Fatigueless structures inspired by nature: A case study

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Abstract

Biomimetic has begun to offer significant potential in providing unique solutions in materials science. However, the full potential of mimicking natural systems can be fully exploited only if we start to look the problem of design of complex structures from the structural side. The present short letter is focused to investigate a simple case study to show the possibility of achieving an ideally fatigueless design inspired by nature. Materials cannot be immune from fatigue, but structures can. This case study is aimed to discuss a preliminary example.

1. INTRODUCTION

Biomimetic has mainly been font of inspiration for developing new materials, but the knowledge on its application with a structural/mechanistic perspective is just at the early stage.[1, 2] Natural objects are unique because they are practically fatigueless (butterfly and bird wings, trees under wind, and fish skeleton) and they can last long without any damage under cyclic loading due to their smart design following the principle of "flectar non flangar." Learning by nature in a systematic way will lead to build functional structures with long-term perfection and optimized in weight and shape. Materials cannot be immune from fatigue, but structures can. Dealing with biomimetic fatigue design, there are only very few but illuminating papers in the recent literature.[3, 4] Taking inspiration from the junction of a trunk and a branch and to the optimized design of a variable nonconstant notch radius, it has been recently shown in some preliminary investigations that the fatigue behavior can be substantially improved in the direction of an ideally fatigueless design, where the failure limit is only given by the material and not by the structure.[3] Spider draglines exhibit a fatigueless response under extreme cyclic torsion conditions at different scale levels.[4] This unique twist response of draglines could find applications in durable and biocompatible miniatured devices. These recent illuminating studies have convinced me and my research team to focus on these very challenging problems. By exploiting the idea of designing fatigueless structures, the probability of failures due to cyclic loadings in real structures and components can be drastically be reduced.

2. RESULTS

The case study investigated herein is the joint between the peduncle and receptacle in sunflowers. Looking to the radius of curvature (Figure **1**), it is evident that is not constant but nature tends to optimize it to achieve the better resistance under cyclic conditions for example under wind loading. We compared experimentally a semicircular configuration with a constant radius and that inspired by nature with a variable radius (Figure **2**). We produced two series of specimens made of Ti6Al4V by using selective laser melting (SLM) process. Both series have been built with the same process parameters. The nature-inspired specimens have shown a much higher fatigue resistance with respect to the specimens with a constant edge radius (Figure **2**). In natural-inspired specimens, fatigue failures initiated not from the notch but from the internal defects of the material validating and proving the idea of an ideally fatigueless structure (Figure **3**). For fatigueless optimized structure, the failure is mainly due to the limitation of the material while the structure is ideally not affected or optimized against fatigue.

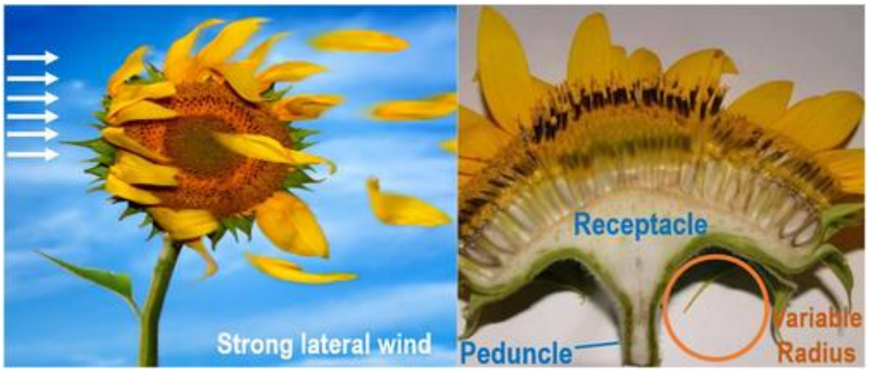

Figure 1: Joint between peduncle and receptacle in a sunflower

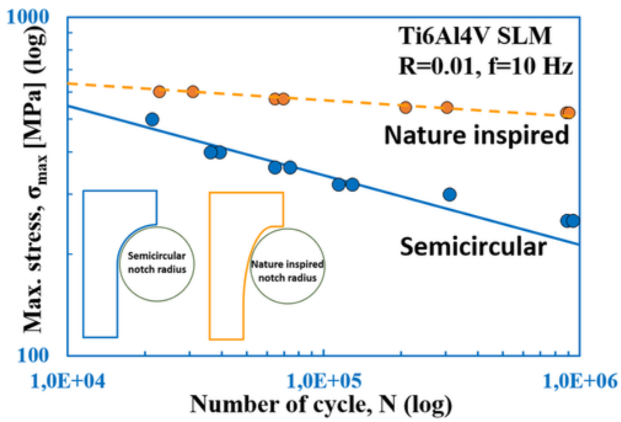

Figure 2: Fatigue results and comparison between a constant notch radius and a nature-inspired radius

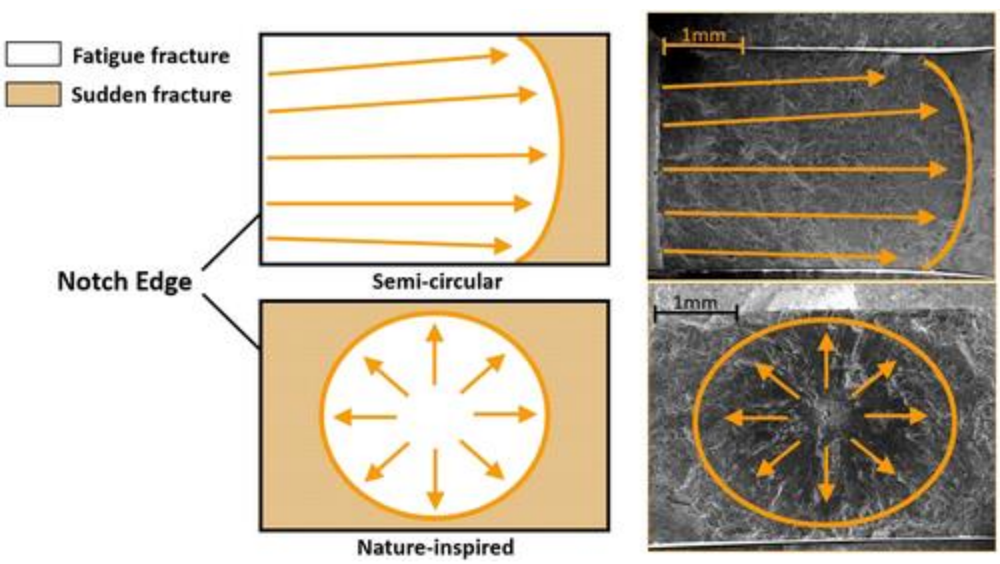

Figure 3: Different initiation sites for specimens with a variable radius (nature inspired) and specimens with a constant radius

3. CONCLUSIONS

A simple case study has been used to validate the concept of fatigueless design of a structure. Learning by nature, translating and formalizing this knowledge to mathematical/mechanics/physics models is a virtuous path that can open completely new horizons in structural design revolutionizing the current state of the art making a jump up to now impossible to do. The topology of the structure will be driven by a smart local fatigueless design more than a global stiffness maximization revolutionizing the concept of topology optimization.

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