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## Open Atlas of Defects as a Supporting Knowledge Base for Cast Iron Defects Analysis

 R. Sika <sup>a,\*</sup>, M. Rogalewicz <sup>b</sup>, A. Kroma <sup>a</sup>, Z. Ignaszak <sup>a</sup>
<sup>a</sup> Division of Foundry, Poznan University of Technology, Piotrowo 3, 61-138 Poznan, Poland

<sup>b</sup> Chair of Management and Production Engineering, Poznan University of Technology, Piotrowo 3, 61-138 Poznan, Poland

\* Corresponding author. E-mail address: robert.sika@put.poznan.pl

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### Abstract

A significant development of the foundry industry contributes to the creation of high reliability and operational strength castings so that they meet specific standards in accordance with customers' needs. This technology, however, is inseparably connected with casting defects in finished products. Cast products are subject to various defects which are considered acceptable or not, which is conditioned by the alloy chemical composition and strength characteristics, that is, generally – qualities to be agreed between the foundry and the customer. It is the latter that led the authors to research on designing a tool enabling the most reliable possible assessment of the emerging casting defects, which after proper consultations can be repaired and the casting – sold. The paper presents an original tool named the Open Atlas of Defects (OAD), developed for the last few years to support the evaluation of cast iron defects using Non-Destructive Testing (NDT) casting defects analysis tools (DCC card – Demerit Control Chart, Pareto-Lorenz analysis and ABC analysis). The OAD tool structure was presented as an integral part of the original system module for acquisition and data mining (A&DM) in conjunction with the possibilities of using selected tools for defect analysis support on the example of cast iron casting.

**Keywords:** Cast iron, Castings defects, Data acquisition, NDT, Computer application

### 1. Introduction

Each production process is linked to the problem of creating products not meeting the assumed requirements. Depending on the nature of the non-compliance the products may be fit for further processing (reprocessing, repair) or may be qualified as so-called shortages (non-sellable products). In case of complex processes such as casting production it should be assumed that each casting has defects, which may be acceptable or not, depending on the agreement between the foundry and the customer. A defect deeming the casting as a shortage is any

inadmissible defect or one the repair of which is unprofitable or impossible.

A casting defect according to the PN-85/H-83105 standard: "Castings. Classification and terminology of defects." [1] is a change of shape, surface, continuity violation and irregularity of the internal structure. Therefore, the ability of a quick detection of potential nonconformities is the key issue in a proper casting production process control. A proper identification of irregularities' causes should enable to minimise shortages production.

A number of factors affect casting processes which have or may have a direct influence on defect creation (systematic or

random cases), therefore for easier identification they have been grouped into three main groups as per potential irregularities:

- Liquid alloy,
- Mould,
- Liquid alloy-Mould interaction.

#### Group I: Liquid alloy

Materials used for cast iron production have a paramount influence on its quality. The materials must meet requirements as per terms of contracts and the standards in force in the country and the foundry. The alloy's chemical composition control is one of the basic methods of foundry processes control. Very often it consists in examining the contents of elements like C, S, Si, Mn and P as well as analysing the chemical composition of mortars, modifiers and ferroalloys [2]. Apart from the smelted material's chemical composition also too low or too high temperature of mould pouring may cause defects, similarly as too fast or too slow pouring. Therefore, the alloy's temperature must be monitored constantly in the furnace, at the moment before the alloy is poured from the furnace into the ladle, in the ladle as well as during pouring the alloy into the mould.

#### Group II: Mould

Another important factor influencing defect formation is the casting mould. In case of casting in so-called traditional moulds (III generation damp masses) excessive moisture of the green sand or insufficient strength may cause numerous tears. Excessive or insufficient permeability of green sand, too many gas forming components, inhomogeneity or incorrectly selected moulding material (e.g. use of a binder with too little refractoriness) may result in formation of defects such as gas type defects or bubbles. There is no doubt that in case of manual moulding the experience and qualifications of the moulder are very important for the proper mould preparation.

#### Group III: Liquid alloy-Mould interaction

The processes occurring at the borderline of liquid alloy-mould are the key factors determining the casting surface quality. Most castings are subject to only partial mechanical treatment, therefore special attention should be paid to manufacturing products with good surface quality resulting directly from the pouring process. The interaction of the liquid metal and the mass may be the cause of various types of surface defects such as burn on, metal penetration, pinholes, improper surface roughness, structure and casting surface composition change etc. Composition and amount of gasses formed at the interface of the liquid alloy-mould have a significant impact on the atmosphere inside the mould, and thus on the degree of adhesion of the mass to the casting. The emanating gasses may also cause cast porosity like bubbles and pinholes [3].

Casting production is associated with a large number of possible problems which may arise. They may be linked to various production process fields and stages. It is therefore important to identify the defects and the causes for their occurrence as soon as possible and in the best possible way.

The article presents an original tool called the Open Atlas of Defects (OAD being developed for the last few years to support the evaluation of cast iron defects using Non-Destructive Testing (NDT) and casting defect analysis tools (DCC card – Demerit Control Chart, Pareto-Lorenz analysis and ABC analysis).

## 2. State of arts

This section presents current approaches of identification and classification of defects created in casting processes.

The key causes for casting defects creation include [4]:

- Improper cast construction,
- Defective model construction or creation,
- Inappropriate moulding material,
- Inappropriate casting mould preparation,
- Improper alloy preparation,
- Poorly chosen mould pouring conditions,
- Improper shaking-out of castings, their cleaning and finishing.

Within each of these groups, a significant number of more specific causes may be distinguished. Further to the above, it was necessary to systematise and unify names and definitions of particular types of defects and to carry out a possibly unambiguous analysis allowing to assign them to the causes of their formation. There are many standards and atlases regarding the description of the causes of defects in iron castings. One of the first papers on this topic was a wide analysis of defects and their causes published by Gierdziewiczski [5]. The author divided defects into the following 10 groups: geometrical shape defects, castings' raw surface defects, moulding material contamination, slag contamination, short run, blow holes, cracks, shrinkage, segregations and inclusions, material defects found in laboratory tests. In each of these groups typical defects were assigned digital and letter symbols [6]. In one of the above publications [7], the author also referred to the work by Pleszinger [8] who, basing on the GOST standards and available publications, put together and assigned numerical symbols to groups and kinds of casting defects, the place and causes for their creation as well as the workers responsible for casting shortages. He assumed that casting shortages should be qualified according to the importance of the defects, dividing them into the following:

- Castings admitted for further usage without repair,
- Castings to be repaired before further usage,
- Castings to be definitely rejected.

Due to the nature of foundry processes, currently there are many classifications of casting defects in literature. In [9], classifications of casting defects according to the Polish and French standards as well as according to the English and German systems are presented. Differences in each classification are schematically shown in Fig. 1.

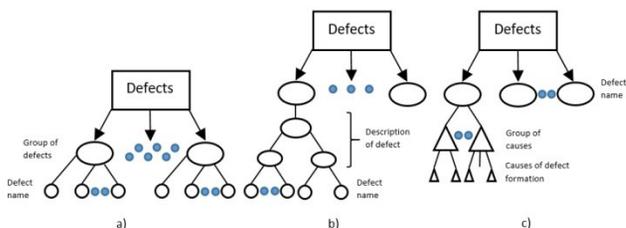


Fig. 1. Schematic classification of classic material casting defects according to: a – Polish standards, b – French standards, c – English and German standards (own study based on [1, 9, 10, 11])

The Polish standard classification is the simplest one as it only has two levels. There are 4 groups on the upper level (shape defects, raw surface defects, continuity interruptions and internal defects), whereas specific defects allowing for unambiguous classification were assigned to the lower level.

The French standard is characterised with a multi-stage structure. There are 7 groups on the upper level (external metal increments, external and internal bubbles, casting continuity interruptions, surface defects, product incompleteness, dimension or shape defects as well as inclusions or structure anomalies). Then there are two intermediate levels with some characteristics or a given group or subgroup. And at the lowest level, just as in the Polish standard, there are names of particular defects. The description of the characteristics facilitating identification of defect creation causes and preventing actions based on the French standard is shown in detail in [12].

The English and German defect classification standard has a system reversed to the ones previously discussed. On the upper level, there are defect names with the assigned cause groups and particular causes. The latter though are not precisely defined which makes this division not always objective.

Apart from attempts to systematise casting defects classification within the specificity of a given country, there are also works in research institutions or production enterprises. At the time of constant computerisation electronic defect atlases are becoming ever more popular. Very often these are digitised books, catalogues or computer systems enabling faster access to information than in case of traditional paper documents. A perfect example of such a solution is an interactive atlas of casting defects available for public viewing, designed by An Investment Casting Institute [13]. It contains descriptions of defects along with their possible cause both at the stage of stamping and subsequent processing. An exemplary "crack" type defect described in the aforementioned atlas is presented in Fig. 2.

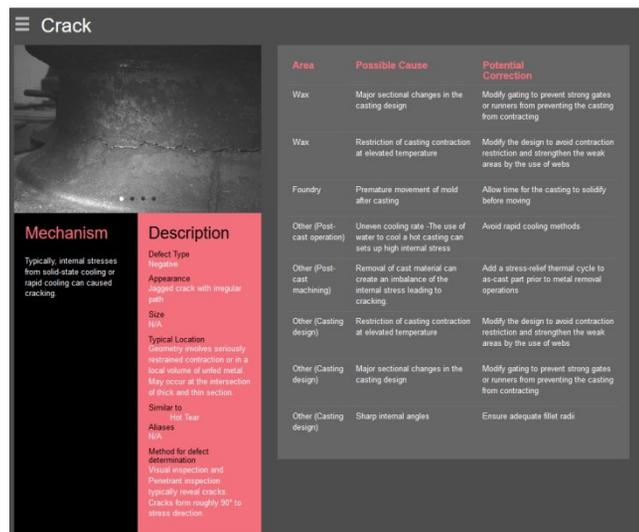


Fig. 2. Atlas of casting defects print screen for the "crack" type defect [13]

In 2015, Harshwardhan Chandrakant Pandit [14] described his original prototype of an electronic atlas of defects called

WebCADAS. He presented an e-learning system implemented in a web-based environment for wide access for practicing foundry engineers. The proposed 2-stage approach was based on linking the defect with its cause and remedies. An example of hierarchical classification of coldshut and casting defects information is shown in Fig. 3.



Fig. 3. Hierarchical classification of coldshut and information about casting defect [14]

One of the first Polish authors to locate the computer diagnostics of casting defects was Kluska-Nawarecka [11]. She presents the most important problems to do with computer systems construction and usage for casting defects diagnostics support. An important Polish foundry system for students and foundry workers support is the "SimulationDB" system developed under the supervision of Malinowski [15]. It stores simulation results, technologies, CAD files, animations, files and solidification parameters.

In spite of many similarities both in the aspect of casting production technologies and defect causes, their appropriate classification method plays a challenging but key role in the proper production problems classification. In many countries work is underway to design original systems facilitating work in foundries both in terms of access and collection of relevant production data on defects (parameters coming from ongoing production registered in fixed time intervals and – if necessary – comments from employees directly related to production processes) and of facilitation and acceleration of interpretation of the defect and its cause. Atlases and catalogues designed from scratch with the participation of casting specialists greatly help in detecting defect causes and help in determining actions to prevent their formation.

Unfortunately, this area still leaves a vast area for improvement. Defects and their causes' names and the mechanisms of defect formation require unification and propagation. In the era of globalisation and the global market it is essential to standardise and unambiguously define the concepts so important in cast production. The foundry industry development is conditioned by their equal understanding both by scientists, producers and their customers.

Many manufacturing enterprises are currently introducing their own defect names as new defects of so far unknown nature occur. In case of periodic occurrence of a specific defect in a series of products, very often the only trace of the problem and its solving can be found in private notes of foundry workers. This approach does not help building long-lasting and useful knowledge of the process. Only recording systematisation and standardisation and using such a universal system can lead to the development of the foundry industry.

As a result of many years of research conducted in various foundries and of interviews with employees and management, the decision of designing an original tool called the Open Atlas of Defects (OAD) was made. The purpose of the tool is to broaden the current trends of information exchange among workers of a given enterprise in terms of unequivocal assessment of the defect and its causes. The first version of the tool with open access for foundry workers is used to support the evaluation of casting defects using Non-Destructive Testing (NDT) methods and to support casting defects analysis with appropriate tools (DCC card – Demerit Control Chart, Pareto-Lorenz analysis, ABC analysis). The results of these works are shortly described in Chapter 3.

### 3. Research results

This Chapter describes a functional of the interactive Open Atlas of Defects accessible for foundry workers. Within the frames of this objective a support tool was designed for defect assessment with the use of Non-Destructive Testing methods (NDT) as well as casting defect analysis module with appropriate tools (control cards for alternative assessment, among others DCC card – Demerit Control Chart, Pareto-Lorenz analysis, ABC analysis).

In an effective defect evaluation, a special browser with a precise name definition according to three groups is helpful (Fig. 4), where:

- Group 1 – the most general, contains information on the origin of defects (described in chapter 1 as Liquid alloy, Mould, Liquid alloy-mould interaction),
- Group 2 – more general, contains information on the type of defect,
- Group 3 – refinement - contains information on the location of the defect (eg defective or scattered defect).

Browser contains a sketch of the defect and – what is important – private photos (Fig. 5) attached by the foundry's employees or authorized persons. Alternatively, CAD/CAE designs can be added to the browser for a specific test cast.

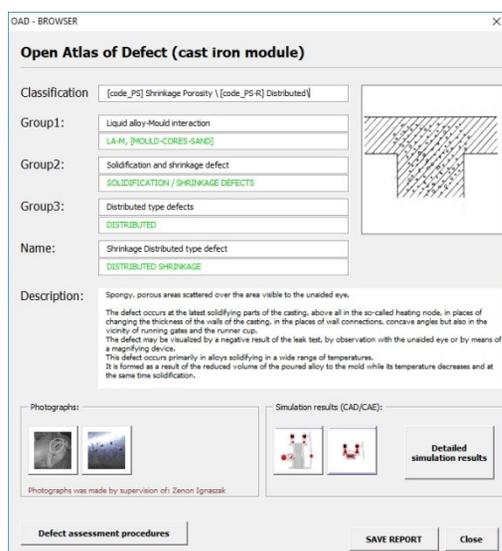


Fig. 4. Main interface of the Open Atlas of Defects



Fig. 5. Example of visualisation of the "shrinkage porosity" defect in the Open Atlas of Defects

The basic OAD functionalities:

- Extended defect description with workers' comments about the defect's causes (Fig. 4, section 'Description') with the possibility of recording discussions similar to internet fora (know-how available only to controllers, technologists and selected management staff), defect photographs (actual casting defects' pictures updated on a regular basis for various manufactured series shown on cast fragments for defects visible on the surface as well as appropriately cut and prepared samples for internal defects – Fig. 4, section 'Photographs'), information on defect assessment (selected data available solely on the company's intranet or outside the company on the basis of the so called B2B – Business to Business co-operation – Fig. 6, section 'Defect assessment procedures').
- Structural development of the module supporting defect evaluation on the basis of non-destructive methods along with a proposal of an original methodology supporting casting defects assessment with a number of non-destructive methods is presented in Fig. 6.
- Introduction of defect intensity into the assessment (according to class C-I, C-II, C-III); C-I class completely disqualifying the casting from sales, the other classes – C-II and C-III classes referring to casting to be sold depending on certain conditions to be discussed with the customer (C-II casting for significant repair, C-III castings for minor repair) – Fig. 6 (supporting defect evaluation) and Fig. 7 (analyse with use of DCC card).

Defect assessment procedures

**Assessment method**

Assessment method: Non Destructive VISUAL

Assessment method - comments:

Parts produced by cores

Defect: Shrinkage Distributed Class: C-I 0 C-II 1 C-III 3

**Basic equipment**

Lighting type: Daylight lighting

Special: Enter the describe: Special lighting

**Complementary equipment**

Endoscope | Another equipment | Assessment conditions

YES  NO

Endoscope type: Flexible endoscope (Fiberscope)

Endoscope name: Enter the name of the endoscope

< ? SAVE Close

Fig. 6. Graphic user's interface for the tool supporting casting defects assessment with various non-destructive methods

Additionally, the designed module containing IT tools for casting defects analysis consists of the parts described below.

**DCC card – Demerit Control Chart** is a control card complementing the card which allows supervision of the number of defects in a sample. In practical terms, separate control cards for various defect types are kept, upon which the number of defects are counted and noted on the card sheet. This may be cumbersome organizationally and technically. The Demerit card has the advantage of the possibility of noting information on defects of various importance on the same control card sheet. Each type of non-compliance is assigned its weight, the weight being the highest for critical defects. A weighted sum being a combination of the number of defects and their importance is noted in the control card (Fig. 7). Depending on its value, relevant activities relating to the product and process are undertaken.

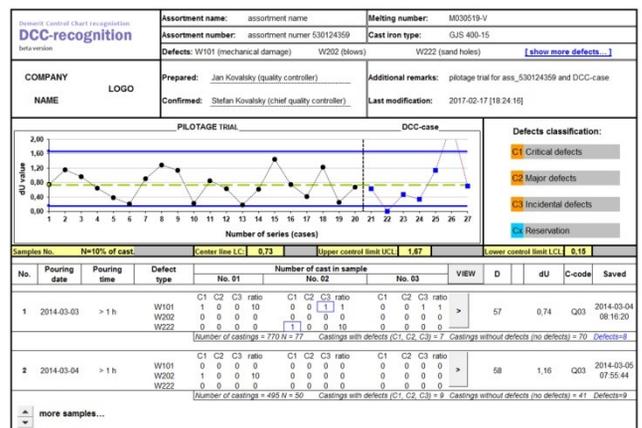


Fig. 7. DCC card – an example of process quality management with three kinds of defects (assortment 530124359)

**Pareto-Lorenz chart** made for any data according to periods and casting assortment, showing the frequency of casting defects in a clear and transparent graphic form (e.g. 80% of all casting shortages caused by 20% of the most common defects).

**ABC defects analysis** – based on the prepared Pareto-Lorenz chart it is possible to analyse defects compiled according to any period and assortment into 3 classes, where: A – the most important class, B – less important class, C – the least important class as per defects frequency.

Open Atlas of Defects is one of the modules of A&DM (Acquisition and Data Mining) system developed since 2006 in the Division of Foundry (Poznan University of Technology) and consists of three sub-modules with the following purpose:

Browser:

- classification / defect type search engine – Fig. 4,
- detailed photographs of particular defect on various cast series can be enlarged – Fig. 5.

Data acquisition (data related to visual assessment of casting defects):

- window supporting entering defect into the database – Fig. 6),
- intensity class of defect - a distinction between repairable / non-repairable defects – Fig. 6.

Casting defects analysis function:

- DCC card - Fig. 7,
- Pareto-Lorenza chart,
- ABC defect analysis.

The designed tool combines new terminology methodology and casting defects assessment on the example of iron alloys and significantly simplify identification of the most important casting defects with the possibility of assigning a new control method. Thanks to the DCC card along with Pareto-Lorenz analysis as well as ABC analysis the user may easier locate the cause of production shortages, which has a direct impact on the profitability of manufacturing products.

## 4. Conclusions

The article presents various methods of casting defects classification based on the Polish, French, German and English standards. Selected electronic atlases of casting defects were presented with a short discussion of the identification method according to individual authors. Moreover, based on many years practice in the described field, the article's authors presented their original tool named Open Atlas of Defects which contains helpful functionality in visual assessment of casting defects (Visual Testing) as well as a module containing an IT tool for casting defects analysis (DCC card, Pareto-Lorenz analysis, ABC analysis). The expanded Open Atlas of Defects is designed to facilitate identification of casting defects causes, collecting process knowledge relating to untypical defects occurrence (defects hard to clearly identify) as well as a proper analysis of shortages level in the Quality Assurance department.

As the next step, the authors are planning to extend the Open Atlas of Defects with a destructive testing module (separately, adherently treaded cast samples) as well as to enable foundry workers to have remote on-line access from outside the company (information exchange among contractors – B2B).

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