia mechanizmów wyszukiwania informacji. Porządkowanie wiedzy jest zadaniem ontologii w jej informatycznym rozumieniu. Naszym zadaniem jest stworzenie takiej ontologii, która pozwalałyby na udostępnienie szczegółowej wiedzy zawartej w treści normy, a nie tylko jej symbolu. Pozwoli to na skonstruowanie systemu eksploracji wiedzy pozwalającego na rozwiązywanie problemów technologicznych w oparciu o dane i reguły zapisane w wielu normach. Stworzona ontologia stanowić będzie podstawę do rozbudowy wiedzy odlewniczej w oparciu o wyniki badań naukowych i doświadczenia praktyczne. W artykule przedstawiono koncepcję i zasady formułowania ontologii dla potrzeb gromadzenia wiedzy technologicznej. Do sformułowania ontologii wykorzystano język RDF (Resource Description Framework) stosowany do reprezentacji informacji w zasobach sieci globalnej (WWW). W artykule zaprezentowano przykłady zapisu wiedzy zawartej w normach ASTM w zaprojektowanej ontologii oraz zasady wyszukiwania informacji.

1. Introduction

The principal function of technical standards is to facilitate exchange of information between various entities taking part in economic activities. First, they determine the technical conditions of product delivery. Second, they specify requirements that the products are supposed to satisfy and the methods of their fabrication and testing. Standards are also the source of information for process engineers who develop production processes and design new production plants. Yet, because of a technique adopted in recording the information content in standards, their effective use as a source of technical knowledge is very difficult. Our studies on codification of knowledge about castings and techniques of their fabrication are focussed on the problem of ordering the technical knowledge into a form of domain ontology. During these studies an attempt has been made at us-

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ing knowledge comprised in these technical standards in designing a part of the mentioned ontology.

The essence and significance of technical standards in Poland has undergone an important change over the past few years. The number of standards has been considerably reduced, as well as the domain that they are supposed to describe. Standards that some time ago were used to describe, sometimes in a very detailed way, the execution of technological processes, are no longer valid, leaving only those documents that describe the related safety requirements. This also refers to the European standards (which are an origin of the standards valid now in Poland) and American standards. Hence, the scope of knowledge comprised in standards must have changed and become more specific. In spite of this, both the structure of knowledge as well as its content recorded in technical standards, can serve as an excellent source of studies on building a domain ontology for foundry practice. It is, however, necessary to formulate the structure of ontology in a such way as to enable its development to include the elements of knowledge, which so far have not been defined by these standards, but which nevertheless are indispensable for process engineers, designer, users and businessmen.

2. Principles of formulating a domain ontology

Two methods of knowledge definition are used. The traditional one consists in the use of relational or object databases. The second method consists in the use of tools and languages developed specially to suit the needs of ontology building. The second solution does not require the degree of knowledge structuring, which is indispensable in building of a database. The languages used by ontology are in most cases based on a very natural way of describing certain elements of reality as objects (things) belonging to a concept class and characterised by certain properties. Yet, contrary to an approach used in object modelling, the set of properties does not need to be predetermined in order to be able to create the instances (objects). One object may simultaneously belong to many classes, even such that do not exist at a given moment. A similar effect can be achieved with the concept of modelling used in databases, providing that the intentional part of the database is considerably restricted on behalf of the extensional part. In practice this means that some properties of objects are not described by the structure of class or relation, but become instances of more general classes (categories). For example, it is not assumed that each casting has to be described by a definite strength parameter (at most having a null value), but that it remains in some relation with the class (category) describing a set of potential features, which include, among others, all possible parameters of mechanical properties. If it be so, then the appearance of a new technical parameter (as a result of science development) will not require changing of the intentional part of data model, but only extension of the extensional part to include new instances of the classes of parameters and relationships between the castings and parameters. Another difference between the database approach and ontology-based approach consist in this that the latter one corresponds better to the requirements of the, Semantic Web, and hence to the concept of knowledge dissemination in wide area networks and introducing some level of automation to the use of these networks (e.g. through automatic knowledge agents). Since the objective of the studies is, among others, building an internet platform for exchange of information and knowledge about foundry, it has been necessary to verify the existing potential of special tools and their capabilities in formulating domain ontologies. This article presents an outcome of the studies on the application of RDF (Resource Description Framework) language in building of foundry ontology based on knowledge recorded in technical standards.

3. Characteristic of knowledge comprised in foundry technical standards

In building an ontology, the knowledge recorded in ASTM standards was used, with simultaneous comparison between these records and the information and structure of European standards. Only the Volume entitled Ferrous Castings; Ferroalloys has been used. The Volume includes 111 standards of different types. The standards can be classified into the following groups according to the description they offer:
- requirements imposed on castings of general use made from different materials,
- requirements imposed on castings of special use,
- requirements imposed on castings of general use but made from special-purpose alloys, e.g. Hadfield austenitic manganese steel castings,
- common requirements for different casting groups, e.g. standard specification for castings, steel and alloy, common requirements, for general industrial use,
- requirements imposed on castings made by special techniques, e.g. standard specification for investment castings, steel and alloy, common requirements, for general industrial use,
- cast alloys,
- auxiliary materials, e.g. standard specification for molybdenum oxide products,
- selected technological procedures, e.g. standard practice for steel castings, welding,

- methods of testing the properties of castings and melts,
- general standards, e.g. standard terminology relating to iron castings.

Each of these groups of standards is characterised by its own structure of information; sometimes even within one single group different additional pieces of information may appear. Standards describing the requirements imposed on castings comprise as a rule the following information: materials and manufacture (melting process, heat treatment, re-melting process, sampling), chemical composition, mechanical requirements, workmanship, finish, appearance, quality, repair, test methods (usually with reference to another standard), inspection, certification, rejection, chemical test, packaging and package marking, and the like ones.

Standards describing requirements imposed on castings made by some definite methods or regarding special applications comprise additional information on some specific features in these groups of products (e.g. for soil pipes, dimensions and permissible variations, coating). Standards with requirements regarding cast products comprise additional information on supplementary requirements, which shall be applied only when specified by the purchaser. Details of the supplementary requirements shall be agreed upon between the manufacturer and purchaser. The specified tests shall be performed by the manufacturer prior to shipment of the castings.

Standards regarding cast alloys and other charge materials (e.g. ferroalloys) have the structure much simpler and comprise information on general conditions for delivery, chemical composition, size, chemical analysis, sampling and possibly also supplementary requirements. Standards describing procedures are characterised by structure differing considerably from standards of other types. For example, A488/A488M-04 (Standard Practice for Steel Castings, Welding, Qualifications of Procedures and Personnel) describes some process parameters, like weld orientation, testing procedure (preparation of test plate, types of tests, etc.), samples of documentation, procedure qualification, performance qualification of welders or operators. Still another structure of information have standards related with tests of different types. For the reason quite obvious their structure and content will depend on the type of test they specify. Quite different will be the definition of test method for evaluating the microstructure of graphite in iron castings and of mechanical testing of steel products. These two standards will practically have no elements in common as regards their information structure. In the case of different types of mechanical tests, the specifications have some elements in common (description, scope, apparatus etc.), but differences are so great that obtaining a consistent data model is impossible.

4. Formulating an ontology

An analysis of the content of technical standards originating from one single document indicates that there is no possibility to determine, in an unambiguous way, the information structure of the content of these standards. The domain knowledge – in this particular case the foundry knowledge – is available also in other reference standards, so ASTM does not exhaust the domain of knowledge which may be comprised in other technical documents. Therefore, it has been necessary to use an analytic approach which consists in discrimination of the least atoms of knowledge possible to designate by the same set of properties, where some of these properties can be of a common nature.

Formulating an ontology one has to be conscious of the purpose it should serve and who is going to use it. An immediate objective of a domain ontology formulated for the field of foundry practice is ordering the knowledge to enable users of this knowledge to use effectively all that has already been investigated. At the same time they should have the possibility of extending this knowledge in an ordered system to enable other users to make use of the new information. If knowledge is limited to the information originating from technical standards, the circle of its users will automatically become limited, too. It has been assumed that the key users of ontology will be businessmen working in casting trade relations and those who are responsible for process planning and casting manufacture.

One of the basic steps in ontology building is formulation of the, reference queries, which express users' expectations. The queries can be divided into the following groups:

- standard queries about the content of a specific standard identified by designation,
- queries about a set of designates of the standards related with a specific problem selected from the list of problems described by these standards,
- queries about the value of a specific numerical parameter (e.g. maximum deviation of casting dimensions, maximum content of an element, etc.), or description (e.g. marking procedure, sampling) used for a specific type of material, casting use, etc.; at the same time it is assumed that the user is the one who selects the conditions of searching,
- query about full content or selected fragments of standards related with a specific problem and/or with the type of casting.

It has been stated that the single (atomic) records of knowledge may have the character of descriptive information, numerical information, and/or drawing. Numerical information may assume the form of scalars or tables (relations – in fact). The pieces of atomic information may be interrelated with each other. For example, standard A 48/A 48M – 03 (Standard Specification for Gray Iron Castings) includes drawing entitled: "Tension-Test Specimens" and complementary tables stating the admissible dimensions of specimens. In this specific case, the values presented in tables can be regarded as a part of the drawing and as such can be presented in a graphic form. Yet, it seems that for the needs of the planning process – specially in the case of automated (agent) systems – it would be much more handy to treat this drawing as two interrelated atomic objects. In the case of numerical data in the form of tables there is a specific relation between objects of the same category. In the proposed model, this type of relation has been denoted by the term ***where***. It defines all the determinants of a given atomic value. If, for example, the class of grey cast iron is an atomic information about this cast iron, then it is interrelated by property ***where*** with information about the tensile strength, which can be formulated so that the class of cast iron determines its tensile strength. In other words it can be expressed by a statement saying that, e.g., minimal tensile strength of cast iron is equal to 30 ksi where casting class is equal to 'No. 30 A'.

Every atomic information is directly interrelated with at least two objects of a different character. One of them is the respective standard identified by designation, another – a specific substantial problem.

The standards, to which the atomic information directly refers, are also interrelated with each other. There are two types of relations between the standards. Some of them make reference to designates of standards in content referring to a specific problem (e.g. it is stated which standard should be used to determine the requirements of quality control process). Other relations are of a hereditary nature, and consist in this that a given standard in part or as a whole inherits the requirements defined in another standard (e.g. the requirements of delivery specification in standards of special applications are an extension of specifications comprised in standards regarding castings of general use). There are also relations between standards and types of castings, standards and substantial problems, and between types of castings and substantial problems. The relations may have an obligatory character (e.g. in client order or in planning of production process to make a casting for a specific end use, the application of a specific standard is mandatory), or they can be optional when, e.g., a substantial problem refers to castings of certain type.

Additionally, atomic information may refer directly or indirectly to certain types of castings. The types of castings can be differentiated using as a criterion the type of alloy used for casting and/or its end use. Since castings can be classified according to different criteria, it seems advisable to distinguish three categories of objects. Instead of a category *type of casting*, we propose *alloy of which the casting was made, casting application* (the use of casting), and the *workmanship of casting*. To reduce the risk of errors, consisting mainly in admittance of an erroneous, configuration of these characteristics (e.g. sewage pipes made by investment process from copper alloys), further in this text only the category "type of casting" which has the admissible instances will be used. Owing to this solution, defining the knowledge about possible interrelations of the above mentioned properties of objects will be easier, and hence searching for this knowledge will be easier, too.

There is a hierarchy in all four categories mentioned above. For example, each iron casting, irrespective of its specific use, is also a product of general use. In a like way, each iron casting is iron casting irrespective of whether made of ductile or malleable iron. In our model this internal relation is represented by the property ***is_part_of*** indicating the rank of hierarchy. The category *substantial problem* deserves special analysis. Depending on the character of standard either taken as a whole or discussed in specific fragments, this term may have very different meanings. The category *substantial problem* may be chemical composition of alloy, type of heat treatment, specification of casting welding process, required performance skills of welders, etc. Like previously, also now and here, the terms are arranged in certain hierarchy. For example, the heat treatment is a more detailed specification of manufacturing process; the type of treatment and the temperatures applied at its individual stages are the next specification of this process variation. Using the previously mentioned property ***is_part_of***, it is possible to construct this hierarchy in respect of a category monolithic from the outside. Yet, it has been decided that, irrespective of the above, it will be better to divide the category *substantial problems* into the following sub-categories, disjoint but interrelated with each other: *quality requirements* (including, e.g., the content of some elements in composition), *manufacturing and auxiliary processes*, and *control methods*. This subdivision seems to find no reflection in the knowledge structure recorded by ASTM standards (only three among the 111 standards comprised in the examined volume allow for the specific nature of manufacturing processes, and specifically for the investment casting process), but taking into consideration the fact that the ontology will be extended, this solution guarantees the possibility of an easy introduction of large volumes of the new knowledge.

The instances of the above mentioned classes will be put in hierarchy by means of the aforementioned property ***is_part_of***.

An outcome of all these assumptions is the structure of ontology as shown in Figure 1. In the model it is also necessary to use the supporting classes, like the units of measures, which are not displayed in this schematic representation.

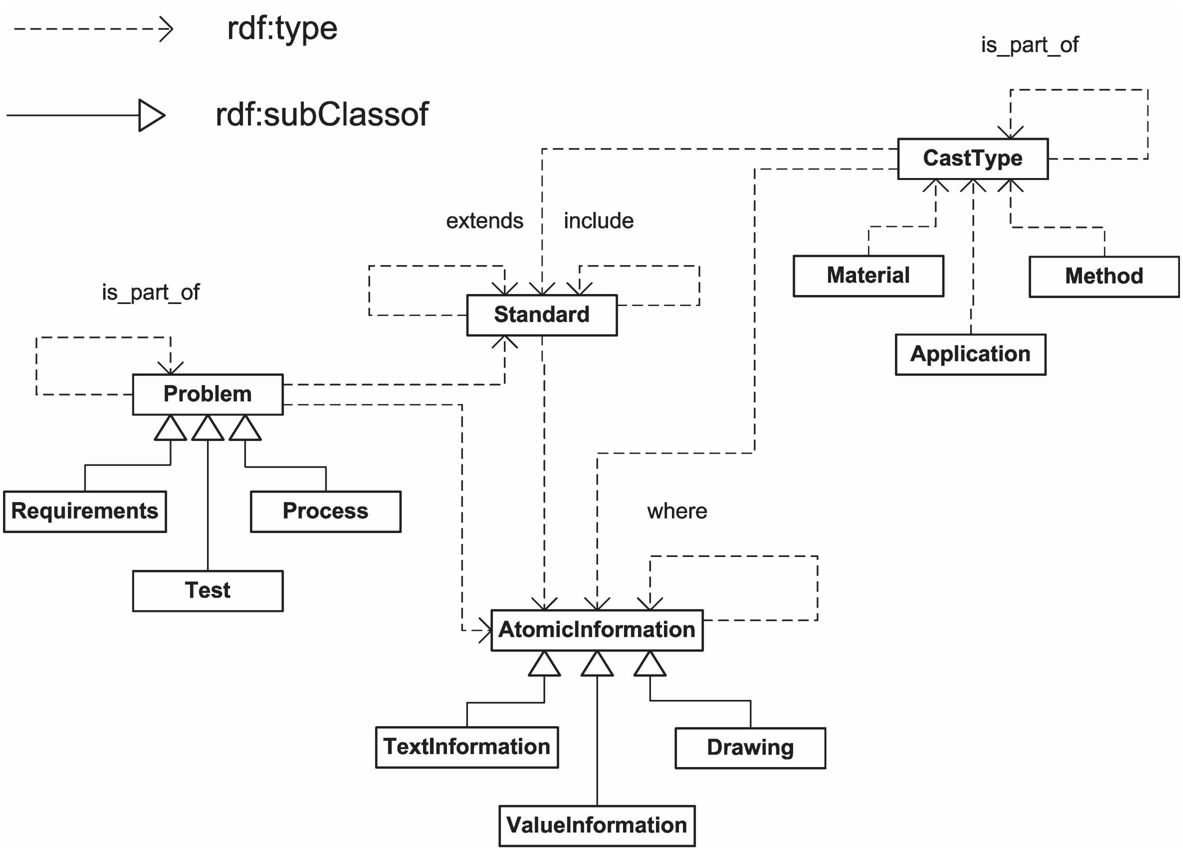

Fig. 1. The structure of ontology

5. Examples of knowledge records and test applications

For ontology operation, the language of RDF (Resource Description Framework) has been used. A test application was created for knowledge collecting, editing and rendering accessible. For this purpose, the authors' own program operating in Java environment, using Jena software, was developed.

Figure 2 shows a diagram illustrating fragment of knowledge about the quality requirements.

Figure 3 shows a diagram illustrating the dimensions of specimen for mechanical testing.

The test application enables searching for information in accordance with the following schema:

a) searching for standards corresponding to:
   – types of castings selected by user,
   – selected manufacturing and auxiliary processes,
   – selected test methods,
b) searching for quality requirements imposed on the selected types of castings,
c) searching for casting types satisfying some specific requirements,
d) searching for selected parameters of the selected test methods,
e) browsing the content of selected standards.

In each of the scenarios, the user operating in an iterative mode makes his expectations every time more precise and specific until satisfactory information is obtained. The way in which the information on quality requirements is obtained is schematically drawn in Figure 4.

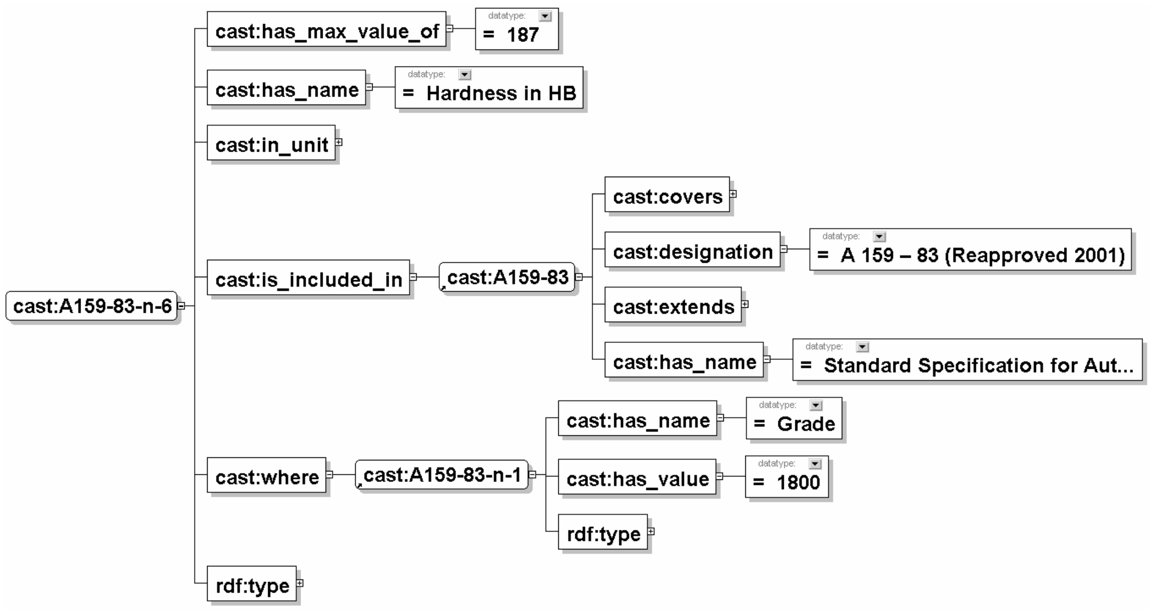

Fig. 2. The fragment of knowledge about the quality requirements

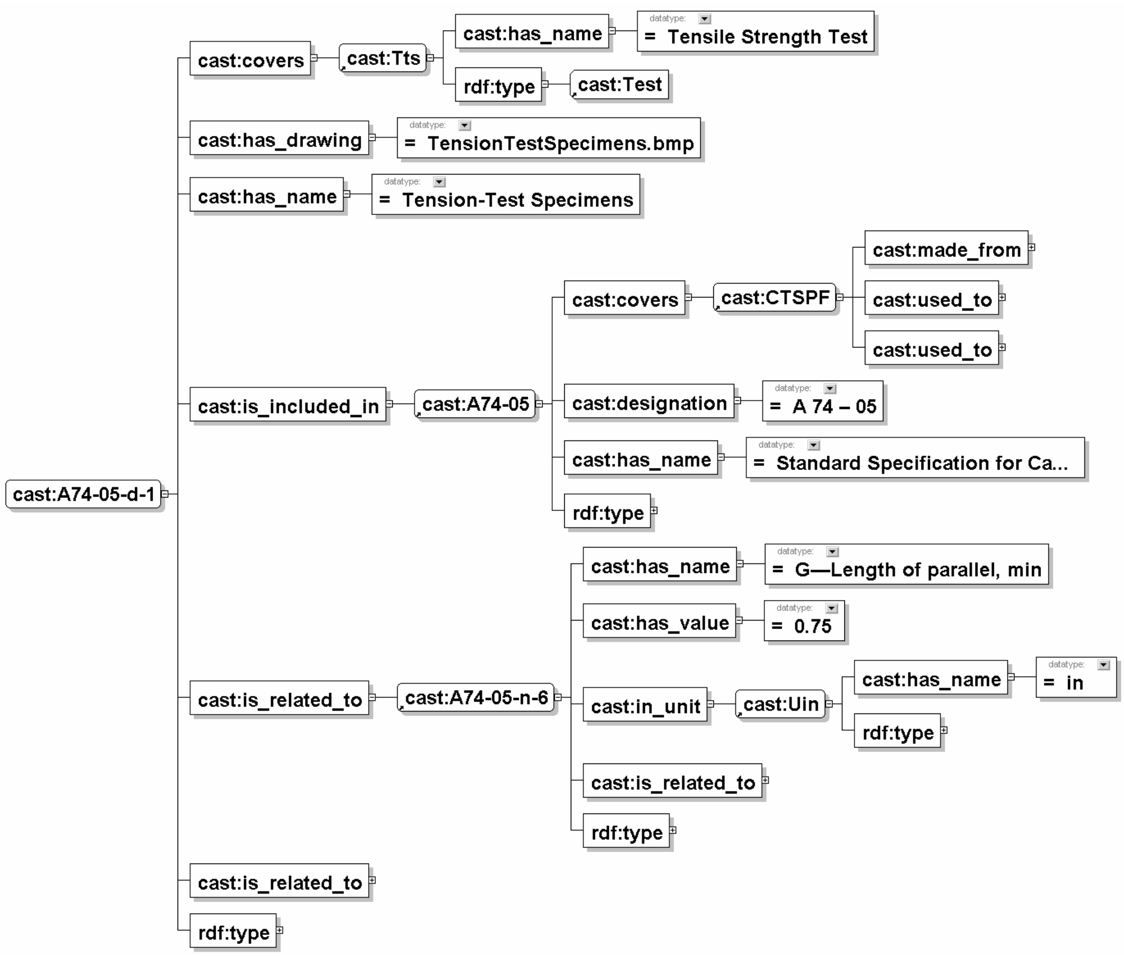

Fig. 3. The dimensions of specimen for mechanical testing

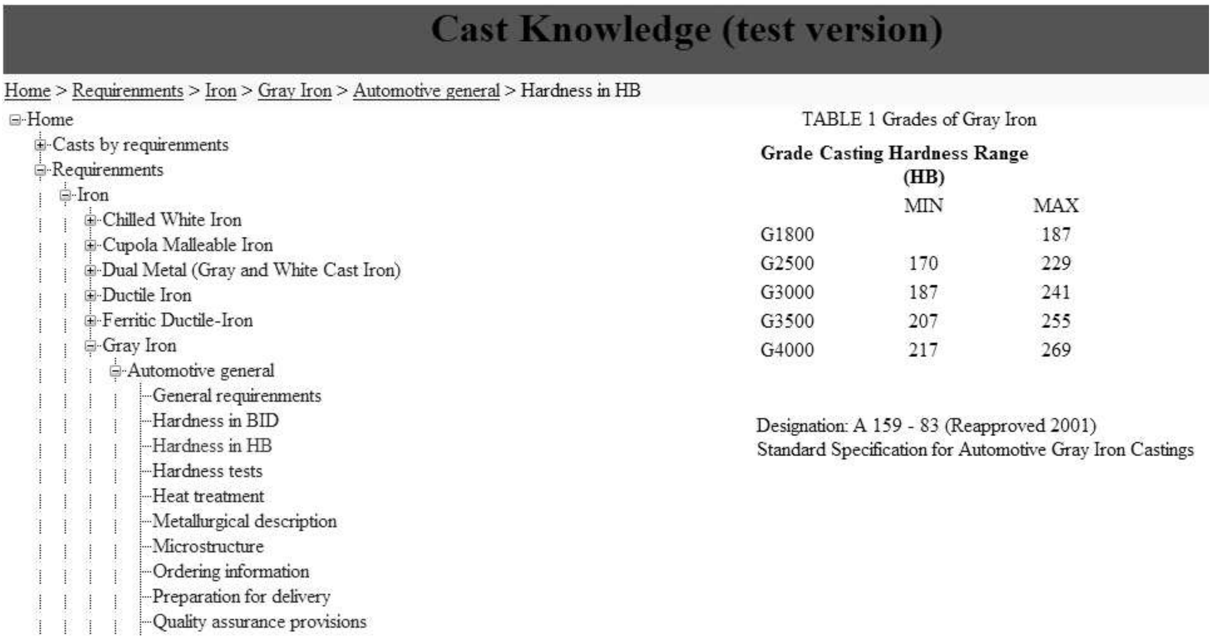

Fig. 4. The quality requirements obtaining

6. Related research

The problem of practical application of knowledge comprised in technical standards is presented in literature rather occasionally. One of the few examples of practical application of this knowledge are investigations carried out by the AGH research team, who developed INFOCAST and OntoGRator, information-diagnostic systems based on the knowledge about surface defects in metal products, formalised in semi-symbolic form [5]. Yet, this solution does not present the content of the standards as such; it only indicates the sources of information related with a specific technical problem. Hence follows the definition used by the authors – “semi-symbolic”.

On the other hand, there is a very rich and comprehensive literature on the principles of formulating an ontology of products. The studies mainly relate to the problem of building an ontology for the needs of trade exchange. Knowledge systematisation for automated information integration of parts libraries [4], ontology-based data modelling for automatic integration of electronic catalogues of industrial components [1], building an operational product ontology system for a government procurement service [7], are some of the examples. The results of investigations presented in the above mentioned publications are to a very small extent only related with technical and technological problems.

An approach similar to that disclosed in this article present these research groups who focus their attention on formulation of ontology to serve the purpose of concurrent engineering and investigations of technology and materials engineering. An outlook of the ideas and the solutions realising different approaches of web-based product and process design can be found in [8, 2, 10]. In [9] the work being undertaken by Brunel University in conjunction with the UK metalforming industry developing a web-enabled database of materials properties for metalforming simulation was presented.

Similar problems related with formulation of ontology for products and technologies occur in the case when an attempt is made at formation of systems for automatic choice of technology and production plan [3, 6].

No information is available on published results of investigations which would be related with building a complex domain ontology in any of the technology sectors.

7. Conclusions

The results of the conducted tests, referring to fragments of the foundry knowledge only, enable drawing of the following conclusions:

– notwithstanding the greatly differentiated information structure of foundry knowledge comprised in technical standards, there is a possibility of building a consistent domain ontology,
– the structure of proposed ontology is simple and at the same time enables recording of the entire knowledge comprised in standards,

– the user developing the knowledge recorded in our ontology can use the option which enables her/him to choose how exact the description of partial information should be and to decide to what degree the information should be recorded in the form of description and to what degree in the form of numerical notation,
– the flexibility of the formulation of queries considerably widens the circle of potential users of ontology (businessmen, engineers, but also scientists and students).

The language used in the description of ontology (RDF) as well as the relevant programming tools enable realisation of the concept of building a domain ontology in the form of useful platforms operating on Internet. Further research in this field will be focussed on a comparison of the results obtained by application of RDF language and tools from Java environment with the results that can be obtained by application of the database models and Structured Query Language in formulation of ontology. Basing on an analysis of the results it will be possible to decide what final form the realisation of target solution should have. The possibility of building a hybrid tool, using mechanisms typical of both Semantic Web and traditional databases as well as inference system operating in SQL has also been taken into consideration.

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