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Diagnostics of crack formation in castings using the logic of plausible reasoning

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ABSTRACT

Purpose: Cold cracks are the defect often encountered in castings. 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.

Design/methodology/approach: Standard of Casting Defects elaborated in Poland, Atlas of Casting Defects elaborated in France, and a Review of Casting Defects elaborated in the Czech Republic. 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.

Findings: The use of LPR (the Logic of Plausible Reasoning) in the representation of knowledge about casting defects introduces a new quality, allowing to take into consideration the specific characteristics of this knowledge such as: uncertainty, definitions hierarchy, the possibility of introducing the diagnostics ranking. In consequence, the diagnostic process becomes more flexible and may be better adjusted to the real technological process conditions.

Practical implications: The efficiency of an expert system diagnosis depends on the data entered previously and on the way in which the knowledge is represented.

Originality/value: In this article various representations of the knowledge have been presented by means of the logic of plausible reasoning.

Keywords: Mechanical properties; Casting defects; Cracks; Knowledge representation; The logic of plausible reasoning

PROPERTIES

1. Introduction

Defects in castings are the phenomenon difficult in diagnosis. Cold cracks are one of the commonly occurring defects. The presence of these defects exposes foundries to the risk of incurring serious expenses, and this is the main reason why their elimination right in the casting process is extremely important. Expert systems are one of the means used in diagnosis of the causes of defects of this type. The knowledge comprised in these systems offers handy tools which, on one hand, prevent these defects from being formed, while, on the other, help to eliminate them if eventually they do happen to occur. One of the possible means of knowledge representation entered to the system is the logic of plausible reasoning, which allows us to create in comfortable way a clear ranking of the obtained diagnoses.

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 [1], Atlas of Casting Defects elaborated in France [2], and a Review of Casting Defects elaborated in the Czech Republic [3]. 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 seldom.

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 [1, 2, 3, 4, 5]

Fig. 1. Example 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 most important in the context of the considered task, are discussed [6, 7, 8, 9, 10, 11].

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

Terms, values and statements describing individual conceptions of given hierarchy were 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 (1)

Statements express dependences occurring between the terms and values

T=R (2)

Where T is a term and R is a statement.

A(B)=R (3)

Example of statement:
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))
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 (A, D(A))
A_1 DIS A_2 in CX(B, D(B) conception A_1 is dissimilar to conception A_2 in context (A, D(A)) (5)
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
$D_1(A) \leftrightarrow D_2(f(A))$ (6)
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
$D_1(A)=R_1 \Leftrightarrow D_2(f(A))=R_2$ (7)
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

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 have been 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 have been ordered. In this article only the data that have vitally influenced the process of inference have been presented.

Design gating system (casting) = incorrect, correct
Temperature difference in particular cast parts (casting)=big, normal, absence (8)
Defect reason (casting) = (casting stresses which affect crack formation, ...); (9)

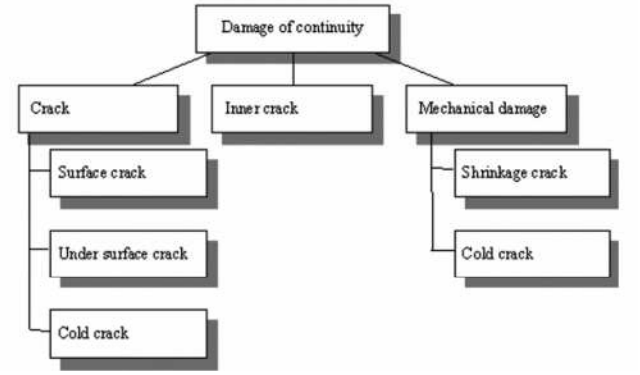

Fig. 2. Example of the hierarchy in casting discontinuities defect

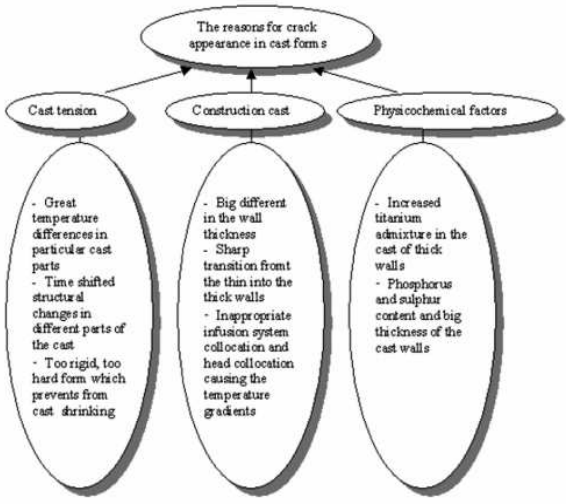

Fig. 3. Examples of the causes of cold crack formation

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

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 (10)
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 (11)

Design gating system (casting) = incorrect ⇔ (casting stresses which appeared because of the temperature difference: γ =very high, α=very big, β=very small (12)

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.

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

The use of LPR (the Logic of Plausible Reasoning) in the representation of knowledge about casting defects introduces a new quality, allowing to take into consideration the specific characteristics of this knowledge such as: uncertainty, definitions hierarchy, the possibility of introducing the diagnostics ranking. In consequence, the diagnostic process becomes more flexible and may be better adjusted to the real technological process conditions.

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 University of Science and Technology, Department of Computer Science in Industry, Faculty of Metallurgy, is currently at the initial stage of implementation. Nevertheless, the initial results of the research create the perspective of interesting practical results.

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