National Aeronautics and Space Administration

TECHNOLOGY SOLUTION

Materials and Coatings

Self-Healing Aluminum Metal Matrix Composite (MMC)

Repairs Large Cracks and Reverses Fatigue Damage in Structural Metal

Fatigue endurance is critical for the airworthiness of civilian and military aging aircraft and for long-duration flight and deep space missions. Estimates are that 90% of structure failures are due to fatigue. NASA has developed a new metal matrix composite (MMC) that can repair itself from large fatigue cracks that occur during the service life of a structure. This novel liquid-assisted MMC recovers the strength of the structure after a healing cycle. The MMC contains both shape memory alloy (SMA) reinforcements and some low-melting phase components which, when heated, essentially clamp the crack edges back together and flow material into the crack's gap for a high strength repair. While current crack repair methods exist, such as doublers or welding overlays, these methods require complex surface prep and bonding, which can be difficult and may result in a region of decreased strength. The new material allows for the repair of fatigue cracks without additional materials or human interaction.

BENEFITS

- Enables Safety: can potentially heal fatigue cracking, helping avoid catastrophic failure of a structure
- Improves Fatigue Endurance: enables crack repair during flight or service to extend the life of structures
- Solves Hard-to-Access Repairs: works where a crack location is difficult to reach or common repair techniques are not applicable
- Reduces Labor and Materials Requirement: works with applied heat; no additional materials or human interaction/labor are needed.

APPLICATIONS

The technology has several potential applications:

- Aeronautics: aircraft structural components such as fuselage skin, stingers, frames, ribs, longerons, stiffeners, doors, tanks, wheel wells, fuel lines, shock struts, and floor beams.
- Commercial Space: spacecraft structural components for longer missions where current repair technologies like welding and bonding are not an option
- Oil & Gas: for repairing cracks in oil-well casings

THE TECHNOLOGY

This materials system is comprised of an Al metal matrix with high-performance SMA reinforcements. The combination of the unique matrix composition and SMA elements allow for this material system to self-repair via a two-step crack repair method. When a crack is present in the matrix material, the MMC is heated above the SMA's austenite start (As) temperature. This initiates shape recovery of the SMA, pulling the crack together as the SMA reinforcements return to their initial length. Concurrently, the increased temperature causes softening and liquefaction of the eutectic micro-constituent in the matrix, which enables the recovery of plastic strain in the matrix as well as crack filling. Combined with the crack closure force provided by the SMA reinforcements completely reverting to their original length, the MMC welds itself together and, upon cooling, results in a solidified composite able to realize its pre-cracked, original strength. The research team has demonstrated and tested the new materials. The team induced cracks in prototype materials based on Al-Si matrix with SMA (NiTi) reinforcements and demonstrated the recovery of tensile strength after healing. Data from tensile and fatigue tests of the samples before and after the fatigue crack healing shows a 91.6% healing efficiency on average under tensile conditions.

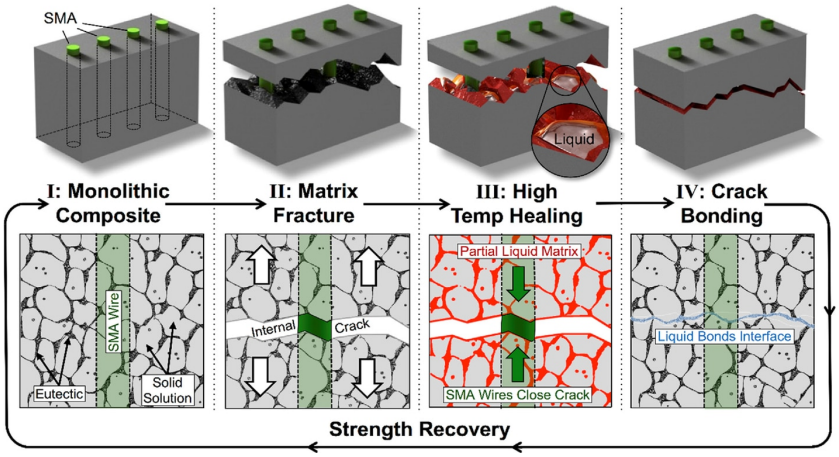
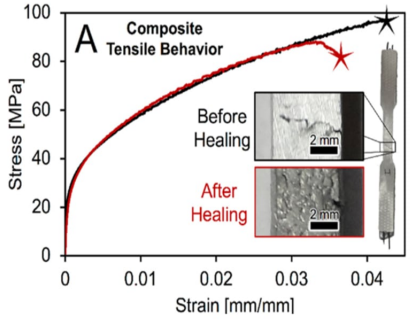


Fig. The healing cycle for liquid-assisted self-healing metal-matrix composites. The system consists of a metallic matrix with a eutectic micro-constituent shown in black and reinforcing SMA wires shown in green (I). After catastrophic failure, the SMA wires deform to bridge the crack (II). To heal the sample, a high temperature healing treatment is initiated, during which the eutectic component melts and SMA wires close the crack (III). During cooling, the eutectic component freezes, welding the crack surfaces and eliminating the crack (IV).



This graph shows the stress/strain data for the mechanical testing of the sample. Note the inset macro-images correspond to the before and after healing heat treatment of a crack along the dog bone-shaped specimen.

PUBLICATIONS

Patent No: 10,597,761

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