Fatigue in Materials, A Key Factor in the Lifespan of Structures

Wear and tear of materials are one of the reasons why buildings and structures can collapse and crumble. It is a process of gradual deterioration of the fastening components that can produce small cracks that eventually lead to failure when subjected to cyclical stress. In-depth knowledge of the components, the weights that must be supported, and the structure's geometry are essential factors in preventing possible incidents from the ' 'project's design itself.

Premature failure of mechanisms and a reduction in expected life span are the most immediate consequences of fatigue in construction materials. "Depending on how the component is designed and the material used, sudden breaks can occur, which can cause serious material and personal damage," stressed Isidoro Iván Cuesta Segura, head of the Structural Integrity Group (GIE) at the University of Burgos (UBU).

This is a process in which structural changes occur in the materials in a permanent, progressive, and localized manner at the specific point that is subjected to fluctuating stresses and deformations. These usually result in a break that occurs "suddenly, after the resulting crack has grown to such dimensions that the remaining section is not able to withstand the required stresses." This outcome can be caused by the effect of a continuous load or variable loads.

Material fatigue failures occur in many mechanical systems in various industries, such as automotive, industrial machinery, and electronic equipment. In recent decades, certain incidents have highlighted the importance of this factor in industrial design.

According to the UBU expert, factors that can affect the vulnerability of materials are:

- Stress concentrators (such as welding, drilling, etc.)
- Loads (static or cyclic) applied to the structure (e.g., wind or waves)
- Wearing phenomena, such as corrosion or hydrogen embrittlement. The latter is a phenomenon of great interest at present due to the need to implement renewable hydrogen as an alternative energy source.

Prevention in the design phase

To minimize the effects of wear on structural components, Cuesta Segura considers it essential to have exhaustive knowledge of the fatigue process aspects, such as the materials used, the loads applied, and the geometry. Furthermore, "there are now computer tools that can predict alteration of the material and therefore modify the component in the early design stages." This is the case with finite element analysis, a computer simulation technique used in engineering, which can predict the appearance of cracks, and nonlinear dynamic finite element analysis, which studies unit deformation problems in propagation.

There are now computer tools that can predict fatigue life and modify the component in the early design stages

Specifically, as a preventive measure, companies in the sector try to design with this potential fatigue in mind, integrating different types of treatments to improve their materials' lifespan. "Some of the most common are those that put residual stresses in the component to eliminate or delay the appearance of cracks that result in failure," he stated. A design based on this reduces structural failures, so engineers can concentrate on creating new components instead of correcting inherited errors.

In fact, it is essential to establish proper planning of preventive maintenance since the concept of "damage tolerance" is currently used, which has led to an increase in the safety of components in terms of fatigue. As the head of the Structural Integrity Group explained, "it fundamentally consists of assuming that cracks will appear in our component, but if we are able to quantify how they will grow and the time it will take for them to reach the critical crack, we can continue using it." This requires a prior analysis of the crack growth rate to establish adequate planning of the revision periods to detect possible failures and have the capacity to find small cracks during maintenance.

Lifespan of materials

There are certain parameters that must be taken into account to determine the strength of materials and their safety, and that they affect the fatigue of materials. These can be divided into three phases:

– Initiation. Small cracks begin to appear in the material, generally produced around sources of stress concentration or on the outer surface, where traction fluctuations are higher. This phase is usually the longest of the failure process.

– Propagation. Some cracks start to grow due to the effect of the load. At this point, the cracks' directions change to those perpendicular to the principal stresses.

– Failure. Final fracture occurs when the component cannot withstand the applied stress and the cracks have advanced to such an extent that the net cross-section of the material is unable to support the full load.

Cuesta Segura notes several approaches that determine breakage depending on the available data of the material used and the loads to be applied. The most common model is the use of S-N curves, which are based on the average life of the component or on a given probability of failure for a particular geometry or component, which, through tests applying cyclic loads to the components (rotational bending, traction, torsional cycles, etc.), makes it possible to check the stress level that a material can withstand during a number of cycles.

Commitments for the future

However, the Structural Integrity Group is committed to another more advanced approach, which "is the use of crack propagation laws, where tests must be performed on the material to determine a series of key parameters that can be used to predict the ' component's number of lifecycles." In this field, one of its latest contributions has been the development of software based on design codes capable of predicting failure in components subjected to cyclic loading.

> ***In the coming years, it will be essential to know the fatigue behavior of new materials, especially those coming from additive manufacturing.***

In fact, using technological tools and methods will help engineers to improve component safety and component selection according to the project type, simplifying and reducing the cost of engineering designs, which, together with advances in analysis and process knowledge and testing capabilities, will greatly reduce fractures and, with them, the likelihood of disasters.

Although studying and testing the components most commonly used in construction will continue (such as concrete), in the coming years it will be essential to know the behavior of the new materials that will be used in different construction sectors, both in building and public works and in civil engineering and energy infrastructure processes, especially "those coming from additive manufacturing, since pores are produced in most of the techniques of this new technology inside the component that promote the growth of cracks," the expert acknowledged. "Knowing how they interact with each other and how they can be prevented or mitigated by applying new post-processing techniques will be key to achieving adequate fatigue lives," he concluded.

Phases of the fatigue life of materials

Fatigue of Structures and Materials. J. Schijve

Article collaborator:

Isidoro Iván Cuesta Segura is a professor in the area of Mechanics of Continuous Media and Theory of Structures at the University of Burgos (UBU) in the Department of Civil Engineering.

He is a member of the Spanish Society of Structural Integrity and, since its creation in 2001, of the Structural Integrity Research Group (GIE) of the UBU, which he currently directs. He is also part of the Consolidated Research Unit UIC163 of the Region of Castilla y León. His field of research focuses on fracture mechanics, fatigue, and numerical simulation of materials and components, as well as additive manufacturing.

He holds a degree in Industrial Technical Engineering and Industrial Organization Engineering from the UBU, where he also obtained a PhD in Civil and Industrial Engineering.