Materials Science & Engineering A 619 (2014) 73–76

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Rapid communication

Al-shape memory alloy self-healing metal matrix composite

P.K. Rohatgi *

Materials Science and Engineering Department, University of Wisconsin-Milwaukee, 3200 N. Cramer St., Milwaukee, WI 53201, USA

ARTICLE INFO

Article history:
Received 30 April 2014
Received in revised form
27 August 2014
Accepted 10 September 2014
Available online 19 September 2014

Keywords:
Metal matrix composites
Shape memory alloys
Self-healing materials

ABSTRACT

Deformation and fatigue in aluminum can lead to catastrophic failure. Aluminum's survivability may be improved by reinforcement with Shape memory alloy (SMA) wire, so cracks do not completely separate, and heating can return the component to its original shape. This work investigates incorporating NiTi SMA wires in an Al-A380 matrix.

1. Introduction

Though self-healing of metals could potentially find many applications, it is a daunting task. To date most research conducted on self-healing metals has focused on either solid-state diffusional healing of microcracks, or Shape Memory Alloy (SMA) reinforced "off-eutectic" matrices. Dynamic precipitation as a method of self-healing has been investigated by Lumley [1], Djugum et al. [2] and He et al. [3,4]. Though this method has shown some promise in preventing creep damage and healing microcracks, this method is unlikely to be able to be applied to macroscopic damage.

SMA-based metal matrix composites (MMCs) have been investigated and thermally-activated healing has been accomplished using a low melting point matrix. However, in higher melting point alloys that are prone to oxidation, this technique has been less successful. Manuel and Olson fabricated 1 vol% continuous uniaxially aligned NiTi SMA wire proof-of-concept composites using Sn–13 at%Bi and Mg 5.7 at%Zn–2.7 at%Al as matrix materials [5,6]. To demonstrate healing efficiency, tensile tests were performed on the composites at room temperature to the extent that the matrix had fractured but the unbroken SMA fibers still bridged the gap. Damaged specimens were then heat treated in vacuum to heal the damage and then again tensile tested to failure to determine the amount of strength recovery. Sn–13 at%Bi healed samples achieved ultimate tensile strength greater than 95% of the undamaged material, but suffered a reduction in uniform ductility possibly due to oxidation and/or embrittlement of the crack surfaces during healing. In Mg 5.7 at%Zn–2.7 at%Al samples it was found that though the SMA wires pulled the crack closed, the rough crack walls prevented full closure and the force applied by the SMA wires could not overcome the matrix strength. Poor wetting of the reinforcement and low strength of the interface were also identified as deleterious to the performance of composites castings.

Attempts have not yet been made to synthesize or heal Al/SMA MMCs. Because of the widespread use of aluminum, any successful healing method would likely have a significant impact on the design, manufacture, and use of these types of components. However, there is a significant practical difficulty in that the rapidly formed oxide layer prevents effective joining of the damaged surfaces. The recovered mechanical properties of healed aluminum alloys will depend on the interface bonding, any residual porosity in the damaged area, changes to precipitation condition (if a heat treatable alloy), the degree of recovery and/or grain coarsening, and the degree to which heating and cooling procedures relax or impart residual stresses. Notwithstanding the above considerations and the fact that healing of the component may require removing it from service in some cases, healing it, and then reinstalling the component, the technique requires only the application of heat, and thus has the potential to be used on a wide range of components. In other words, one need only possess a source of heat rather than store a large number of replacement parts on hand or have replacement components delivered from some centralized warehouse. In certain cases the cracked component may remain in place and only the application of heat near the cracked region may be necessary to pull the crack surfaces together.

2. Experimental procedure

Aluminum Alloy A380 (Al–8Si–3.5Cu) acquired from NT Ruddock (Bedford, Ohio) and .5 mm diameter Flexinol NiTi actuator

* Tel.: +1 414 229 4987; fax: +1 414 229 6958.
E-mail address: prohatgi@uwm.edu

http://dx.doi.org/10.1016/j.msea.2014.09.050
0921-5093/

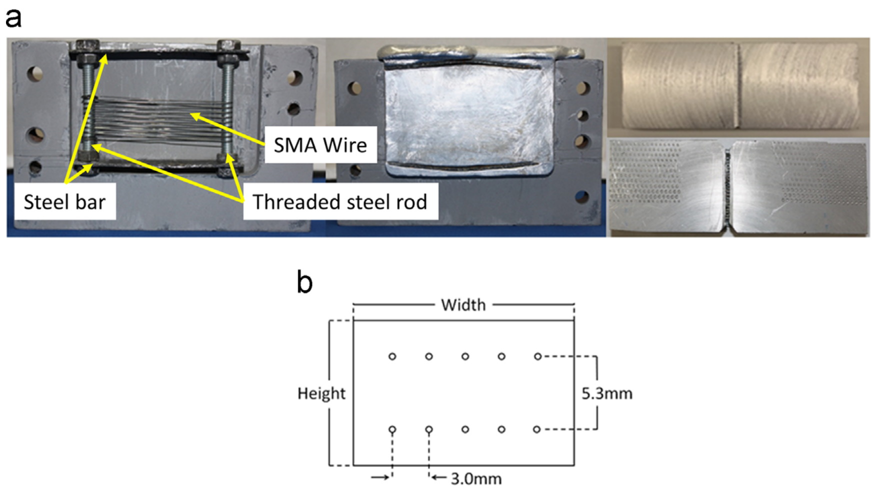

Fig. 1. (a) Synthesis of Al-A380/NiTi SMA (left and center) notched before and after cracking sample (right) and (b) (lower) schematic of reinforcement arrangement.

Table 1
Sample conditions and variation.

Number of fibers	Sample size			Test temperature (°C)	Crack width (mm)	Time to SMA activation (s)	Crack closure duration (s)	Rate of crack closure (mm/s)
	Length (cm)	Height (cm)	Width (cm)					
56	10	1.2	4.4	235	4.32	505	345	.0125
34	10	1.2	2.7	235	3.56	237	115	.0310
28	10	1.2	2.5	300	3.81	248	105	.0363
2	10	1.2	3.9	235	3.88	60	170	.0228
1	10	1.2	3.0	235	3.25	50	200	.0163

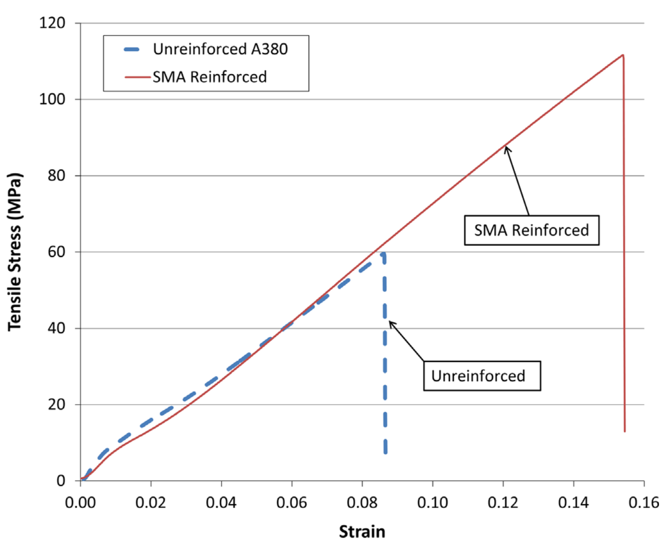

Fig. 2. Tensile stress–strain curve for 100 cm × 3.8 cm × 1.2 cm notched sample containing 0 and 58 wires.

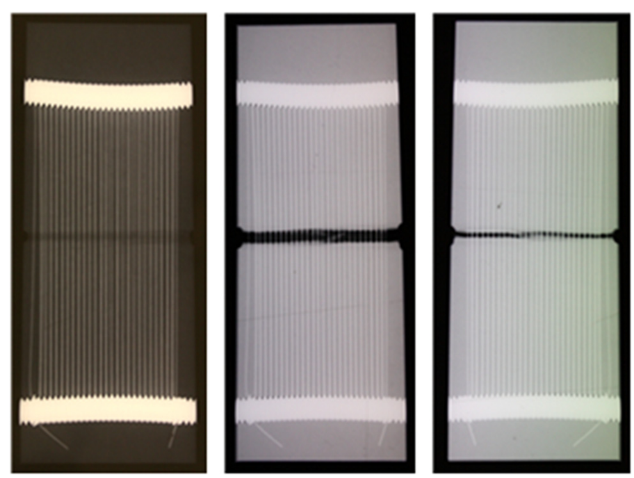

Fig. 3. Sample X-ray: (a) before fracture, (b) after fracture, (c) after heat treatment. The bright threaded rods running vertically on the left and right of each image are the threaded steel rods that remained in the test bars during testing.

wire having an austenitic temperature of 90 °C manufactured by Dynalloy (Tustin, CA, USA) were used to synthesize 10 cm × 1.2 cm samples of various widths. Threaded steel rod having a diameter of 5 mm and 2 cm × 2 mm steel bars were used as a frame to create the wound SMA preform and ensure uniform spacing. The "SMA preform" that is thus created by wrapping SMA wire around the frame of threaded steel rods is shown in the left-most image of Fig. 1a. The Al-A380 was melted at 950 °C in a BN-coated graphite crucible and poured into a steel mold containing the SMA preform. Both mold and preform had been preheated to 150 °C. The sample was sectioned to remove the steel bars. Because of poor wettability between the SMA wire reinforcement and the A380 matrix, the Al/SMA interface is poor and does not allow for effective load transfer. Therefore the threaded steel rods were left in the test bars to transfer the load caused by the shrinking of the thermally-activated SMA wires to the matrix.

A 45° V-shaped notch approximately 1 mm deep was machined around the entire perimeter in the middle of the sample to act as a crack guide and the sample was tensile tested to failure using a SATEC Model 50Ud Universal Testing Machine at constant