S. KLUSKA-NAWARECKA, E. NAWARECKI, B. ŚNIEŻYŃSKI, D. WILK-KOŁODZIEJCZYK

ISSN 0543-5846
METABK 54(1) 263-266 (2015)
UDC – UDK 669.163:338.984.047/167/168=111

THE RECOMMENDATION SYSTEM KNOWLEDGE REPRESENTATION AND REASONING PROCEDURES UNDER UNCERTAINTY FOR METAL CASTING

Received – Prispjelo: 2014-02-06
Accepted – Prihvaćeno: 2014-08-20
Review Paper – Pregledni rad

The paper presents an information system dedicated to requirements recommendation and knowledge sharing. It presents methodology of constructing domain knowledge base and application procedure on the example of production technology of Austempered Ductile Iron (ADI). For knowledge representation and reasoning Logic of Plausible Reasoning (LPR) is used. Both equally applicable LPR for formalization the knowledge of foundry technology, as well as the described system solution have the unique character.

Key words: metal casting, the production of Austempered Ductile Iron, recommendation system, Logic of Plausible Reasoning

INTRODUCTION

With highly dynamic changes taking place in the modern industry, which comprise the introduction of new technologies, new raw materials and semi-finished products, the growing demands of customers and the results of research conducted, easy access to current information and domain knowledge becomes the condition of rational planning, rational management of production facility and effective implementation of the technological process.

The specific character of the foundry industry poses specific requirements on the means and tools for knowledge acquisition, its formal representation, and later efficient sharing. This specific character is due to the high complexity of the currently applied physico-chemical processes, for which there is no precise mathematical description, and also to the difficulty in measuring the parameters enabling current control of the process [1-6]. As a consequence, both the knowledge sourced from experts, as well as the measurement of technological parameters are of an incomplete and uncertain character.

This study presents the concepts of the casting knowledge representation based on the use of the logic of plausible reasoning (LPR), proposed by Collins and Michalski [7-12]. LPR is a relatively new formalism for which there are no extensive data concerning the industrial applications, but it seems that it should prove to be very useful precisely in the case of handling the knowledge, which is uncertain and incomplete.

S. Kluska-Nawarecka, The Foundry Research Institute, Poland; E. Nawarecki, AGH University of Science and Technology, Poland; B. Śnieżyński, AGH University of Science and Technology, Poland; D. Wilk-Kołodziejczyk, The Foundry Research Institute, Poland, AGH University of Science and Technology, Poland

The presented considerations outline the basic principles of the operation of an LPR formalism. Against this background, an original solution of the computer-aided information system, designed to collect and share the knowledge in the domain of foundry and metallurgy, has been presented.

The implemented solution has a pilot character and is mainly used to verify the desired functionality and therefore at a given stage of work it has been limited to implementation of a relatively simple area of knowledge, expressed in the form of LPR formulas. As an example, the article presents a set of formulas for ductile iron and ADI along with the results of the inference procedures based on the use of these formulas.

LOGIC OF PLAUSIBLE REASONING

The Logic of Plausible Reasoning (LPR) has been developed as a tool for modeling of human reasoning, and therefore some issues important for applications in the automated reasoning systems (e.g. variables) have not been taken into consideration. On the other hand, in the LPR, some solutions have been introduced that do not seem necessary and make the system implementation and creation of knowledge bases much more difficult. The modified formalism has been designated as LPR^0.

The language used by LPR^0 consists of a countable set of constants C, variables X, the seven relational symbols, and logical connectives → and ∧. Formally it is a quadruple: $L = (C, X, \{V, H, B, E, S, P, N\}, \{\rightarrow, \wedge\})$. The relational symbols (V, H, B, E, S, P, N) are used for defining relationships:

- H–defines the hierarchy between concepts; expression $H(o_1, o, c)$ means that o_1 is o in a context c;

- B–used to present the fact that one object is placed below another one in a hierarchy;
- V–used for representing statements: V (o, a, v) is a representation of the fact that object o has an attribute a equal to v;
- E–used for representing relationships; the notation E(o_1, a_1, o_2, a_2) means that values of attribute a_1 of object o_1 depend on attribute a_2 of the second object o_2;
- S–determines similarity between objects; S(o_1, o_2, c) represents the fact that o_1 is similar to o_2 in a context c;
- P–represents order between concepts: P(o_1, o_2) means that concept o_1 precedes concept o_2;
- N–used for comparing the concepts; N(o_1, o_2) means that concept o_1 is different from the concept o_2.

LPR formula means every atomic formula: H(o_1, o_2, c), B(o_1, o_2), V(o, a, v), E(o_1, a_1, o_2, a_2), S(o_1, o_2, c), P(o_1, o_2), N(o_1, o_2), where $o, o_1, o_2, a, a_1, a_2, c, v \in C \cup X$, a conjunction of atomic formulas and implications in the form of $\alpha_1 \wedge \alpha_2 \wedge ...\alpha_n \rightarrow$ V(o, a, v), where $n \in \mathbb{N}$, $n>0$. It is assumed that α_i has the form of $V(o_i, a_i, v_i)$, $P(v_i, w_i)$ or $N(v_i, w_i)$, and $o, o_i, a, a_i, v, v_i, w_i \in C \cup X$ for $1 \leq i \leq n$.

To take into account the parameters describing the uncertainty and incompleteness of knowledge, the presented formalism should be extended by adding the algebra of labels [13, 14]. *Label algebra* LPR^{0}denotes a pair A =$(A, \{f_{ri}\})$, where A is a set of labels, while $\{f_{ri}\}$ is a set of functions defined on labels: $f_{r_i} : A^{|pr(r_i)|} \rightarrow A$, where $pr(r_i)$ are the premises of rule r_i (described below). *Labelled formula* denotes a pair f: p, where f is formula, and p is label. *Knowledge base* is any finite set of labeled formulas, not containing besides the implication premises any N-type formulas.

Inference rules are used to construct the proof of formulas – the operation which corresponds to reasoning. Each rule r_i has the following form:

$$\frac{\begin{array}{c}\alpha_1 : p_1 \\ \alpha_2 : p_2 \\ \vdots \\ \alpha_n : p_n\end{array}}{\alpha : p} \tag{1}$$

Labelled formulas α_i: p_i are called the premises of r_i rule, and formula α: p is called its conclusion. As mentioned earlier, with labels of the premises, one can calculate the labels of conclusion, using label algebra $\mathcal{A}$:

$$p = f_{r_i}(p_1, p_2, ... p_n) \tag{2}$$

Due to lack of space, only rules that operate on the statement are presented. Index attached to the name of the rule tells us what is transformed: o is an object, and v is the value. These rules are shown in Table 1. GEN$_o$ and SPEC$_o$ are generalisation and specialization of objects in statements, SIM$_o$ represents reasoning by analogy (similarity) between objects, and MP is classical modus ponens inference rule.

Having introduced the inference rules, one can define the proof of the labelled formula φ from a set of labelled formulas *KB*. The practical use of an LPR formalism has been made possible by the development of appropriate inference algorithm LPA which searches for the proofs and calculates labels of a given formula using Knowledge Base [15].

Table 1 **Selected inference Rules operating on the statements**

GEN$_o$	$\dfrac{\begin{array}{c}\mathrm{H}(o_1,o,c)\\ \mathrm{E}(o,a,o,c)\\ \mathrm{V}(o_1,a,v)\end{array}}{\mathrm{V}(o,a,v)}$	*SPEC$_o$*	$\dfrac{\begin{array}{c}\mathrm{H}(o_1,o,c)\\ \mathrm{E}(o,a,o,c)\\ \mathrm{V}(o,a,v)\end{array}}{\mathrm{V}(o_1,a,v)}$
SIM$_o$	$\dfrac{\begin{array}{c}\mathrm{S}(o_1,o_2,c)\\ \mathrm{E}(o_1,a,o_1,c)\\ \mathrm{V}(o_2,a,v)\end{array}}{\mathrm{V}(o_1,a,v)}$	*MP*	$\dfrac{\begin{array}{c}\alpha_1 \wedge ... \wedge \alpha_n \rightarrow \mathrm{V}(o,a,v)\\ \alpha_1\\ \vdots\\ \alpha_n\end{array}}{\mathrm{V}(o,a,v)}$

LPR-BASED INFORMATION SYSTEM

Specialized software allowing to make inferences in LPR^0 has been developed. The goal of the system is to provide an inference tool for searching items matching a description given by the user. Architecture of the system is presented in Figure 1. All the domain knowledge is stored in a Knowledge Base (KB). When user searches for the information, it provides a query, which is translated into LPR query formula and proof searching algorithm is executed. It returns items matching the query sorted by label values.

Query q has the following form:

$$q = \alpha_1 \wedge \alpha_2 \wedge ... \wedge \alpha_m \tag{3}$$

where α_i has a form of V(o_i, a_i, v_i) or P(v_i, v_i'). Query q represents description of some concept the user is looking for. It usually contains some variable representing the concept, and the inference algorithm returns substitution for this variable, which represents an answer.

Software for the inference engine is developed in Java. In Figure 2 one can see the class diagram of the main package. Engine class is responsible for proof searching. Knowledge Base stores all the knowledge available for the inference engine. Proof represents the proof tree being built. It is connected with sub trees by Vertex class. Substitution and Unification Exception classes are used to process variables. To assist knowledge base development, graphical user interface has been added (Figure 3).

CASTING TECHNOLOGIES KNOWLEDGE BASE

In this section sample Knowledge Base describing casting technologies is presented. It was prepared to

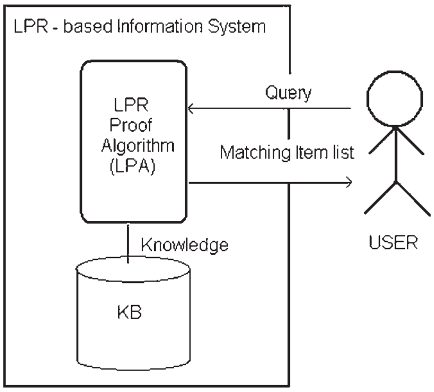

Figure 1 Architecture of LPR-based Information

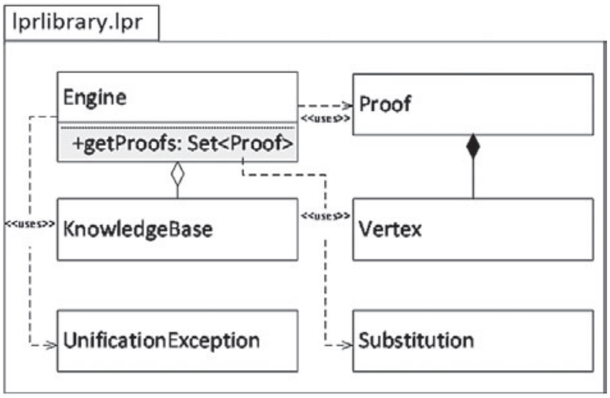

Figure 2 Class diagram of the inference engine package

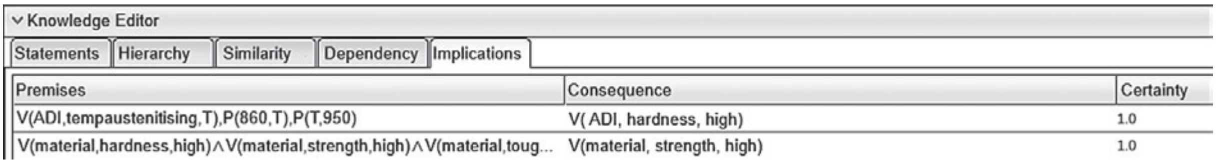

Figure 3 Knowledge editor window

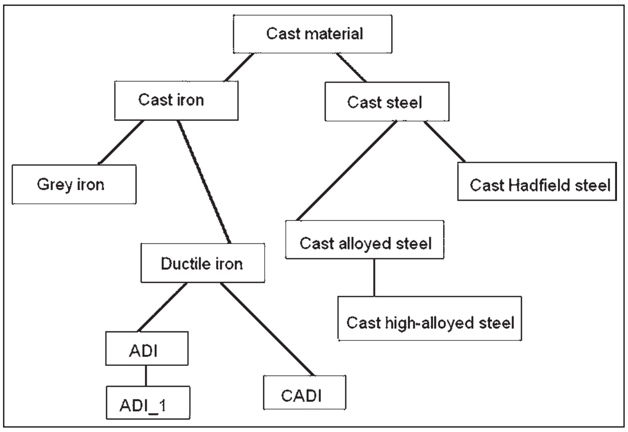

Figure 4 Hierarchy of cast materials

demonstrate LPR reasoning method. Figure 4 presents cast material hierarchy.

Below selected formulas are presented. Labels representing uncertainty are omitted for simplicity.

V(material, hardness, high) ∧ V(material, strength, high) ∧ V(material, toughness, high) → V (material, strength, high)

V(ductile iron, post-casting treatment, heat treatment)

V(cast material, strength, high) ∧ V(cast material, abrasibility, low) ∧ (cast material, damping capacity, high) → V(cast material, application, gears)

V(cast Hadfield steel, price, high)

S(cast Hadfield steel, ADI, parameters)

E(ADI, application, ADI, parameters)

E(ADI, strength Rm, ADI, austempering temperature)

E(ADI, toughness, ADI, austempering time)

V(ADI, tempaustenitising, T) P(860, T), ∧ P(T, 950) → V(ADI, hardness, high)

H(ADI_1, ADI, all properties)

E(ADI, hardness, ADI, all properties)

V(ADI, thickness structure, G) ∧ P(G, 13 mm) → V(ADI, price, low)

V(ADI_1, thickness Structure, 10mm)

E(ADI, hardness, ADI, all properties)

V(ADI_1, tempaustenitising, 900)

S(ADI, cast high-alloyed steel, strength)

E(ADI, resistance to abrasion, ADI, strength)

V(cast high-alloyed steel, resistance to abrasion, high)

To show the reasoning process, the following problem is considered. Some user wants to get recommendations from the system of what material the rake should be made. He is looking for material *M* such that its hardness is high, the cost is low, and the resistance to abrasion is high. It is formalized by the following query: V(M, hardness, high) ∧ V (M, cost, low) ∧ V(M, resistance Abrasion, high)

Inference algorithm returns the following substitution:

$$M = ADI\_1 \tag{4}$$

where ADI_1 is a specific example of ADI (it is a standard product of some company), subjected to specific treatment processes, with certain additions, which are expressed in the knowledge base with appropriate formulas. The following inference process is applied to infer the conclusion (4).

Step 1. Hardness

The knowledge base contains the rule

V(ADI, tempaustenitising, T) ∧ P (860, T), P (T, 950)→V(ADI, hardness, high)

Using the inference rule $\mathbf{SPEC}_{o\rightarrow}$ for this implication and the following two formulas:

H(ADI_1, ADI, all properties)

E(ADI, hardness, ADI, all properties)

it is possible to derive specialization of this implication:

V(ADI_1, tempaustenitising, T) ∧ P (860, T) ∧ P(T, 950) → V(ADI_1, hardness, high)

The knowledge base contains information about *ADI_1* austenitising temperature:

V(ADI_1, tempaustenitising, 900)

hence it can be inferred using **MP** that V(ADI_1, hardness, high).

Step 2. Price

Having in the knowledge base the formula

V(ADI, thickness Structure, G) ∧ P(G, 13 mm) → V(ADI, price, low)

and knowing that

V(ADI_1, thickness Structure, 10mm)

the system can infer in a similar way that the cost of production will be correspondingly low:

V(ADI_1, price, low).

Step 3. Abrasion resistance

A similarity between cast iron and cast high-alloyed steel is used. Knowing that:

S(ADI, cast high-alloyed steel, strength)

E(ADI, resistance to abrasion, ADI, strength)

V(cast high-alloyed steel, resistance to abrasion, high),

using the SIM_o rule of inference, the following formula is derived:

V(ADI, resistance to abrasion, high)

The above statement is specialised for *ADI_1* using $SPEC_o$ inference rule and the following formulas:

H(ADI_1, ADI, all properties)

CONCLUSIONS

The paper presents some rules for the representation and sharing of domainknowledge in the area of foundry technologies based on the use of LPR formalism.

The presented rules for the description of knowledge in terms of LPR as well as the examples of constructing such knowledge for ductile iron and ADI show that the process of creating the knowledge base is in the case of such notions of much more intuitive character and closer to the human way of reasoning than while using conventional formalisms - for example, bivalent logic or fuzzy logic.

The disclosed reasoning shows how the knowledge gained from the source materials (standards, publications) as well as expert knowledge expressed in natural language can be easily written in the form of rules and theorems of the LPR language.

The conducted computational tests confirmed the functionality of the pilot implementation of the system in terms of both inference and generalisation of knowledge shared with the help of this system.

Acknowledgements

This paper was made on basis of a research project LIDER/028/593/L-4/12/NCBR/2013

REFERENCES

[1] R. S. Michalski, A theory and methodology of inductive learning, Artificial Intelligence (1983) 20, 111-161.

[2] S. Kluska-Nawarecka, Z. Górny. D. Wilk-Kołodziejczyk, A. Smolarek-Grzyb, The logistic of plausible reasoning in the diagnosis of castings defects, Archives of Metallurgy and Materials, 52 (2007) 3, 375-380.

[3] S. Kluska-Nawarecka, et al. The use of LPR (logic of plausible reasoning) to obtain information on innovative casting technologies, Archives of Civil and Mechanical Engineering, 14 (2014) 1, 25-31.

[4] J. Pearl, Fusion, propagation, and structuring in bayesian networks, Artificial Intelligence (1986) 29, 241-288.

[5] Z. Górny, S. Kluska-Nawarecka, D. Wilk-Kołodziejczyk, Attribute-based knowledge representation in the process of defect diagnosis, Archives Of Metallurgy And Materials 55 (2010) 3, 819-826.

[6] S. Kluska-Nawarecka, D. Wilk-Kołodziejczyk, K. Regulski, et al. Edited by: Nguyen, NT; Kim, CG; Janiak, Book Series: Lecture Notes in Artificial Intelligence 6592 (2011), 52-61.

[7] R. S. Michalski, K. Dontas, D. Boehm-Davis, Plausible reasoning: An outline of theory and the validation of its structural properties. In: Intelligent Systems: State of the Art and Future Directions, Z. W. Ras (ed.), Elsevier Science Publishers B. V., North Holland, 1990, pp. 260-269.

[8] A. Cawsey in Using plausible inference rules in description planning, Fifth Conference of the European Chapter of the Association for Computational Linguistics (EACL-91), Congress Hall, Berlin, 1991, pp. 642-646.

[9] A. Collins and R. S. Michalski, The logic of plausible reasoning: A core theory, Cognitive Science (1989) 13, 1-49.

[10] M. R. Hieb and R. S. Michalski, A knowledge representation system based on dynamically interlaced hierarchies: Basic ideas and examples, Technical report, George Mason University, 1993.

[11] M. Virvou in A Cognitive Theory in an Authoring Tool for Intelligent Tutoring Systems, IEEE International Conference on Systems Man and Cybernetics, Tunisia, 2002, pp. 410-415.

[12] M. Virvou and B. Du Boulay, Human plausible reasoning for intelligent help, User Modeling and User-Adapted Interaction (1999) 9, 321-375.

[13] D. M. Gabbay, LDS –Labelled Deductive Systems, Oxford University Press, 1991, pp. 282-232.

[14] B. Śnieżyński, Probabilistic Label Algebra for the Logic of Plausible Reasoning, Intelligent Information Systems 2002, Advances in Soft Computing, M Kłopotek et al. (ed.), vol. 17, Springer, Poland, 2002, pp. 267-277.

[15] B. Śnieżyński, Proof Searching Algorithm for the Logic of Plausible Reasoning, Intelligent Information Processing and Web Mining, Advances in Soft Computing, M. Kłopotek et al. (ed.), vol. 22, Springer, Poland, 2003, pp. 393-398.

Note: The responsible translator for English language is Krystyna-Bany-Kowalska, (The Foundry Research Institute, Poland)