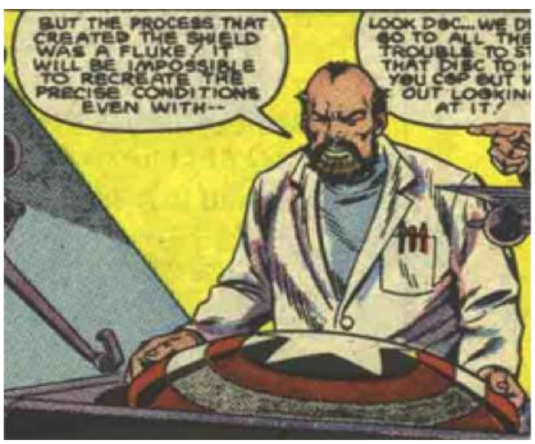
The Making of Captain America's Shield

Realizing a Future of "Indestructible" Materials though State-of-the-Art Synthesis and Processing Tools and Characterization Strategies

by Suveen N. Mathaudhu

In July 2011, Paramount Pictures will release "Captain America: The First Avenger" as a feature film. This movie is based on a Marvel Comic initially released in 1941, which tells the story of Steve Rogers, a weak man who is transformed into a super-soldier by an experimental serum injection. Captain America's purpose was originally to serve as a super-weapon for the United States against the Axis powers of World War II. Two things which have been ubiquitous to Captain America in the comics, TV shows and movies that have spun-off are his patriotic red, white and blue uniform and his "indestructible" shield [Captain America Comics, #1, *Marvel Comics,* 1941].



Dr. Myron MacLain explaining his accidental synthesis of vibranium alloy © Marvel Comics

Through retroactive continuity of the comic book series, we know some details about the making of this shield. It was fabricated in part from the fictional meteorite element, "Vibranium", which has the unique properties of being able to absorb all kinetic energy directed at it, [Captain America #303-304, *Marvel Comics,* 1985]. Dr. Myron MacLain, a government metallurgist, had been tasked directly by President Roosevelt to develop indestructible tank armor. The material was created when MacLain fell asleep during his experiments, and the vibranium and iron bonded mysteriously into an indestructible alloy; the exact composition and processing strategies would forever remain a mystery. The disc form, based on the material being cast into a tank hatch mold, was given to Captain America to serve as his shield.

Seventy-years after President Roosevelt tasked Dr. MacLain with creating a new indestructible material, we are still searching for ways to synthesize and process materials with the ability to absorb or channel kinetic energy. From a materials science perspective, this can be accomplished by concurrent increases in strength and toughness [Ritchie, R.O., "The quest for stronger, tougher materials", *Science*, 320, 2008]. The ability to make such materials has been significantly enhanced by a number of recently developed tools.

Firstly, the ability to create such unique materials has been facilitated by the capability to engineer microstructures and process materials under extreme yet precise conditions to obtain novel and far-from-equilibrium microstructures. A very recent example is the synthesis of world-record toughness bulk metallic glass [Demetriou et al., A damage tolerant glass, *Nature Materials*, 2011]

Secondly, the development of serial-sectioning electron back-scatter diffraction (EBSD), and x-ray or atom-probe tomography methods have enabled three-dimensional reconstruction of nano- or microscale features which critically control macroscopic behavior. At the same time, tools such as high resolution transmission electron microscopy (HRTEM) and atomic force microscopy (AFM) have enabled visualization of features and phenomena at scales considered unreachable even a decade ago [Liddicoat, P.V., "Nanostructural hierarchy increases the strength of aluminum alloys", *Nature Communications,* 2010].

Lastly, computational materials science for process simulation and design has been tremendously enhanced with the meteoric growth of computing power and speed. The worldwide acceleration of integrated computational materials engineering (ICME) has enabled more detailed understanding of the complex effects of processing on the resultant microstructures, and thus the enhanced properties [National Materials Advisory Board, "Integrated computational materials engineering: a transformational discipline for improved competitiveness and national security", The National Academy Press, 2008].

In the "real" world, Dr. MacLain would have told President Roosevelt that an indestructible material was physically impossible, but nonetheless, as a process metallurgist, he very likely would have used some combination of all of these tools to make the alloy. The vision of the ARO Synthesis and Processing program is to facilitate the discovery and illumination of *processing* – *microstructure* – *property* scientific linkages for optimal creation of superior structural materials through creative combinations of the tools and strategies presented here. ARO seeks white papers from those who think they can meet this vision, and perhaps, approach the property limits envisioned only in comic book realms.

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