

Title	What are the possible causes of tensile test failure?		
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Introduction

In the previous contributions of this series, it was shown how metallurgical control of cast iron is strongly influenced by the management of inoculation and nucleation potential throughout the melting process. In particular, it was demonstrated how failure to stabilize the base iron, uncontrolled in-stream inoculation, and over-inoculation phenomena can lead to microstructural defects and non-compliant mechanical properties, often without clear indications from conventional control methods.

This fifth paper focuses on one of the most representative, yet also most critical, assessments of material quality: the tensile test.

The tensile test is a fundamental tool for evaluating the mechanical behaviour of castings, providing key information on strength, yield limit, and ductility, parameters directly related to the safety and reliability of components in service.

In industrial practice, tensile test failure is often interpreted as a problem related solely to chemical composition or improper testing conditions. However, experience shows that even with a chemical composition within specification, test specimens may fail to meet the required mechanical properties. This phenomenon is the result of a combination of factors, including internal defects, non-optimal microstructures, and unstable metallurgical conditions, which reduce the intrinsic mechanical potential of the material.

The aim of this work is to provide a structured overview of the main causes that can lead to tensile test failure, distinguishing between factors related to the material, microstructure, and test execution, without addressing normative or procedural aspects of the test itself. Particular emphasis is placed on metallurgical causes, often less evident but decisive, which promote crack initiation and propagation during testing.

In continuity with the previous papers, it will also be shown how the management of inoculation and base iron preconditioning directly influences the outcome of the tensile test, through control of microstructure and prevention of defects such as carbides, porosity, and local inhomogeneities. Once again, process control based on thermal analysis proves to be an essential tool for ensuring metallurgical stability and mechanical compliance.

What is the real significance of the tensile test in cast irons?

The static tensile test is one of the most important methods for evaluating the mechanical properties of metallic materials and is widely used as an acceptance criterion for cast iron components. This test allows determination of key parameters describing the elastic-plastic behaviour of the material up to fracture, including:

- ultimate tensile strength;
- yield strength;
- percentage elongation at fracture.

In cast irons, the tensile test is particularly critical because the measured values are directly influenced by the microstructure, namely:

- graphite morphology;
- nature of the metallic matrix;
- presence of internal discontinuities.

Compared to faster checks such as hardness testing or chemical analysis alone, the tensile test provides a global assessment of the metallurgical quality of the casting, combining in a single result the effects of defects, microstructural heterogeneities, and solidification conditions.

For this reason, tensile test failure should not be interpreted as an isolated event or merely as a testing issue, but as a clear indication of reduced mechanical potential, often linked to metallurgical causes developed upstream in the process.

Why and how does material fracture occur during a tensile test?

Fracture of the specimen during a tensile test is the result of a progressive damage process that begins well before macroscopic failure becomes visible. At the microstructural level, plastic deformation induces localized micro-plasticity in the metallic matrix, typically at heterogeneities such as graphite particles, inclusions, porosity, or microstructural discontinuities.

These regions act as stress concentrators where micro-voids nucleate. As deformation increases, these micro-voids grow and coalesce into an internal crack, which propagates until final fracture. The fracture mode, ductile or brittle, depends on the ability of the microstructure to accommodate plastic deformation prior to failure. In cast irons, this behaviour is strongly influenced by:

- internal defects such as shrinkage microporosity, inclusions (dross, sand, inoculant residues, or undissolved alloys), gas porosity, and cold shuts, which reduce the effective load-bearing cross-section;
- matrix microstructure, particularly the presence of carbides, localized martensitic structures, or excessively hard pearlite, which promote brittle fracture;
- non-compliant graphite morphology, such as flake, vermicular, chunky, or degenerated graphite, which interrupts matrix continuity and facilitates crack initiation;

- surface conditions of the specimen, including high roughness or surface degeneration due to metal-mould interaction.

Even in the absence of evident macroscopic defects, an inadequately controlled microstructure can significantly reduce the mechanical potential of the material. In such cases, fracture is not due to a single abnormal event but rather reflects an overall lower metallurgical quality that becomes evident in a global test such as the tensile test.

Why can the tensile test fail even when everything appears to be under control?

Tensile test failure represents the final manifestation of reduced mechanical potential, but the causes are often multiple and not immediately identifiable. In industrial practice, it is common to observe specimens that fail to meet strength or ductility requirements even when chemical composition and process parameters appear compliant.

The causes of tensile test failure can be grouped into three main categories: internal defects, suboptimal microstructure, and test execution conditions. Among these, the first two play a predominant metallurgical role.

Internal defects and crack initiation sites

Defects such as shrinkage microporosity, inclusions (dross, sand, inoculant residues, or undissolved ferroalloys), gas porosity, and cold shuts act as stress concentrators, reducing the effective cross-section of the specimen. During the tensile test, these defects promote early crack initiation, accelerating void coalescence and leading to premature fracture.

Microstructure and metallurgical condition of the material

Even in the absence of visible defects, microstructure plays a decisive role. Critical factors include:

- non-compliant matrix, characterized by incorrect hardness, excessive pearlite, or presence of brittle phases;
- presence of carbides, either from direct or inverse chill;
- non-ideal graphite morphology, such as flake, vermicular, or degenerated graphite;
- local microstructural inhomogeneities.

Under these conditions, the material may appear acceptable in terms of hardness or chemical composition but may behave intrinsically brittle under tensile loading, fracturing before reaching the required strength or elongation values.

Influence of test execution

Finally, some causes are related to test execution, such as incorrect loading rate, misalignment of the specimen, inadequate surface finish, or unfavourable environmental conditions. While these factors can affect results, they are generally secondary compared to metallurgical causes, which determine the true load-bearing capability of the material.

What role does inoculation play in tensile test failure?

Inoculation has a direct and often decisive impact on the tensile test outcome, as it governs the nucleation potential of cast iron and, consequently, the development of microstructure during solidification. Improperly calibrated or non-adaptive inoculation practices can lead to microstructures that significantly reduce the material's ability to undergo plastic deformation under load.

- In under-inoculation conditions, cast iron with low nucleation potential tends to solidify in a metastable manner, promoting carbide formation, locally hard pearlitic areas, or heterogeneous microstructures. These rigid and brittle phases limit plastic deformation, accelerate microvoid nucleation, and lead to premature fracture, often with elongation and strength values below specification.
An additional critical aspect concerns graphite morphology and distribution, which deteriorate as nucleation potential decreases. This effect is particularly evident in ductile irons, where spheroidization is strictly interdependent with inoculation. In such conditions, degenerated graphite forms local stress concentrations in the matrix, facilitating crack initiation and further compromising tensile behaviour.
- Conversely, over-inoculation can also negatively affect tensile performance. An excessive density of graphite nuclei may lead to premature graphite precipitation, non-optimal particle distribution, and shrinkage microporosity, as discussed in the third paper of the series.

It is important to note that these effects are not always correlated with average chemical composition and may develop even in processes that appear stable. Static inoculation practices, without consideration of the actual nucleation potential of base iron, cannot compensate for variations due to charge materials, returns, melting time, or thermal conditions, transferring this instability directly to mechanical test results.

Therefore, tensile test failure is often the final manifestation of uncontrolled inoculation management. Only through an approach based on base iron preconditioning, dynamic adjustment of inoculation practices, and process control supported by tools such as ITACAX™, ITACA Stream™, and ITACA Vision™ can a stable microstructure and consistent mechanical response be ensured.

Conclusions

This work has shown that tensile test failure is rarely an isolated event but rather the result of metallurgical instability developed upstream in the process. Even with compliant chemical composition, internal defects, suboptimal microstructures, and metastable phases can significantly reduce mechanical potential and lead to premature fracture.

Improper inoculation management, both under- and over-inoculation, can compromise nucleation, graphite morphology, and matrix continuity, directly affecting tensile test results. In this sense, the test does not merely measure material strength but reflects the entire metallurgical history of the cast iron.

In continuity with previous papers, this contribution confirms that mechanical compliance is achieved not by correcting results downstream, but through upstream metallurgical control based on stable base iron, adaptive inoculation practices, and process monitoring supported by thermal analysis. Only in this way does the tensile

test become a consistent verification of a properly controlled process, rather than an unpredictable critical point in quality control.