A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 52 2007 Issue 3

S. KLUSKA-NAWARECKA* **, Z. GÓRNY*, D. WILK-KOŁODZIEJCZYK** ***, A. SMOLAREK-GRZYB**

THE LOGIC OF PLAUSIBLE REASONING IN THE DIAGNOSIS OF CASTINGS DEFECTS

LOGIKA WIARYGODNEGO ROZUMOWANIA W DIAGNOSTYCE WAD ODLEWÓW

Quick diagnosis of the cause of crack formation enables preventing the formation of other cracks in the next casting process and enables also, as far as it is possible, a repair of the existing defect. In this task expert systems are a very useful tool. The efficiency of an expert system diagnosis depends on the data entered previously and on the way in which the knowledge is represented. In the article there has been presented the Logic of Plausible Reasoning with the rules of its usage on the example of "crack" fault. Drawing attention to advantages of such an approach in relation to solutions used in existing expert systems.
Keywords: Casting defects; Cracks, Knowledge representation; The Logic of Plausible Reasoning; Expert systems

Szybka diagnostyka przyczyny powstania wady pozwala na nie dopuszczenie do powstania nowych w kolejnym procesie odlewania, oraz jeżeli to możliwe naprawienie powstałej. W procesie takim bardzo pomocne są systemy ekspertowe. Skuteczność ich diagnozy uzależniona jest od informacji wprowadzonych do nich oraz od sposobu reprezentacji tej wiedzy. W pracy podano krótką charakterystykę LPR ilustrując zasady jej wykorzystanie na przykładzie wady „pęknięcie". Zwracając uwagę na zalety proponowanego podejścia, w stosunku do rozwiązań stosowanych w istniejących systemach ekspertowych.

1. Introduction

Issues connected with the usage of expert systems in diagnosis are the subject of numerous research as well as industrial solustions[1][2][3][4]. However, there are still many aspects which are not examined. It is connected mainly with the diagnosis procedures conducted in conditions of incomplete specification (without the knowledge of some technological parameters values) and situations when the used knowledge comes from different (often heterogeneous) sources. Getting successful solutions for such examples requires the usage of more advanced formalisms of representation of the knowledge about faults and adequate inference procedures.

The aim of the article is to present some possibilities in this field which are given by the Logic of Plausible Reasoning (LPR) in relation to specific type of castings faults. The Logic of Plausible Reasoning is a new formalism for which there have not been any substantiated industrial applications yet. However, the Logic of Plausible Reasoning has got many properties which in the experts' opinions create interesting prospects of its usage in casting diagnosis.

In the article, against a background of short description of the LPR, there has been presented an example of description of the knowledge connected with particular castings faults (cracks). There have been presented the most important features of suggested approach indicating its advantages in relation to typical ones used in existing expert systems.

2. Cold crack and the way it is represented in the logic of plausible reasoning

The inference has been carried out on the example of the cold crack defect. The data related with this defect have been entered to the system basing on the information derived from several sources such as:
• Standard of Casting Defects elaborated in Poland [5],
• Atlas of Casting Defects elaborated in France [6],

* FOUNDRY RESEARCH INSTITUTE, 30-418 KRAKÓW, ZAKOPIAŃSKA 73, POLAND
** FACULTY OF METALLURGY, UNIVERSITY OF SCIENCE AND TECHNOLOGY, 30-059 KRAKÓW, 30 MICKIEWICZA AV., POLAND
*** THE ANDRZEJ FRYCZ MODRZEWSKI KRAKÓW UNIVERSITY COLLEGE, 31-002 KRAKÓW, 9 KANONICZA STR., POLAND

• Review of Casting Defects elaborated in the Czech Republic [7].

These sources are the knowledge compendium of casting defects. Basing on such information, serving as a defect description, the cause of the defect formation and the way of preventing it have been created as formalisms, which enable an inference to be carried out, the aim of which is to establish the cause of the defect.

2.1. Description of defects

Crack is a straight or slightly curved and zigzagging crevice in casting wall, which has been formed at low temperatures in the spot, where the alloy is subjected to elastic deformation. Cracks can also be formed after the casting has been completely cooled down in a mould, or while knocked out, or as a result of its premature removal from mould. They can also occur during later heat treatment, though the latter case happens rather seldomly.

The surface of the crack is usually grainy and clean, sometimes with coloured swelling, or distinct signs of oxidation, depending on the temperature and on the process stage, at which the crack has been formed, i.e. when cooling down in a mould, during de-gating and infusions with oxygen, or while heat treated [5][6][7][8][9][14][15][18][19].

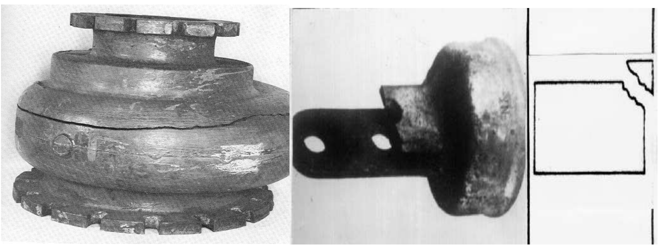

Fig. 1. Examples of crack defect

2.2. Knowledge about crack representation with The Logic of Plausible Reasoning (LPR)

Full description of the rules of logic of plausible reasoning can be found in the literature. In the scope of this article only few elements of this formalism, which are the most important in the context of the considered task, are discussed [14][15][16][17][18][19].

The essence of the Logic of Plausible Reasoning consists of creation of rules of logical dependences. The dependency of cast forms quality (faults) on the causes of the faults enables to establish the hierarchy of causes importance. Vertexes represent classes of objects and objects (groups of defects and defects), or manifestations of objects (the appearance of a specific reason of the defect formation). Edges represent relations between the conceptions (pertinence of defect to a definite group, assignment of defect to the reason of its appearance).

In the LPR the set of rules and relations, which express the quality of the described knowledge, is introduced.

Terms, values and statements describing individual conceptions of given hierarchy are given. For the group of defects occurring in metal products they can assume the following form:

Term A – a vertex of certain hierarchy,

B – term's argument

Term's form A(B)

Value – a conception or a set of conceptions

Statements express dependences occurring between the terms and values

$$T = R \tag{1}$$

Where T is a term and R is a statement.

$$A(B) = R \tag{2}$$

Example of statement, term, value:

Terms

mechanical damage(bronze cast)

Referents

mechanicalDamage(cast) = crack

shapeDefect(cast) = {bulge, trapping, ...}

Statement

mechanicalDamage(cast) = absent

mechanicalDamage(cast) ≠ blue

damageMechanical(casting) = crack

defectsShape(casting) = {knob, flash, ...}

Relations that define mutual positions of conceptions in a hierarchy are GEN and SPEC.

A_1 GEN A_2 in CX (A, D(A)) conception A_1

occurs in hierarchy above A_2 in context (A, D(A)) (3)

A_2 SPEC A_1 in CX (A, D(A)) conception A_2

occurs below the conception A_1 in context (A, D(A)) (4)

A_2, A_1 – featured conceptions,

CX (A, D(A)) – defines the context of considered dependencies

A – conception placed above A_2 and A_1 in hierarchy

D(A) – term defining characteristic for A feature

Example of relation SPEC and GEN

defectShape GEN defectMechanical in CX (casting, damage(casting))

defectShape SPEC defectCasting

Relations SIM and DIS – describing similarities and dissimilarities of certain conceptions:

A_1 SIM A_2 in CX(B, D(B) conception A_1 is similar to conception A_2 in context (B, D(B)) (5)

A_1 DIS A_2 in CX(B, D(B) conception A_1 is dissimilar to conception A_2 in context(B, D(B)) (6)

Example of relation SIM
defectShape SIM disContinuities in CX (defectCasting, Defects(defectCasting))

Mutual dependencies and mutual implications defining the measure of conception equipoise:
Mutual dependency

$$D_1(A) \leftrightarrow D_2(f(A)) \quad (7)$$

an additional element could be:
+ meaning positive dependency, so if one term value is increasing, the other term value is increasing, too
or
– meaning negative dependency, so if one term value is increasing, the other term value is decreasing

Example of mutual dependence:
defectCasting(casting)↔ designCasting(casting)

Mutual implication

$$D_1(A) = R_1 \Leftrightarrow D_2(f(A)) = R_2 \quad (8)$$

Example of mutual implication
knocking outCasting(casting) = correct damageMechanical(casting) = absence

There are associated parameters assigned to each formula that characterize uncertainty of contained information. The following presents an interpretation of those parameters:

- γ – certainty grade of the formula
- φ – value frequency
- μ_a – argument multiplicity
- μ_r – value multiplicity
- τ – typical character of subordinate conception in a given context
- σ – similarity degree existing between the conceptions in a given context
- δ – object domination in a set of superior objects
- α – strength with which the left side of the implication (or dependency) influences its right side
- β – strength with which the right side of the implication (or dependency) influences its left side
- μ_a – argument multiplicity defines how many objects a given descriptor value has
- σ – similarity of objects in respect of the characteristics defined by a descriptor given in the context
- α – certainty degree with which on the basis of the term's value on the left side we can define the term's value on the right side
- φ – describes how many elements of the conception being an argument has a characteristic defined by the value
- μ_r – defines cardinality of the value set of a given term

Examples of using the parameters defining the uncertainty of information:
If we conclude that it often comes to a cast crack while cutting the trapping off, our conclusion may be written down as follows:

defectReason(coldCrack)=(castDamagingDuringCutting-TheTrappingOff))γ=big φ=often

If we want to say that reasons of cast defects leading to mechanical cast damage make up a small percentage of all cast defect reasons and mechanical cast damages account for a small percentage of all the cast defects, we may write it down in the following way:

defectReason(mechanicalDamage)={improperSprueRemoval,improperHeadRemoval,improperTrappingRemoval, improperRemovalOfOtherTechnologicalSurpluses}
μ_a=small μ_r=small

Argument transformation in statements – generalization:

A(0) = R: γ_1, φ, μ_a
O‘ GEN O in CX (O‘, D(O‘)): γ_1, ι, μ_a
D(O‘) A(O‘): γ_3,α

A(O‘)=R: γ =f(γ_1,φ, μ_a,γ_2, ι, δ, γ_3,α) (9)

Value transformation in statements – specialization:
D(a)=R_1,...: γ_1, φ, μ_r
R‘ SPEC R in CX (d, D(d)): γ_2, ι, δ
D(d) A(d): γ_3, α
A SPEC A: γ_3

D(a) = R‘,...: γ =F(γ_1, φ, μ_r, γ_2, ι, δ, α, γ_4) (10)

Example of value transformation in statements

defectReason(coldCrack)={castDamagingDuring-CastKnocking,
castDamagingDuringTrapKnocking,
castDamagingDuringOtherManipulations}
γ_1=*quite big* φ=*average* μ_r=*big*

These values big, small are used as linguistic values. The explanation of linguistic values as expressions established arbitrarily in natural language corresponding to different parameters ranges.

improperRemovalOfTechnologicalSurpluses SIM castDamagingDuringOtherManipulations in CX (defectReason, castDefects(defectReason);
γ_2=*big* σ=*big*

castDefects(defectReason)$\Longleftrightarrow$ *continuityDefects (defectReason)* γ_3=*big* α=*big*
coldCracks SPEC continuityDefects γ_4=*quiteBig*

---

defectReason(coldCrack)=
{improperRemovalOfTechnologicalSurpluses,...}
γ=*big*

3. Description of cold crack defect diagnostics

3.1. Diagnostics using the Logic of Plausible Reasoning

A description of the Logic of Plausible Reasoning and its basic assumptions and formalisms have been discussed in previous publications [10, 11]. In this article only the assumptions and formalisms, which have crucial influence on the process of inference are described.

On the basis of the inference previously implemented and connected with the cold crack defect, a hierarchy and the relevant statements have been created. Also, the data connected with the classification of the defect, causes of its formation, and the preventive means are ordered. In this article only the data that have vitally influenced the process of inference have been presented.

Pictures 2 and 3 present an example of hierarchy possible to implementation in the expert system. The hierarchy presented in the picture 2 has been created on the basis of faults division into classes, groups and subgroups used in different sources of data and knowledge (literature of norm, atlas, the Czech Republic). The hierarchy presented in the picture 3 is based on the causes of fault creation. Creating the hierarchy is the first step in building system based on the LPR. Attention should be paid to the fact that creating of hierarchy is in the particular case activity integrating used sources of knowledge.

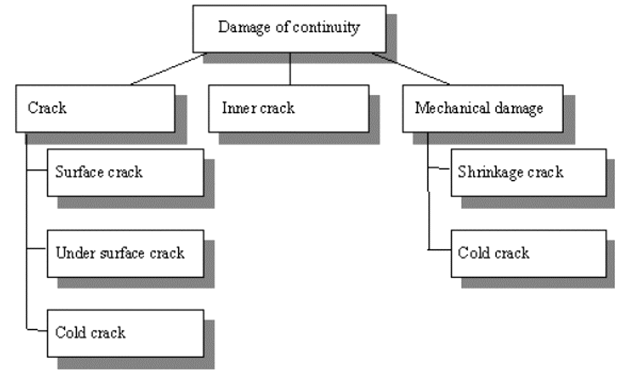

Fig. 2. Example of the hierarchy based on usage of different faults classifications

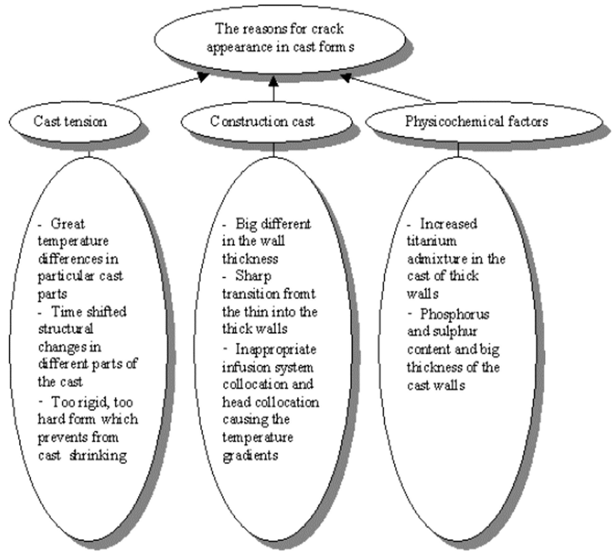

Fig. 3. Examples of hierarchy based on causes classification of fault creation

We assign the terms and values that are necessary in this inference process done with The Logic of Plausible Reasoning:

Design gating system (casting) = incorrect, correct
Temperature difference in particular cast parts (casting)=big, normal, absence
Defect reason (casting) = (casting stresses which affect crack formation, ...);

The information uncertainty parameters should be settled down. The following parameters will take part in the chosen inference process: α-certainty factor of dependence that knowing the value of left side term, the right side term value is within recognition. Parameter β is defined in analogical way but in opposite effect direction.

An example of the following notation means that incorrect location of the gating system results in great temperature differences. A value of this dependency is highly assigned (very big). An implication operating in the opposite direction, which is the temperature difference influencing the gating system location, has a very small meaning. The parameter γ determines the certainty of any information.

Design gating system (casting) = incorrect (temperature differences (casting): big:
γ_1 *= big,* α_1*=very big,* β_1*=very small*

Design gating system (casting) = incorrect
⇔ *(temperature differences in particular cast parts (casting)=big:* γ_1*=very high,* α_1*=very big,*
β_1*=very small*
Temperature differences in particular cast parts (casting)=big ⇔ defect reason (casting) casting stresses which appeared because of the temperature difference: γ_2 *=very high,* α_2*=very big,*
β_2*=very small*

Design gating system (casting) = incorrect ⇔ (casting stresses which appeared because of the temperature difference: γ*=very high,*
α*=very big,* β*=very small*

In the foregoing conclusion we have obtained the diagnosis that the reason for cold crack appearance are casting stresses which appeared because of the temperature difference.

Apart from the information about the cause of defect occurrence we also obtain information on the reliability of the received information.

The certainty of this diagnosis has been qualified as high. The gating system location influence on a defect reason has been qualified as high, however the defect appearance reason influence on the gating system location is very small. It was possible to be specified thanks to uncertainty parameters which have been used.

This example has been created on the basis of inference called implication transformation which occur in the Logic of Plausible Reasoning. The symbolic notation of this kind of inference has been presented below.

$D_1(A) = R_1 \Leftrightarrow D_2(A) = R_2 : \gamma_1, \alpha_1, \beta_1$
$D_2(A) = R_2 \Leftrightarrow D_3(A) = R_3 : \gamma_2, \alpha_2, \beta_2$

$$D_1(A) = R_1 \Leftrightarrow D_3(A) = R_3 : \gamma = f(\gamma_1, \gamma_2), \quad \alpha = f(\alpha_1, \alpha_2), \beta = f(\beta_1, \beta_2) \qquad (11)$$

The last statement is obviously trivial from the technological point of view. However, as far as formal aspects are concerned it should be taken into account in order to assure the entirety of knowledge representation.

4. Conclusions

Presented conceptions of description of technological knowledge about castings faults with the usage of the LPR, although they have been presented shortly, give as it seems some view on this formalism features. Carried considerations have been related to one type of faults (crack). However, used proceedings can be carried on in analogous way for other faults with similar features.

In the article, attention has been paid to two essential advantages of knowledge representation based on the LPR:

– possibility of taking into consideration different forms of indefinitness (lack of accuracy) in applaying to source knowledge disposal, indefinitness;
– ability to integration of knowledge coming from different sources (in particular case norms and different countries catalogues).

Such possibilities don't exist in known realisations of expert systems in the filed of castings faults diagnosis.

To sum up, it can be said that results in the current stage of research are promising. Within the confines of continuation it is expected to elaboration of specialist software supporting creation of technological knowledge modules and then realisation of diagnosis procedures based on usage of the LPR.

The research into the use of the Logic of Plausible Reasoning in diagnostics carried out at the Center of Competence for Advanced Foundry Technology and at the AGH University of Science and Technology, Department of Computer Science in Industry, Faculty of Metallurgy, is currently at the initial stage of implementation.

The Commissioned Research Project No 3 T08B07229 No PB2 KBN 114510

Acknowledgements

Authors like to express their thanks to dr Anna Adrian, dr inż. Jarosław Durak (from University of Science and Technology, Department of Computer Science in Industry, Faculty of Metallurgy) and mgr inż. Teresa Wójcik (from Foundry Research Institute).

REFERENCES

[1] S. Kluska-Nawarecka, J. Tybulczuk, M. Kisiel-Dorohinicki, H. Połcik, E. Nawarecki, Distributed information system for

foundry industry with application of multi-agent technology, Archives of Foundry, **6**, 18, 45-52, (2006) (in Polish).
[2] B. Mrzygłód, S. Kluska-Nawarecka, Collecting and formalization of knowledge about surface faults of metal products, Archives of Foundry **5**, 17, 175-182, (2006) (in Polish).
[3] L. A. Dobrzański, M. Krupiński, J. H. Sokołowski, Application of artificial intelligence methods for classification of defects of AL.-Si analyse casting, Archives of Foundry **6**, 22 (2006).
[4] J. Talar, P. Jarosz, J. Kusiak, K. J. Staszak, Artificial intelligence based modelling of the direct copper flash smelting process, Research in Polish metallurgy at the beginning of XXI century, Committee of Metallurgy of the Polish Academy of Sciences, „Akapit" Krakow, 81-101, (2006).
[5] Podział i terminologia wad, Polski Komitet Normalizacji Miar i Jakości, PN-85/H-83105, Dz. Norm i Miar, 1 pozycja 2, 1986. (in Polish).
[6] G. Héron, C. Mascaré, G. Blanc, Recherche de la qualité des piéces de fonderie; Editions Techniques des Industries de la Fonderie, Paris, 1986. (in French).
[7] T. Elbel, F. Havliček, P. Jelinek, P. Leviček, J. Rous, K. Stransky, Vady odlitkú ze slitin železa (klasifikace, přičiny a prevence), MATECS, Brno, 1992. (in Czech).
[8] J. Baler, M. Köppen, Podręcznik wad odlewniczych, wady związane z masami formierskimi i zapobieganie ich powstawaniu, IKO-Erbslöh, Maral, 1994. (in Polish, in German).
[9] S. Hasse, Guß– und Gefügefehler, Erkenung, Deutung, und Vermeidung von Guss und Gefügefehlerbei der Erzeugung von gegossenen komponenten, Schiele und Schőn, ISBN: 3 7949-698-5, Berlin, 2003. (in German).
[10] B. Kalandyk, J. Głownia, Slag-gas defects on industrial casting of carbon and alloys cast steels, Archives of Foundry **6**, 22, 254-259, (2006) (in Polish).
[11] L. Sozański, Possibilities of an an assessment of surface discontinuities of casting, Archives of Foundry **6**, 18 (2006).
[12] E. P. Busso, N.P. O'Dowd, K. Nikbin, Mechanistic Studies of High-Temperature Crack Initiation in Single Crystal Materials, Journal of ASTM International (JAI), ISSN: 1546-962X, (2006).
[13] J. Yamabe, M. Kobayashi, Influence of casting surfaces on fatigue strength of ductile cast iron, Fatigue & Fracture of Engineering Materials and Structures, **29**, 6, 403-415, (2006).
[14] A. Collins, R. S. Michalski, The logic of plausible reasoning: A core theory, Cognitive Science **13**, 1, 1-49, (1989).
[15] A. Collins, Fragments of a theory of human plausible reasoning, Association for Computational Linguistics, University of Illinois 194-201, (1978).
[16] R. S. Michalski, A theory and methodology of inductive learning, Chapter in the book, Machine Learning: An Artificial Intelligence Approach, TIOGA Publishing Co., Palo Alto 83-134, (1983).
[17] D. Bohem-Davis, K. Dontas, R. S. Michalski, A Validation and Exploration of the Collins-Michalski Theory of Plausible Reasoning, Reports of the Machine Learning and Inference Laboratory, George Mason University, 1990.
[18] S. Kluska-Nawarecka, D. Wilk-Kołodziejczyk, Integration of heterogeneous knowledge components using logic of plausible reasoning, Conference on: Intelligent Information Systems, Pol. Poznańska, 52-61, Poznań, (2005).
[19] B. Mrzygłód, D. Wilk-Kołodziejczyk, A. Adrian, J. Durak, Application of the logic of plausible reasoning to diagnostic of faults in metal products, KomPlasTech 2005, Wyd. „Akapit", Ustroń, 2005, 11-18 (in Polish).

Received: 18 June 2007.