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## Quality control of cast iron: extreme value statistics applied to CT measurements

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### Abstract

In this presentation, we will summarize the main results of a research activity aiming at predicting the size of the defect at the origin of fatigue failure in large spheroidal cast iron presses. The endurance limit of the material is largely influenced by the ineluctable presence of defects related to the casting process, such as voids and degenerated graphite. The aim of this activity was to determine a reliable and robust way to control the material in production and to reject the parts which do not meet the company's quality requirements. Defect measurements have been performed with 2D and 3D techniques (i.e. metallographic analyses and computed tomography) and different maxima sampling strategies have been applied to the data, to determine a reliable and robust distribution of the largest defects. The maximum defect in the component volume was estimated adopting the concepts of statistics of extremes. The goodness of the results has finally been validated considering the largest defect detected in the most stressed component volume.

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**Keywords:** defect tolerant fatigue assessment; computed tomography; statistics of extremes; spheroidal cast iron; degenerate graphite

### Nomenclature

A area  
BM Block Maxima sampling  
CT computed tomography  
F cumulative probability  
MA metallography  
 $n$  volume ratio for the application of statistics of extremes

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|                   |                                                       |
|-------------------|-------------------------------------------------------|
| $N_u$             | number of exceedances over the threshold              |
| POT               | Peaks-over threshold                                  |
| $u$               | threshold for POT maxima sampling                     |
| $V$               | volume                                                |
| $V_0$             | control volume for maxima sampling                    |
| $V_c$             | component reference volume                            |
| $V_n$             | volume to be considered applying statics of extremes  |
| $V_{ref}$         | reference volume for data comparison                  |
| $\lambda, \delta$ | scale and shape parameters of the Gumbel distribution |
| $\rho_u$          | density of exceedances over the threshold             |
| $\sigma$          | parameter of the negative exponential distribution    |

## 1. Introduction

How to deal with fatigue in presence of defects is an old and deeply investigated topic. After the introduction of defect tolerant design concepts in the mid 1980s by Murakami and Endo (1986), this kind of analysis has been adopted for several applications and various materials and manufacturing techniques. The application of these concepts requires the estimation of the maximum defect which can occur inside a component. Sometimes, this information is not available a-priori, therefore quantitative measurements together with specialised statistical analyses are required. This is the case of the presses analysed in this paper. Given their massive dimension, the small production numbers and the different contractors providing the cast raw parts, the quality of the castings may be variable and heterogeneous. Due to the cost of discarding the raw parts, the company wants to improve the quality assessment and acceptability rules and define an internal procedure to be applied on all the parts before starting the following manufacturing phase.

### 1.1. Scope on detection and analysis of extreme defects

The dangerous defect types that can be found in the cast iron are porosity and degenerate graphite. An easy and cheap way to measure the defect distribution is the investigation of small polished sections at the microscope, which was often used in the past due to the lack of more sophisticated techniques (see Murakami (1994)). When the defects become the fracture origin, it is well recognized that, in a volume of material subjected to the same cyclic stress, the fatigue failure occurs at the largest defect or inhomogeneity (see Murakami (2002)). Therefore, the estimation of fatigue strength in presence of defects needs the estimate of the prospective size of maximum defect in the component volume. The impossibility to prepare and analyse large material areas was overcome adopting the concepts of statistics of extremes (see Coles (2001); Reiss and Thomas (1997)), which allows to estimate the distribution of the maximum defect in a larger volume of material than the one investigated.

Needing only the dimension of the maximum defects, the *block maxima* (BM) sampling can be used. This sampling strategy consists in subdividing the area in several sub-parts and measuring only the largest defect detected in each one. The size of the defects is usually expressed considering the  $\sqrt{\text{area}}$  parameter. The resulting data can then be described by a Gumbel distribution (Murakami and Beretta (1999) provides a summary of this research). Although it is commonly used and described in the standard ASTM E2283-03 (2003), this process has some drawbacks (e.g. bi-dimensional measure, small sampling areas achievable, need to polish the surface, definition of the reference area for the BM application not straightforward). Moreover, the measurements obtained from 2D analyses do not refer to the maximum size of the defect, but the position in which the polished section intersects them is random. Therefore, a general underestimation of the maximum defect size can generally be expected. This limitation can be overcome applying probabilistic coefficients dependent on the shape of the defects (see Sahagian and Prousevitch (1998)), but the application of these concepts can become very inaccurate when dealing with complex shapes as in the present case.

A more actual and simple way to measure the defects is the adoption of computed tomography (CT). Even being more expensive, this technique allows to analyse large material volumes and has the further advantage of describing

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