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Editorial

Failure Mechanisms in Alloys

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1. Introduction and Scope

The era of lean production and excellence in manufacturing, while advancing with sustainable development, demands the rational utilization of raw materials and energy resources, adopting cleaner and environmentally friendly industrial processes. In view of the new industrial revolution (through digital transformation), the exploitation of smart and sophisticated materials systems, the need for minimizing scrap and increasing efficiency, reliability, and lifetime, on the one hand, and the pursuit of fuel economy and the limitation of the carbon footprint, on the other hand, are absolute necessary conditions for the imminent growth in a globalized and highly competitive economy. These parameters require the development and fabrication of high-resistance metals and alloys and the explicit knowledge of their potential damage and degradation processes, in order to ensure long-lasting service, avoiding undesired, costly, and catastrophic failures.

The occurrence of unexpected failures in critical industrial and transportation sectors could lead to serious accidents or even to catastrophes, having a crucial impact on infrastructure and society in general. Profound knowledge about failure mechanisms in metals and alloys is an absolute prerequisite, which leads to the understanding and determination of the root source of the failure(s) and to their successful prevention. Together with failure mechanisms, the recognition of service conditions (temperature, type or nature of the environmental parameters, loading conditions, assembly parameters, and interactions with neighboring components) and the information pertaining to the industrial production processes involved in the fabrication of the metal component are of critical significance in order to put all the failure "puzzle pieces" in a meaningful and reasonable order. The "reconstruction" of a failure event is mainly focused on the interpretation of its natural complexity and the unfolding of the logical sequence of the events involved. These failure-linking stages, which occurred concurrently, intermittently, or successively, gave rise to the final ultimate failure, in a "backward-thinking" procedure. The organization of a failure investigation is a multi-step, structured, and disciplined process that must be limited in time and budget, according to the requirements and the project objectives. The collection of the "pieces" and "clues" during a failure investigation is a diligent and multi-tasking process. In the real world, missing pieces disrupt the continuity and clarity of the "cause-and-effect" chain relationships, converting them from deterministic to fuzzy or stochastic.

Failure analysis is an interdisciplinary scientific topic, reflecting the opinions and interpretations coming from a systematic evidence-gathering procedure, embracing various important sectors, imparting knowledge, and substantiating improvement practices. The deep understanding of a material or component's role and properties is of central importance for "fitness for purpose" in certain industrial processes and applications. The "scheme" presenting the interaction loci of the failure analysis area can be simply presented as the "knowledge triangle", illustrated in Figure 1.

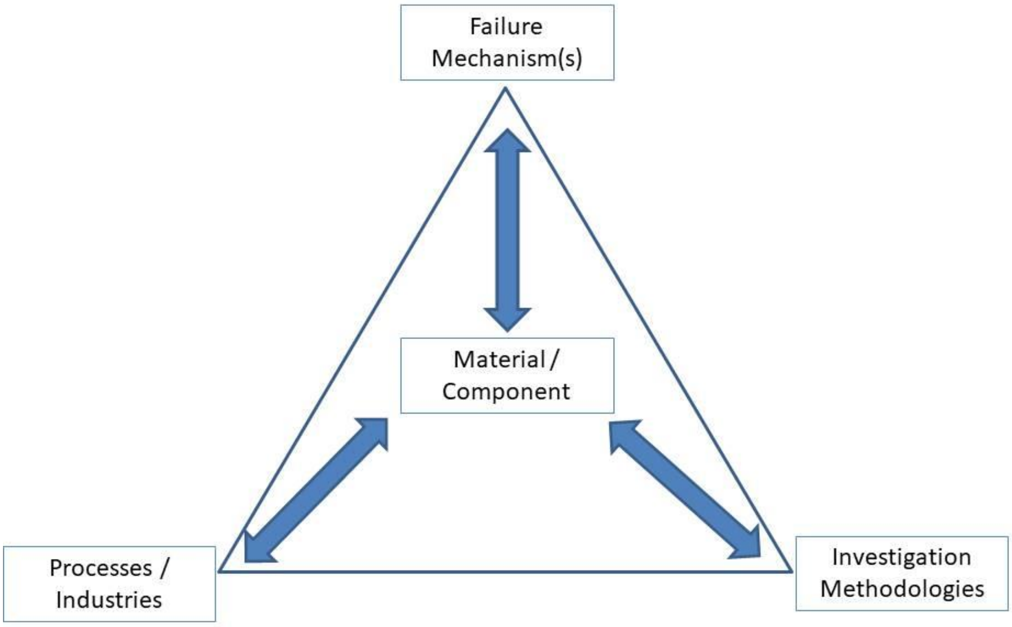
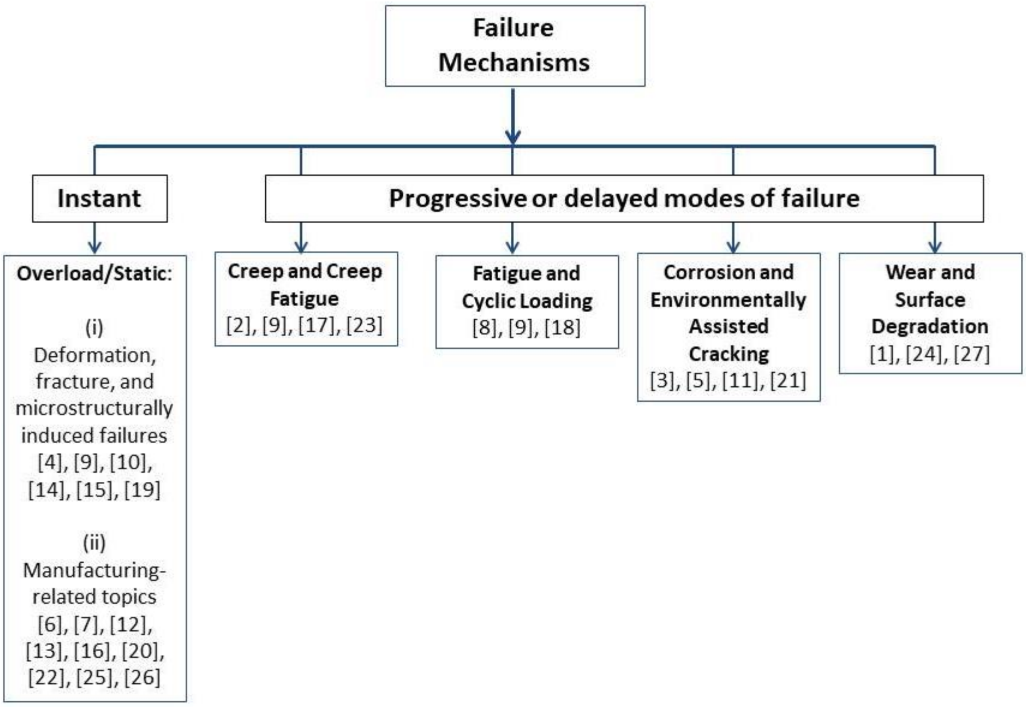


Figure 1. The failure analysis "knowledge triangle", presenting the interaction areas and the central role of the understanding of a material or component's role and properties.

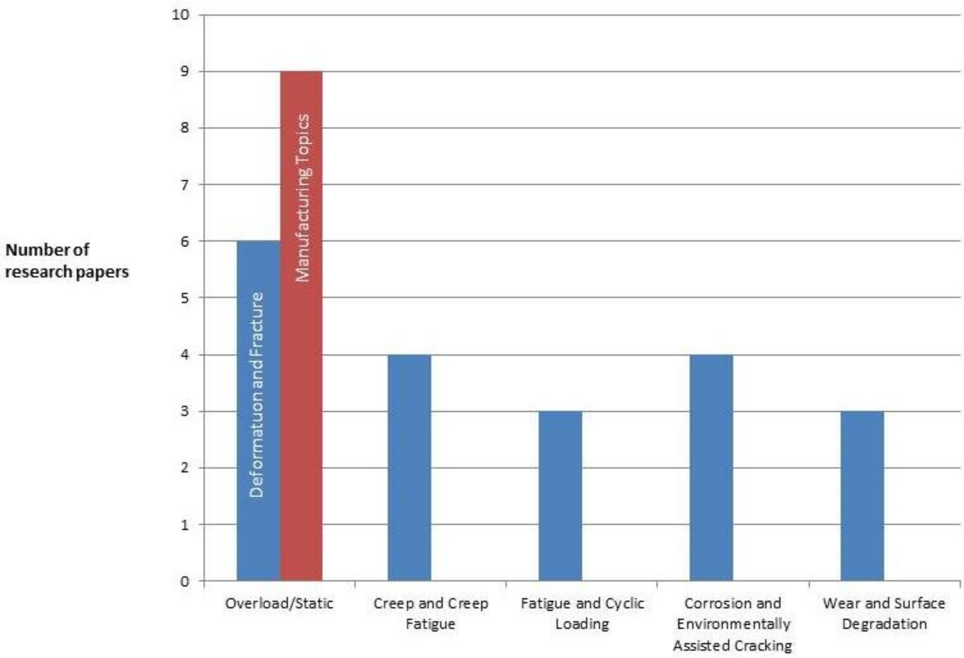
2. Contributions

The Special Issue "Failure Mechanisms in Alloys" contains in total twenty-seven (27) research articles [1–27], with two review papers among them (see [9] and [24]). The contents of this collection cover a wide spectrum of the cross-disciplinary fields of the entire domain of failure analysis, providing valuable contributions in diverse and challenging topics exhibiting interests in the investigation of failure mechanism, industrial processes, and approach methods (Figures 2–4). Moreover, different groups of materials are involved in the presented studies (Table 1).

Almost the complete range of the general types of failure mechanisms has been addressed in the published works gathered in this Special Issue. Instant overload as well as progressive failure modes are included (Figure 2a). More specifically, the broad category of static overload includes more generic subjects also from the field of manufacturing-related topics, where the effect of deformation and fracture was studied as an important and undetached ingredient of the fabrication process per se (e.g., hot and cold working, machining). Therefore, the mostly "intense area" (Overload/Static) comprises studies concerning general deformation and fracture phenomena, as the result of instant loading/testing conditions [4,9,10,14,15,19] and studies related to manufacturing and production processes [6,7,12,13,16,20,22,25,26]. Testing and modeling procedures addressing the evolution of deformation and fracture during forming [7,13,26], the impact toughness, [4] and certain production process characteristics [25] are also included. Nevertheless, shear fracture processes that emerged in machining and chip formation are also part of this broader group of studies, relevant to manufacturing topics (see [12,16,20]).



(**a**)



(**b**)

Figure 2. (**a**) Categorization of the subject "Failure Mechanism", as it was addressed by the studies contained in this Special Issue; (**b**) distribution graph presenting the number of papers focused on the various failure mechanisms, which were ad hoc considered herein for simplicity purposes.

"Progressive" or "delayed modes of failure" possess exceptional interest in various industrial sectors, such as the chemical, mechanical, and manufacturing industries and in plant machinery. Four basic categories can be distinguished (Figure 2a):

a. Creep and Creep Fatigue failure modes [2,9,17,23];
b. Fatigue and Cyclic Loading [8,9,18];
c. Corrosion and Environmentally Assisted Cracking [3,5,11,21];
d. Wear and Surface Degradation [1,24,27].

The relevant number of studies' distribution graph is presented in Figure 2b.

It can be seen from Figure 2b that manufacturing-related topics occupy a significant percentage of the content, reflecting the importance of failure assessment and the emergence of failure and damage prognosis and prevention, as the basic component of the knowledge and learning processes required for quality improvement in industry.

Considering the "Process/Industry" as a classification criterion, the published studies are relevant with certain industries or processes involved as far as the observed failure mechanism is concerned (Figure 3). More specifically, the main industrial processes involved are presented as follows:

(i) Casting and Metal Forming [6,7,11,13,15,19,24–26]
(ii) Machining [12,16,20]
(iii) Chemical/Petrochemical [3,17,21,23]
(iv) Heat Treatment [22]
(v) General Plant Machinery [1,9,18,24]

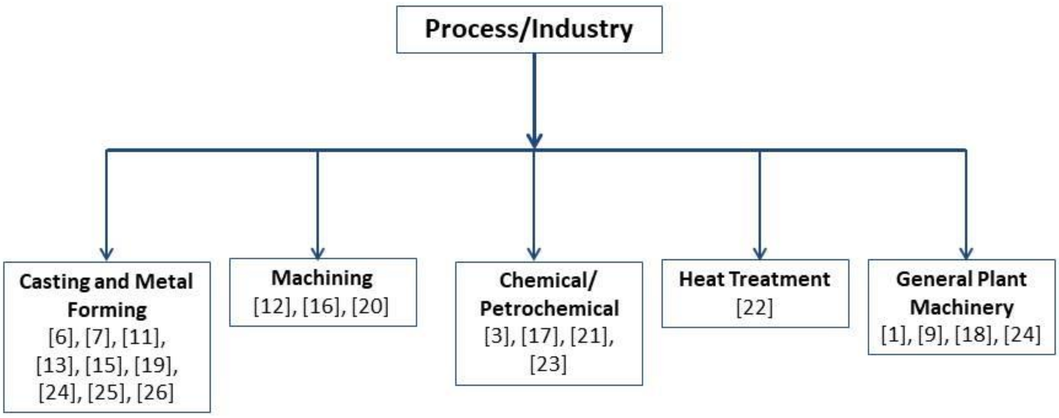


Figure 3. Classification according to the "Process/Industry" relevant criterion, addressed in the studies of this Special Issue.

The metal component manufacturing industry (casting, metal forming, and machining) seems to be highly involved, as one of the primary industrial component production sectors, in highlighting the efforts in understanding material behavior and taking actions for failure prediction and prevention.

Based on the "Investigation Method/Approach", several broad categories can be distinguished (Figure 4):

1. Phenomenological and Experimental [1–9,11–27]
2. Numerical Modeling [6,7,10,12,13,15,25,26]
3. Statistical and Stochastic [8,16,20,22,25]
4. Systems or Quality [9]
5. Combined (experimental, analytical, numerical model, etc.) [3,6–8,12–16,18–20,22,25,26]

As can be readily observed, the experimental and empirical approach is the dominant methodology of failure investigation. In addition, the emergence of numerical simulation, using finite element modeling (FEM), tends to be very popular in the prediction of material behavior and potential failure prevention. The contribution of quality and organization systems is very promising in the case of complex processes, where teamwork in process planning, risk assessment, resource allocation, and implementation of improvement actions is a key concept in modern quality assurance and management.

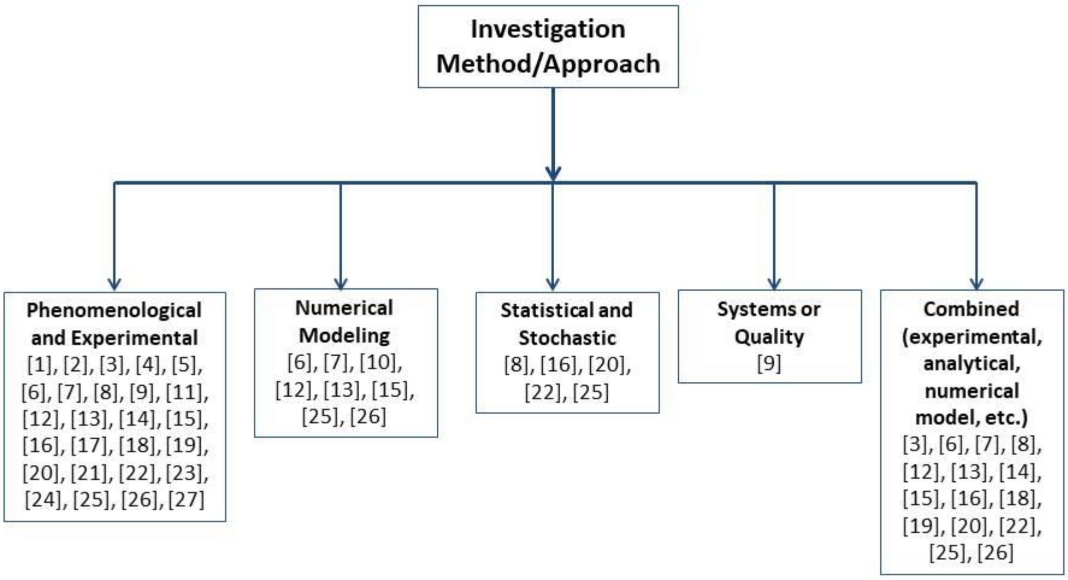


Figure 4. Classification based on the relevant "Investigation Method/Approach" followed in the studies of this Special Issue.

A broad range of materials was covered in the present studies (see Table 1). Ferrous metals (structural steels, stainless steels, and special resistance steels) are more frequently investigated, indicating the importance of this material type in engineering constructions and in severe process environments.

Table 1. Representative types of engineering material types of investigation.

Material Type	Reference
Structural and pipeline steels	[1,5,9,13,16,20,22,27]
Cast iron	[14,19]
Special resistance and stainless steels	[3,4,9,11,17,18,21,23,24]
Wear resistant coatings and surface layers	[24,27]
Ti, Ti alloys	[7,12]
Al alloys	[13,25,26]
Mg alloy	[13]
Cu, Cu alloys	[6,9,10]
Nanomaterials	[10]
W–Cu composite	[15]

3. Conclusions

The present collection of studies reflects the profound interest in the specific field of research, covering a wide range of failure mechanisms, processes, and investigation methodologies. The majority of the studies followed a phenomenological and experimental approach, while it seems that there was a general contribution tendency toward numerical simulation, to further enrich the value of the research results and broaden the application perspectives, especially in the case of larger-scale metal-forming and manufacturing processes. Ferrous alloys (structural, special purpose or resistance, stainless steels, cast irons) constitute the majority of the studied materials, since they are considered one of the principal sources of construction components and are used in various industrial sectors.

On a final note, it is hoped and strongly believed that the accumulation of additional knowledge in the field of failure mechanisms and the adoption of the principles, philosophy, and deep understanding of the failure analysis process approach will strongly promote the learning concept as a continuously evolving process, leading to personal and social progress and prosperity.

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Conflicts of Interest: The author declares no conflict of interest.

Dedication: This Editorial is dedicated to the memory of an exceptional scientist, researcher, academic teacher, and mentor, Dimitrios I. Pantelis, Professor of the School of Naval Architecture and Marine Engineering of the National Technical University of Athens (NTUA), who passed away in October 2019. His legacy of academic, scientific, and human values will stand as a model of inspiration.

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