ARCHIVES of FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 17
Issue 1/2017

216 – 222

38/1

Development of Cloud Based Casting Defects Categorization System (CDCS)

Amit V. Sata
Mechanical Engineering Department, B H Gardi College of Engineering and Technology,
Anandpar, Kalawad Road, 361162 Rajkot, India
Corresponding author: E-mail address: ameetsata2000@gmail.com

Received 29.08.2016; accepted in revised form 10.10.2016

Abstract

Defects affect the properties and behavior of the casting during its service life. Since the defects can occur due to different reasons, they must be correctly identified and categorized, to enable applying the appropriate remedial measures. several different approaches for categorizing casting defects have been proposed in technical literature. They mainly rely on physical description, location, and formation of defects. There is a need for a systematic approach for classifying investment casting defects, considering appropriate attributes such as their size, location, identification stage, inspection method, consistency, appearance of defects. A systematic approach for categorization of investment casting defects considering multiple attributes: detection stage, size, shape, appearance, location, consistency and severity of occurrence. Information about the relevant attributes of major defects encountered in investment casting process has been collected from an industrial foundry. This has been implemented in a cloud-based system to make the system freely and widely accessible.

Keywords: Casting, Defect, Categorization, Cloud-based

1. Introduction

Metal castings are widely used in various industrial applications including automobile, aerospace, chemical, and biomedical. In industrial practice however, many castings are rejected, repaired or recycled due to presence of defects. It is also anticipated to identify causes for the identified defects, and to suggest remedies to prevent it. However, appropriate identification of a specific defect is considered to be one of the most critical steps towards prevention of defects.

This is usually accomplished by an experienced foundrymen (they may use their linguistic or scientific approach) or technical literature (research papers, reference books, defect atlas, etc). However, it is usually difficult for newly joined foundry engineer to correctly identify specific defect (e.g. sand inclusion or slag inclusion; gas porosity or shrinkage porosity), and suggest their remedies. Various researchers proposed different methodologies to categorize the defects, and are discussed next.

2. Previous research

In general, chronic defects (that occur continuously) can be controlled by appropriate changes in the process parameters. On the other hand, sporadic defects that occur due to sudden undesirable deviations from the normal process, are more difficult to diagnosis and cure (Donohue & Frye, 1999). The International Atlas of Casting Defects (Rowley, 1974) describes 30 different types of defects, which are generally applicable to gray iron castings produced in sand molds. The International Committee of Foundry Technical Association has described as many as 98 defects in castings with graphical representation (Ransing, et al., 1995). The defects can be categorized based on their physical appearance, location, formation principle, and consequences.

Herold, (2006) proposed an alternate approach based on comparing the radiographic image of a casting defect with that of a known casting defect. Higher density type of defects include inclusions, while lower density defects include shrinkage (single shrink hole, cluster of holes and sponge defect), blow hole (single blow hole and porosity), and surface defects (die mark and blacking). This approach is very useful for categorizing of sub-surface type of defects. However, many other defects, especially those occurring on the surface (mismatch, flash and fins) are not covered in this approach. Many defects occurring in ferrous castings produced in sand molds are not covered by the above approaches (Alagarsamy, 2003). These include vermicular graphite, chunk graphite, exploded graphite, grain boundary carbides, gas voids with oxide layer, blister, leaker, doughnut, and shrinkage at riser contact. Other important characteristics of the defects (formation mechanism, size, and severity) are also not covered in these approaches. Cocks, (1996) proposed a similar categorization of die casting defects based on their location. Surface defects mainly alter the aesthetical and functional characteristics of castings, while internal defects affect the service life of castings.

Chen, (1997) categorized die casting defects based on three types of causes: mechanical (improper die design, machine set-up, injection system, injection pressure, injection velocity, etc.); metallurgical (improper composition, melting, and filling of molten metal); and process (improper filling time, venting, heat removal mechanism, die layout, etc.). Another approach (Yu, 2001) is based on six categories related to physical phenomena involved in casting process: mold/core, mold filling, shrinkage, segregation, stress, and micro-structure. Mold/core related defects include mold/core crack, slag inclusion, and sand inclusions. Mold filling related defects include no-fill (misrun), entrapped gas (blowholes), and weld line (coldshut). Shrinkage defects include macro-shrinkage, micro-porosity and gas porosity. Segregation defects include indigenous (freckles and beta flecks) and exogenous (hard alpha particles). Stress related defects comprise cold cracking, hot tearing and distortion. Micro-structure defects are related to dendrite arm spacing, grain structure and morphology. Campbell, (2003) also classified defects as gas porosity, shrinkage porosity and hot tearing or cracks. The advantage of this approach is that once identified in terms of causes, the defects are easy to prevent (by controlling the causes), but the categorization itself (in terms of the causes) is not easy. Also, some defects (like flash, fins, veining, and mismatch) are not covered.

A few researchers categorized casting defects using a combination of location and formation mechanism. Gariboldi et al., (2007) proposed a multi-level and hybrid approach for categorizing metallurgical defects in high pressure die castings on the basis of geometry and origin of defects. Bonollo et al., (2013) prepared a standard based on this approach of categorization collaboration with the Italian Association of Metallurgy.

The categorization of casting defects as proposed in literature and currently adopted in industry is primarily on the basis of defect geometry, location and metallurgical origin. Most of the prior work is focused on defects in sand casting and die casting processes. There is a need to evolve a comprehensive set of attributes to correctly categorize the defects. Recently, Sutoova & Grzincic, (2013) presented a Microsoft Excel based catalogue of defects specifically applicable to aluminum castings. This catalogue provides a number, description, visualization, detection method, causes and corrective actions for each defect. There were eight different categories: defect shape and dimension, surface, discontinuities, cavities, macrostructure and microstructure, chemical composition and properties related defects, other defects and external defects.

To summarize, several different approaches for categorizing casting defects have been proposed in technical literature (table 1). Most of these approaches are applicable to either sand casting of ferrous alloys or die casting of aluminum alloys. They mainly rely on physical description, location, and formation of defects. Even for the categorization methods that are based on causes, it is very difficult to specify the exact remedy to prevent the occurrence of defects, since several causes may be involved. There is a need for a systematic approach for classifying investment casting defects, considering appropriate attributes such as their size, location, identification stage, inspection method, consistency, appearance of defects.

Table 1.
Summary of literature on classification of defects

Researcher (Year)	Different methodologies adopted for classification of defects			
	Physical description	Location	Source	Detection method
Davies (1973)	---	✓	---	✓
Rowley (1974)	✓	--	---	---
Cocks (1996)	---	✓	---	✓
Chen (1997)	---	---	✓	---
Yu (2001)	---	---	✓	---
Campbell (2003)	---	---	✓	---
Herold (2006)	✓	---	---	---
Gariboldi et al. (2007)	✓	---	✓	---
Bonollo et al. (2013)	✓	---	✓	---
Sutoova and Grzincic (2013)	✓	✓	✓	---

3. Proposed approach

A hierarchical, comprehensive and systematic approach suitable for categorization of investment casting defects is proposed here. All major defects encountered in investment casting, such as ceramic inclusion, crack, flash, misrun, rough casting surface, shrinkage, slag inclusion, and sweating are covered. The hierarchical schema for the categorization of casting defects comprises three levels (figure 1).

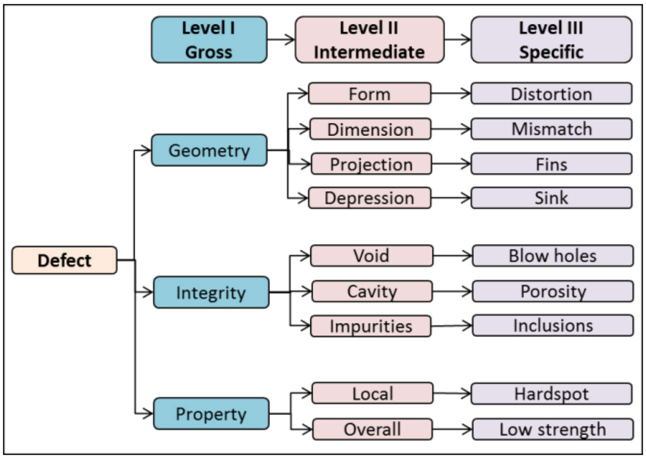

Fig. 1. Schema for hierarchal categorization of defects

The top level represents the gross (overall) category of defect, largely based on its effect on product function. This categorization is based on standard inspection methods practiced in the foundry: visual, NDT and mechanical testing. Information about the stage of detection (inspection) is also captured from the foundry. There are three categories in this level: geometry, integrity and property related defects. Any defect that alters the geometry (shape and dimensions) of the casting with respect to the original design, is categorized as geometry defects. These are usually identified by visual inspection, and may require expensive remedial measures such as additional machining. Any defect that affects the internal soundness of castings, usually because of the presence of a void or impurity, is categorized as integrity defect. These are usually identified by various NDT techniques such as radiography. These defects usually lead to outright rejection and recycling (remelting) of the casting. The last category in the top level is property related defects, which imply that the mechanical properties of the casting fall outside (usually below) the desired range. The properties are ascertained by mechanical testing. Poor properties affect the service life of the product; they can be modified by heat treatment and other remedial measures, but add to manufacturing cost.

The second level represents the intermediate stage of categorization, which is based on finding the values for a set of qualitative attributes of the gross defect. There are mainly three attributes of the defect: size, shape and appearance (figure 2). The size of defect could be small or large. The shape of defect could be spherical/oval, flat or linear. The appearance could be shiny/matt, smooth/rough, regular/irregular. In this level, the geometry defects are categorized into form, dimension, projection and depression defects. Form defect, such as distortion, alter the overall shape of the casting from its designed shape. Dimension defects, such as mismatch, change the size of the casting along or across the parting line (originally on the wax pattern). Unwanted projection (for example, fin) or depression (sink mark) also alter the geometry of the cast part. In a similar way, the second gross defects related to integrity, are categorized in terms of void, porosity, and impurity related defects, all of which affect the internal soundness of a cast part. Voids include blow hole and shrinkage cavity. Cavity defects include gas porosity and shrinkage porosity. Inclusions include ceramic and slag particles. The third gross defects, related to mechanical properties are categorized as overall or local. Overall property defects imply that a mechanical property (tensile strength or hardness) measured on a test casting falls outside the desired range, leading to rejection of the entire batch. The local property defect (such as hard spot) implies that the property is outside the range in only a localized region or section. This can lead to machining problems (cutting tool breakage).

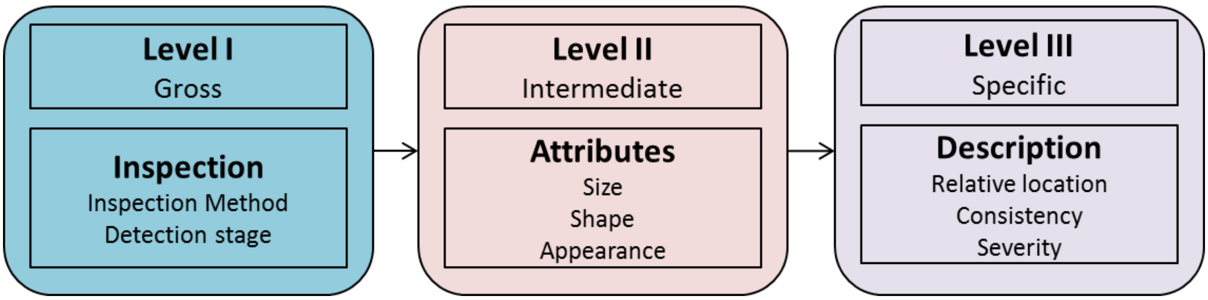

Fig. 2. Process for categorization of defects

In the third level, defects are described further, based on information related to design, material, process and inspection, which helps in categorizing the specific defect. The information includes: relative location, consistency and severity of the defect. The location of defect is described with respect to the overall geometry and other features of the casting, for example: surface/sub-surface/deep inside; in thin/thick section; near/far from corner; close to hotspot/core/gate, etc. Consistency could be low or high. Severity (effect of the defect) could be low or high. Categorization of the specific defect usually requires the involvement of expert foundry engineers relying on their past experience.

4. Defects knowledge base

A knowledge base of investment casting defects has been created by collecting the relevant information from industrial foundries. Each defect is characterized using various attributes mentioned in the previous section; this information is stored in a tabular format along with an image of a typical defect (to enable visual understanding and comparison). The first field is the gross type of defect (geometry, integrity, property). The next three fields are related to its detection, size, and shape. The last four fields are related to the third level of categorization: appearance, location, consistency, and severity. In addition, the probable causes of each defect, related to design, material and process parameters are also listed.

For example, one of the most common defects in investment castings, shrinkage, is categorized as a integrity at the gross level, since it mainly affects the internal soundness of the casting. In the second level, this defect is further attributed as on the basis of its detection stage (finish machining, in this case), small defect (based on size), oval defect (based on shape) and rough defect (based on appearance). The final stage of categorization involves specifying its location (internal, in this case), consistency (usually at hotspot) and high severe (based on severity). The above information about the defect is shown in figure 3. Similarly, categorization of other major defects including misrun and ceramic inclusion are also shown in figure 4 and 5.
These knowledge base can be easily extended to any other defects, or to specific combinations of casting alloy and application sector (automobile, aerospace, biomedical, valves, etc.).

Name	Shrinkage
Type	Integrity
Detection stage	Finish machining
Size	Small
Shape	Oval
Appearance	Rough
Location	Internal
Consistency	Hotspot
Severity	High

Causes	Design Parameters	Material Parameters	Process Parameters
Volumetric contraction	Size of feeder	Metal composition	Degree of superheat
Insufficient metal poured	Number of feeder	Percentage of shrinkage	Capacity of laddle
	Location of feeder		

Fig. 3. Categorization of a defect – shrinkage

Name	Misrun
Type	Geometry
Detection stage	Ejection
Size	Small
Shape	Spherical
Appearance	Smooth
Location	External
Consistency	Opposite to gating
Severity	High

Causes	Design Parameters	Material Parameters	Process Parameters
Less molten metal poured	Volume of casting	---	Capacity of ladle
Low fluidity	Location of gate	Composition of metal	Pouring temperature
Premature freezing	Thin sections	Thermal property of mold	---
Metallostatic pressure	Pouring height	Mold surface roughness	---
High flow resistance	Location of vents	---	Mold permeability

Fig. 4. Categorization of a defect – misrun

Name	Ceramic inclusion
Type	Geometry
Detection stage	Fettling
Size	Small
Shape	Flat
Appearance	Rough
Location	External
Consistency	Near mold elements
Severity	Low

Causes	Design Parameters	Material Parameters	Process Parameters
Metal and mold reaction	Metallostatic height	Composition of metal	Pouring temperature
	Filling rate	Composition of sand	Binder for sand

Fig. 5. Categorization of a defect – ceramic inclusion

5. Cloud based casting defect categorization system (CDCS)

The proposed categorization of casting defects has been implemented in a cloud-based environment to enable identification of a specific defect occurring in an industrial foundry. The system is based on the concept of case based reasoning, and comprises three major modules: database, system interface and user interface. Its architecture and data flow are shown in figure 6.

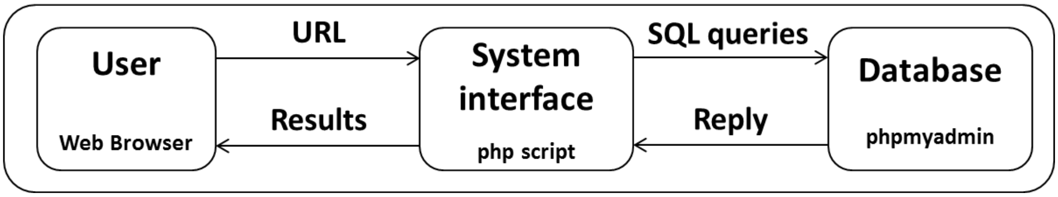

Fig. 6. Architecture of cloud-based classification system

In database of the casting defects identification system is based on the categorization methodology described earlier. The relevant information for each defect is stored using a Structured Query Language (SQL) schema. This is essentially a table that includes the data related to casting defects (row wise) and their categorization (column wise). It has provision to insert a photograph of each type of defect. The schema was implemented using a well-known open source platform for SQL called phpmyadmin.

The second module, system interface, facilitates the interface between user and database. This has been implemented using a server side scripting language called .php, a popular tool for web programming. The script takes the input from the user, and transfers it to phpmyadmin in the form of SQL queries. It also receives the reply from the database and transfers it back to the system interface. The system also presents various causes based on the user inputs to identify the most probable causes to the user. This helps foundry engineers to minimize casting rejections by optimizing the related parameters, if needed, by working with product and tool engineers. The user interface module enables the interaction of user with the system through any standard web browser. The beta version of investment casting defects categorization system has been implemented on the server of the author’s institute (www.gardividyapith.ac.in/ CDCS). It can be freely assessed by any user (figure 7).

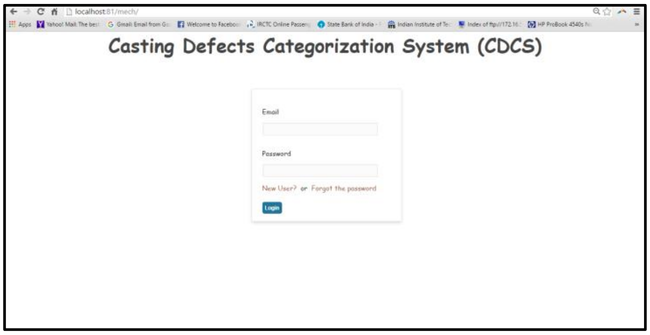

Fig. 7. Cloud-based castings defects categorization system

The key steps for using the system are briefly explained next. Figure 8 shows the main input screen of the system. The user has to select various attributes of a particular defect observed in the foundry, using the drop-down menus for each attribute. The inputs for a sample defect identification exercise, including the type of defect (geometry, integrity or property); followed by other attributes (location, size, detection stage, identification method, consistency, and appearance) of the defect. Based on these inputs, the system identifies the specific defect (in this case, shrinkage porosity), and shows its attributes along with an image for comparison purpose (figure 9).

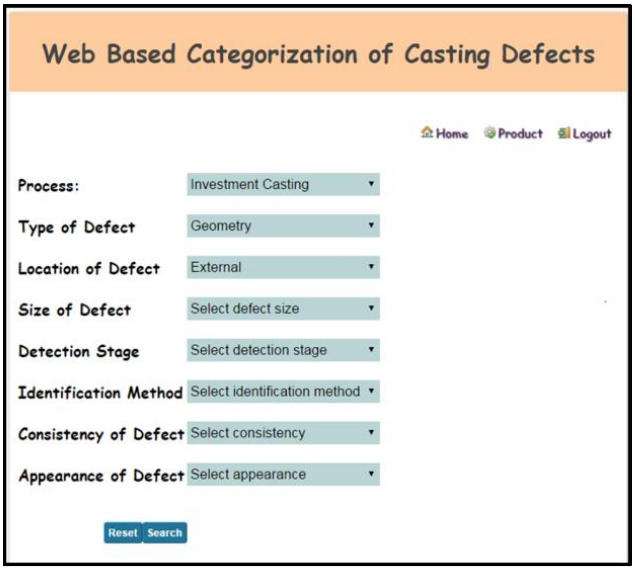

Fig. 8. User input screen for cloud-based categorization system

Fig. 9. Categorization and display of the defect

6. Conclusion

A systematic methodology for categorization of investment casting defects has been proposed in this work. This methodology is based on a hierarchical scheme, with multiple attributes related to the detection stage, size, shape, appearance, location, consistency and severity of the defects. The requisite knowledge base has been evolved using information obtained from industrial foundries, including photographs of typical defects. This has been implemented in a cloud-based environment, and demonstrated. This is expected to create a greater awareness about investment casting defects. However, the proposed system can easily be extended for other casting processes by acquiring knowledge required for categorization of defects. The acquired knowledge further can be added in data base of the proposed system, and can be demonstrated with minor adjustment in system. This is the first step toward reduction of rejection in foundries, and considered to be one the most important steps towards prevention of defect. Proper categorization of casting defects leads to suggestion of appropriate causes and remedies related to the defect, and helps in reducing the rejection in foundries. There various methodologies available including casting simulation, artificial intelligence, statistical, etc. can be adopted to prevent the occurrence of defects.

References

[1] Alagarsamy, A. (2003). Casting Defect Analysis Procedure and A Case History. Keith Mills Symposium on Ductile Cast Iron 2003.

[2] Donohue, T. & Frye, H. (1999). Characterization and Correction of Casting Defects. Advanced Casting Technology.

[3] Ransing, R.S., Srinivasan, M.N., & Lewis, R.W. (1995). ICADA: Intelligent Computer Aided Defect Analysis for Castings. *Journal of Intelligent Manufacturing. 6*, 29-40.

[4] Rowley, M. (1974). *International Atlas of Casting Defect* (1st ed.). Schaumburg: AFS.

[5] Yu, K.O. (2001). *Modeling for Casting and Solidification Processing* (Illustrated ed.). Ohio: CRC press.

.