FRACTURE AND THE LIMITATION IT PLACES ON TECHNOLOGY: FROM LITHIUM-ION BATTERIES TO MEDICAL IMPLANTS

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Abstract

New technologies often bring along new fracture issues as they develop, or they place a renewed focus on some existing aspects of fracture. For example, electronic packaging, as it developed as a technology, led to a renewed focus on fracture caused by thermal stresses and thermal expansion mismatch. It also required much research on cracks at the interface between two materials, layered systems and channel and mud cracking. More recently, the development of lithium-ion batteries caused extensive work on fracture due to lithiation swelling in electrode storage particles and on crack-like lithium filament growth in solid electrolytes. Medical implants require much attention to fatigue fracture in their design, and utilization of some materials including Nitinol has brought forward new research on fatigue failure and its mechanisms. The highly variable human physiology causes the implants to be in diverse conditions and environments, leading to a renewed focus on reliability engineering for fatigue failure.

1. Overview

The International Congress of Fracture community is well aware of the limitations that fracture places on technology, as it has focused on that aspect of the subject from the beginning. Civil infrastructure, transportation platforms, and machines of all type are prone to fracture, whether by fatigue or due to excessive stress, and a significant element of the design process, and of the resulting design itself, focuses on avoiding fracture. While the impact of fracture on technology, and the resulting limitations, is an age-old problem, what is of significance is that new technologies bring along new aspects of the fracture issue, or cause greater emphasis to be placed on one attribute or the other of the subject of fracture in engineering systems.

Electronic packaging for microelectronics and similar devices brought along a renewed emphasis on fracture due to thermal expansion mismatch, but also required extensive novel developments for the understanding of cracks at the interface between 2 different materials. The importance of electronic packaging also brought on an emphasis on fracture in layered materials, it highlighted novel behavior such as channel and mud-cracking, and new phenomena such as electromigration led to the voiding and the severing of vias and lines.

In a related area, electrochemical energy storage systems, such as lithium-ion batteries, have brought forward novel aspects of fracture, such as the cracking and fracture of electrode storage particles due to lithiation swelling. This phenomenon leads to the sequestering of lithium, leading to capacity fade, and enhancement of internal resistance, causing voltage fade. Storage material fracture is also one of the features of lithium-ion batteries that limits fast battery charging, as rapid operation of the battery induces a greater degree of storage particle fracture. The objective of utilizing all solid-state batteries is being inhibited by a form of fracture, namely the growth of lithium metal filaments into solid electrolytes. These filaments ultimately connect between the cell electrodes, causing short-circuiting and battery failure.

Prosthetic medical implants, such as synthetic heart valves, stents and inferior vena cava filters, are all potentially prone to fatigue fracture of their metal components. While fatigue fracture of most metals used in implants, such as stainless steel, titanium alloy and cobalt-chrome systems, is very well understood, the use of novel materials such as Nitinol, a shape memory alloy, complicates the fatigue fracture behavior. A significant issue in implants is the great variability in the environment faced by the device, as the human physiology is so diverse. In some cases, such as prostheses for the aortic valve, the conditions to be experienced are quite predictable, but still within a range of conditions. However, in other applications, such as inferior vena cave filters, the conditions experienced by any given implant is very difficult to predict. This raises a renewed emphasis on design against fracture by statistical reliability methodologies.

2. Outlook

What will the future bring? That is very uncertain. However, what is clear is that many new technologies that come along will bring about new fracture issues and a renewed emphasis on some specific aspects of the fracture vulnerability of engineering materials.

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