A SELF-HEALING SYNTACTIC FOAM UNDER MULTIPLE IMPACTS

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Introduction

Syntactic foams have evolved from being used as buoyancy, insulating and cushioning materials (1960s), to structural composite sandwich cores in many military and civilian applications since early 1990s [1]. It is well reported that these sandwich constructions are susceptible to low velocity impact damages, which results in a very low post-impact load bearing capacity [2]. Recently, many studies have aimed at healing damage in polymers at a microscopic level by incorporating capsules/fibers with healing agents [3]. Limitations like release of excess healing agent, inability to heal damages multiple times etc. made researches think of employing a shape memory polymer (SMP) with the unique property of shape memory effect (SME) [4] in healing the damage. The driving force for shape recovery is the increase in conformational entropy of the polymeric chains when heated above the glass transition temperature (T_g) of the SMP. This study addresses the use of a unique SMP as the polymeric matrix for synthesizing a glass microballoon based syntactic foam and studying its shape memory functionality to heal structural scale damage caused due to multiple low velocity impact events.

Materials and Experimentation

The syntactic foam was fabricated by dispersing glass microballoons (Potters Industries Q-cel 6014: effective density of 0.14g/cm^3) and multi-walled carbon nanotubes (Cheap Tubes Inc.: density of 2.1g/cm^3) into a shape memory polymer matrix (polystyrene, CRG industries, T_g of 62^{o}C). Nanotubes were dispersed using an ultrasonic probe and a three-roll mill. The foam was poured into a closed mold and cured at 75°C for 1 day, 90°C for 3 hours and 100°C for 3 hours. The core was sandwiched between two woven glass fabrics using a vacuum assisted resin infusion method (VARIM) as in Fig.1. After curing, the sandwich was machined to 152.4mm × 101.6mm × 12.7mm specimen and was subjected to a low velocity impact at the center using an Instron Dynatup drop tower, followed by a free recovery (unconstrained healing) done in an industrial oven at 100^{o}C for 3 hours. After recovery, the sample was impacted and healed again until seven rounds. Compression after impact (CAI) and compression after impact and healing tests were also performed to evaluate the residual load bearing capacity of the sandwich structure. Ultrasonic inspection (UltraPac) was performed on all specimens both before impact and after impact for each impact-healing cycle using a 1MHz transducer.

Results and Discussion

The maximum impact force, maximum deflection, impact duration, initiation energy, and propagation energy after each impact are summarized in Fig.2. It can be noticed that the impact response is statistically the same for each round of impact. This suggests that the damage induced by each impact has been effectively healed by the shape recovery process. Typical CAI stress-strain curves are shown in Fig.3. The variation of yield strength values with seven rounds of impact and healing is depicted in Fig.4. The CAI yield strength after the 1st impact is about 83.9% of the original yield strength without impact (control specimens, 12.23MPa); after 1st healing, the yield strength is about 93.8% of the original strength. This suggests that the self-healing has recovered a major portion of the lost strength. After the 7th impact, the CAI yield strength is about 94.9% of the original yield strength; after the 7th healing, the residual strength is about 113.6% of the original yield strength. This suggests that after 7 rounds of impact-healing cycles, the sandwich specimens are actually gaining some strength. The impact damage and healing of the damaged area after each round of impact can be visualized by a C-scan in Fig. 5 and the damage healing/crack closure at micro length-scale can be observed by the SEM image in Fig. 6.

Acknowledgement

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References

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Fig.1 Vacuum Assisted Resin Infusion Method

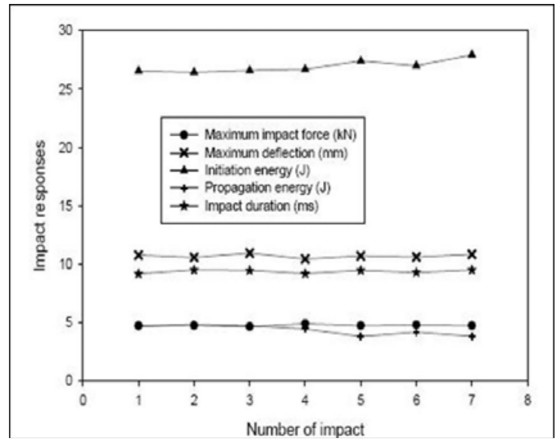

Fig.2 Impact response of the smart foam cored sandwich panels under multiple impacts

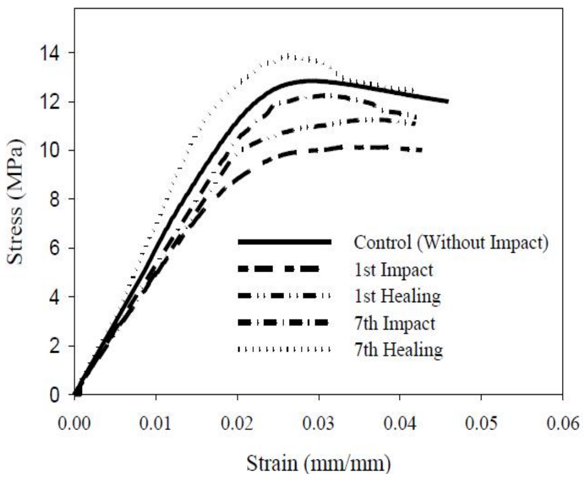

Fig 3. Typical CAI stress versus strain plots for various impact and healing cycles

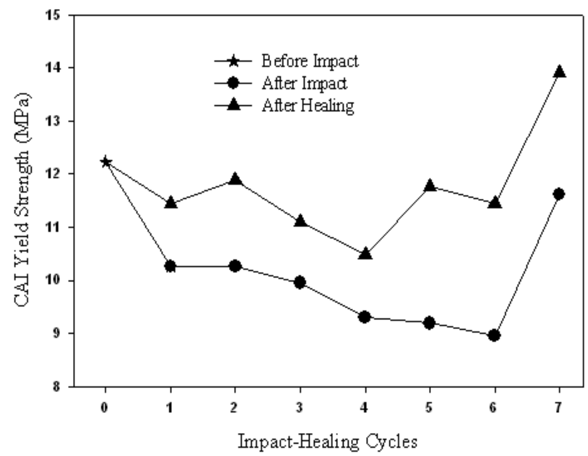

Fig.4 Variation of CAI yield strength with impact-healing cycles

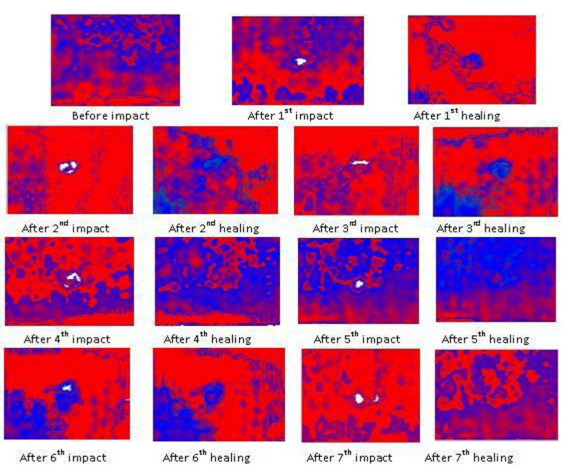

Fig. 5 C-scan images of the sandwich panels after each impact and healing cycle

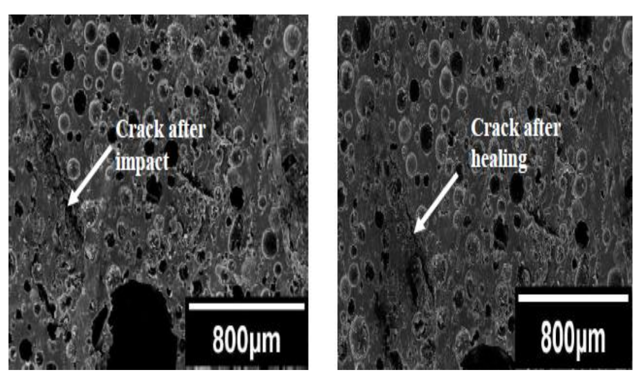

Fig.6 SEM pictures showing the effect of healing on the microcrack