Self-Healing Metal
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Abstract

Self-healing has always been an attribute associated with living organisms, while unknown to man-made materials. In the last 15 years, researchers have had the most success with polymers, as they are the most malleable of the material groups. However for metal, one of the most important materials in society today because of its particular chemical properties, self-healing has remained an unattainable characteristic due to these same properties, at least until now. Recent research, done by graduate student Guoqiang, and professor of material science and engineering Michael Demkowicz, both at MIT, have discovered the key to self-healing metals. When under tension, the nickel alloy they were testing healed itself. This occurred due to migrating grain boundaries in the nickel, which migrated to fill the crack. These migrations can occur when under any applied pressure, though only when disclination is present. It is still in the testing phase, but when fully understood and perfected this would be instrumental in making deep sea oil wells much safer from leakage as well as having an infinite other possible applications.
Introduction

Healing is a long process involving doctors, medicines and machines for humans and a lot of ingenuity or replacement parts for manmade objects. However, where generally a human body can heal itself if part of it is damaged, man-made materials cannot. Just think if that torn piece of metal that was once a car door healed the same way a finger does when cut. It’s an insane idea right? Not anymore. Recent research, published in 2013 at MIT by graduate student Guoqiang and professor of material science and engineering Michael Demkowicz, just might make that situation a reality in the foreseeable future [1].

Previous Research in Self-healing materials

Over the last 15 years, there has been a lot of research going into self-healing materials. The easiest specimens to study and understand to date have been the polymers, and consequently, most of the research is focused on them. Polymers are generally susceptible to chemical changes, which have been mainly implemented through the use of microcapsules, or micro scale chambers used to hold chemicals. The microcapsules release chemicals used to heal the polymer when mechanical damage occurs [2]. Moving from the study of polymers to the study of metals, the results have not been as promising. However, recent research has shown that grain boundaries and disclinations are instrumental to understanding how metals can self-heal. A grain boundary refers to a region separating two crystals (grains) in a crystalline structure [3]. Disclination is a defect in a crystalline
structure where a boundary extends only partway into a grain [1]. Below, Figure 1 shows a visual representation of grain boundaries and disclination defects.

![Figure 1: In the picture the grain boundaries are represented by GB and the disclination defect is represented by Disclin. [4]](image)

A previous research paper in metals dealing with grain boundaries and disclinations, states that “disclinations create high local stresses capable of initiating the formation of nanocracks” [5]. Disclinations are therefore usually considered defects, which are harmful to the metal.
MIT’S Discovery [1]

It is well known that accidents in labs can lead to life changing breakthroughs in science. That’s where penicillin came from, after all. So why not have an accident that helps science take a major step forward? In fact graduate student Guoqiang and professor Michael Demkowicz thought they had made a mistake when they became the first people to discover that metal is able to self-heal. They were analyzing how a crack developed in nickel under tension, when the metal healed while being pulled apart. Further baffling the researchers was the fact that the material had done so with no help from them, something even polymer research has been unable to accomplish. History was made, and unintentionally so.

How it works

Upon realizing that their results were in fact real, the next question was to understand how they worked. As Demkowicz explained [1], “We had to go back and check, instead of extending. [the crack] was closing up. First, we figured out that, indeed, nothing was wrong. The next question was: ‘Why is this happening?’” The answer to this question appeared when a closer look was taken at the grain boundaries in the crystalline microstructure of the metal. In this case the metal was nickel, which is the key element in super alloys used in applications such as deep-sea oil wells. The grain boundaries of the nickel appeared to migrate when pressure was applied to pull them apart. This migration moved the grain boundaries so that they actually closed up the crack. This phenomenon was carefully documented in a video that shows the crack healing as the nickel alloy is slowly pulled apart. To view
this video you can visit [http://www.youtube.com/watch?v=E9poznjfOLA](http://www.youtube.com/watch?v=E9poznjfOLA) [6]. A progression of stills are shown below in Figure 2.

![Figure 2: Stills from a video showing the Ni under tension. Progressing from top left to bottom right, the crack can be seen in the bottom middle [6].](image)

The grain boundary migration is very specific in metals and can only occur if a disclination defect is present [1]. Disclinations have been known and viewed as a curiosity for almost a century. Indeed, the MIT researchers didn’t even know that that was what they were looking at initially [1]. Further, as seen in the previous research, disclinations were viewed as harmful defects to metal crystalline structures [5]. However, the fact that disclinations have strong stress fields, which caused previous researchers great worries, is what reverses the effects that are applied to crack metal, and therefore heal it [1]. Essentially, the stress is so high that it turns in on itself and fuses the metal together [1]. The reason why disclinations cause such high stress points in the metal is not clearly documented anywhere,
however it is mentioned in every paper as being present. The reason for the lack of
documentation may be because they were not considered important until now.

Further Study Needed

Now that the full import of disinclinations are known, serious study can be
made in to how to manipulate them for our purposes today. Researchers are now
looking in to how different alloys are affected by this effect and how they can design
a material so that it is an intrinsic property [1]. This study will take a lot of careful
research and may therefore take several years. But now that the initial
breakthrough has been made researchers hope to implement everyday applications
in the foreseeable future.

Applications

As stated earlier a very practical application for self-healing metal would be
in deep-sea oil wells as well as numerous other structures that operate under high
pressure. By understanding disinclinations, other types of damages commonly seen
in metals such as plastic flow instability, being the compromising of structural
integrity due to shape or density deformation, and metal fatigue could be helped or
slowed [1]. These types of damages occur in aircrafts, oil wells, cranes, and many
other important industrial devices [1]. More specifically, think of a deep-sea oil well
constantly under pressure; this discovery could hopefully make oil leaks into the
ocean a thing of the past. The potential of this new field is limited only by
imagination.
References:

http://web.mit.edu/newsoffice/2013/tension-can-fuse-metal-1009.html,  


[6] MIT. “Self-healing metal.” Internet:  