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The role of shape memory alloy on impact response of glass/epoxy laminates under low temperature

K. W. Kang[1,*], H. J. Kim[2] and J. K. Kim[3]

[1]*Department of Sports Engineering, Korea Institute of Sport Science, Seoul, Korea*
[2]*Korea Railroad Research Institute, Gyeonggi-Do, Korea*
[3]*Department of Mechanical Eng., Hanyang University, Seoul, Korea*

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Abstract

The paper aims to evaluate the impact response of glass/epoxy laminates with embedded shape memory alloy (SMA) subject to low velocity impact at various temperatures. For the goal, the impact tests were performed by using an instrumented impact-testing machine at three temperatures: 293K, 263K and 233K for the baseline (laminates without SMA wires) and SMA laminates (laminates with embedded SMA wires). And the resultant damages were inspected through the scanning acoustic microscope (SAM). Also, based on the impact force history and the damage configuration, the impact resistance parameters were employed to evaluate damage resistance of laminates with embedded SMA wires. As a result, it was observed that the damage resistance of glass/epoxy laminates is influenced by embedded SMA wires and embedding SMA wires into laminates does not compromise the structure any differently to laminates without wires. In fact, it has been shown that under lower temperature, the SMA laminates have a little superior damage resistance compared with the baseline laminates.

Keywords: Glass/Epoxy laminates; Shape memory alloy; Low velocity impact; Impact resistance

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1. Introduction

Composite materials offer numerous advantages over more conventional materials because of their superior specific strength and stiffness. The use of composite materials has become increasingly common in a wide range of structural components and engineering application such as in high speed train, aerospace, marine and sports engineering [1, 2]. Many such applications involve components that are subjected to various loadings and these can cause damage, degradation of material properties and eventually the premature failure of the structure [1, 2]. There is currently an increased interest in the application of the composite materials with embedded shape memory alloy (SMA laminates) to control or relax the damage in composite materials [3, 4].

An important factor whether SMA composite materials can be used reliably in daily structures is the behavior of the composite materials during impact. Composite structures in general are susceptible to a wide range of damage and defect which are produced during manufacture as well as during service [5]. Impact damage is one of the main problems that composite structures face and there is a possibility to have impact damage during service. Hence, a reasonable way of reducing such damage should be determined so that the integrity of the structure is not compromised. One possible way to increase impact damage resistance of composite structure is by embedding SMA wires into composite structures. Although the SMA wires embedded within the layers of composite structures can enhance their resistance

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[*]Corresponding author. Tel.: +82 2 9709550, Fax.: 82 2 9709593
E-mail address: kwkang68@daum.net

to low velocity impact, the impact resistance is, however, greatly influenced by the constituent materials and their lay-ups [5]. Therefore, more research is of necessity to understand the impact damage behavior when SMA wires are embedded into composite laminates.

Moreover, because most composite structures are used out-of-doors, it cannot be avoided that the structures are subjected to severe environment conditions such as low temperature. The study of impact response of composite materials subjected to environmental conditioning other than ambient is more realistic and many pieces of research [6-10] have investigated the effect of environmental condition on impact damage behavior of composite materials. Karasek et al. [6] have evaluated the influence of temperature and moisture on the impact resistance of an epoxy/graphite composite material and found that only at elevated temperatures has moisture had a significant effect on damage initiation energy. The study by Bibo et al. [7] have shown that temperature is capable of altering the nature and extent of impact induced damages and Ibekwe et al. [8] have experimentally studied the impact and residual load carrying capacity of unidirectional and cross ply laminates at low temperatures. From this literature survey, almost all the previous studies were focused on impact response at elevated temperatures and there is currently a lack of understanding of the low velocity impact behavior of SMA composite materials at low temperatures.

The present study aims to understand the damage behavior of glass/epoxy laminates with embedded SMA wire subjected to low velocity impact under low temperature. For this goal, a series of impact and non-destructive tests are performed on the baseline (glass/epoxy laminates without SMA wires) and SMA laminates (glass/epoxy laminates with embedded SMA wires) under various temperatures (293K, 263K and 233K). The impact damage parameters determined from the impact force and energy histories are employed. And then, the role of SMA wires on damage resistance capacity is evaluated using these parameters under various temperatures.

2. Experimental procedure

2.1 Materials and specimen

The composite material used here was unidirectional 24 ply glass/epoxy laminates (TBCarbon SGP125NS) obtained from a prepreg having a thickness of about 0.2 mm. Plates of nominal volume fraction of fibers v_f=50% were processed in an autoclave according to manufacturer's recommended cure cycle. The mechanical properties were obtained from tensile tests according to ASTM D-3039-00 [11] and the results are summarized in Table 1.

Table 1. Mechanical properties of glass/epoxy laminates.

Longitudinal elastic modulus, E_{xx}	Transverse elastic modulus, E_{yy}	Possion's ratio, ν_{xy}
43.9 GPa	2.74 GPa	0.31

Table 2. Mechanical properties of Ni-Ti SMA alloy.

Temperature	Yield strength, σ_y	Elastic modulus, E_{xx}	Possion's ratio, ν_{xy}
293K	280 MPa	41 GPa	0.43
363K	710 MPa	83 GPa	0.43

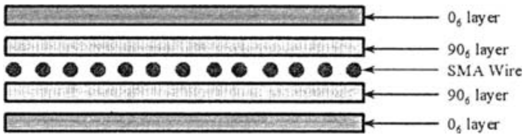


Fig. 1. The SMA wires embedded within the layers of laminates.

The shape memory alloy was the Ni-Ti SMA wire with 0.4 mm-diameters and inserted with the pitch of 5 mm at neutral plane of the laminates having a stacking sequence of $[0_6/90_{12}/0_6]$ as shown in Fig 1. The mechanical properties of Ni-Ti SMA wire are shown in Table 2. The manufactured plates were then cut into specimens and their dimensions were 90 mm in width and 120 mm in length.

2.2 Low velocity impact tests

The Dynatup model 9250 HV impact test machine was used to conduct the low velocity impact tests. The drop-weight tester consists of a drop tower equipped with an impactor, which has a hemispherical nose, and a variable crosshead weight arrangement, high bandwidth digital signal processing (DSP) electronics, self-identifying load cells, and Impulse^{TM} control and data acquisition software.

Prior to impact tests, the specimens were cooled to test temperatures (293K, 263K and 233K) in the environmental conditioning chamber (Dynatup model 7800-080) during three hours to ensure the thermal equilibrium with the environmental condition. The specimens were round-clamped with the opening of 76.2 mm-diameters. The radius and mass of the hemispherical impactor were 6.35mm and 6.45kg, respectively. After being impacted, the specimens were inspected by using the scanning acoustic microscope (SONIX model HS1000, frequency 5MHz).

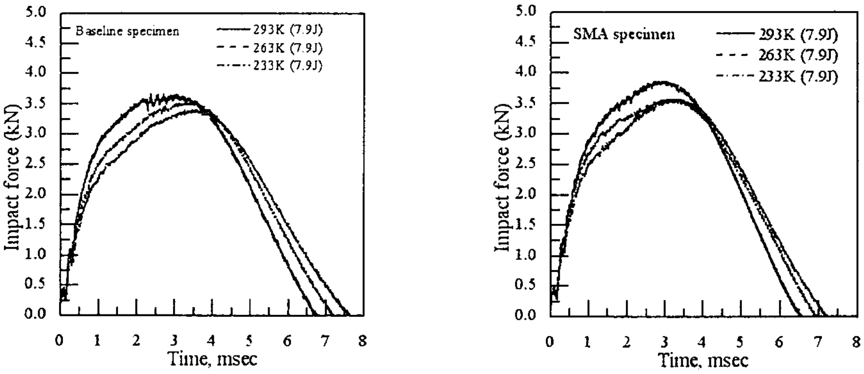
3. Results and discussion

3.1 Impact response at the various temperatures

To understand the overall impact response according to the laminate types (baseline and SMA laminates) and test temperature, the impact tests were made at the plate center, with the energy level of about 7.9J at the various temperatures (293K, 263K and 233K) for baseline and SMA laminates and their force histories are shown in Fig. 2. From Fig. 2, the impact response is changed according to the test temperature and laminate types, as the temperature decreases, the contact duration between the impactor and the laminates is longer and the maximum impact force is reduced for both the baseline and SMA laminates. Also, at the same temperature level, the force history for SMA laminates is slightly different from the baseline laminates. It is, however, not easy to identify quantitatively the difference of impact response between the baseline and SMA laminates; therefore, it is of necessity to adopt so-called the impact damage parameters being capable of describing the impact response, to evaluate the role of SMA wire on impact response under various temperatures.

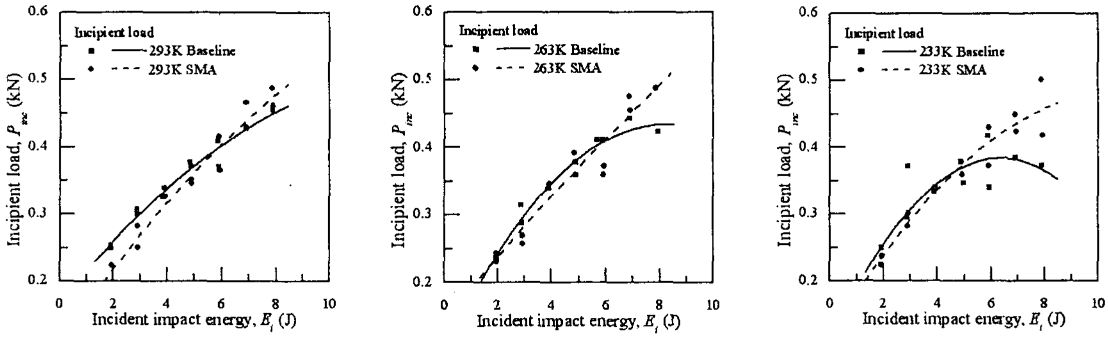
When composite laminates are subjected to impact loading, various damage processes may occur. These damage processes are associated with the laminates' energy absorbing capacities and can be characterized by the force and energy histories obtained during the impact tests. The area under the history diagram is equal to the change in momentum of the impactor and, from this the energy absorption under impact loading could be determined by the parameters derived from the impact force and energy histories that are used to characterize damage processes during impact [12]. Based on these, Kang et al. [13] have proposed the impact damage parameters and successfully evaluated the damage tolerance of filament wound pressure vessel. Among them, the authors have employed the following five parameters: (1) load at incipient damage P_{inc}, (2) energy absorbed at incipient damage E_{inc}, (3) maximum load P_{max}, (4) force-deflection curve, and (5) energy absorbed during impact E_{ab}.

Fig. 3 shows the incipient load, P_{inc} obtained at three temperatures against the incident impact energy E_i. This figure shows similar rising trends in loads with an increase in incident energy at the ambient temperature for both laminates. As the temperature decreases, however, the SMA laminates have quite different behavior from baseline laminates: the loads in SMA laminates continually increase at higher incident energy level while the loads in baseline laminates are greatly reduced and this behavior is more remarkably in lowest temperature. The incipient energy, E_{inc} exhibits a little different behavior from the incipient load, as shown in Fig. 4; the energy is increased with an increase in incident energy even at higher incident energy and lower temperatures. The trend in maximum impact force, as shown in Fig. 5, is



(a) Baseline laminates (b) SMA laminates

Fig. 2. Force histories for baseline and SMA laminates.

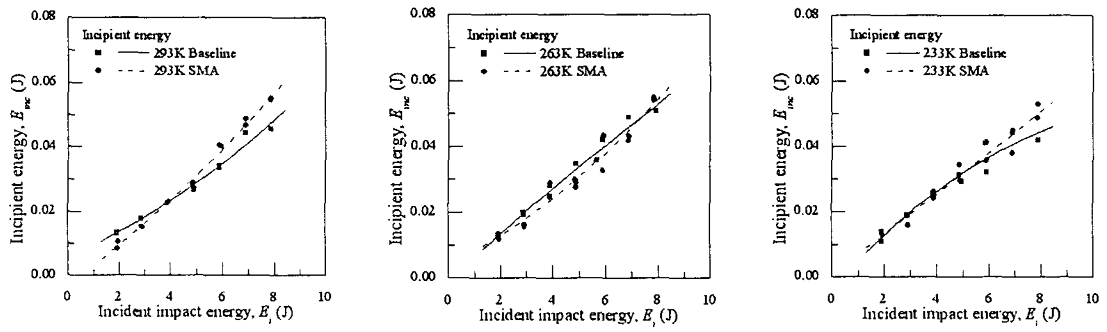


(a) Temperature: 293K

(b) Temperature: 263K

(c) Temperature: 233K

Fig. 3. Incipient load.

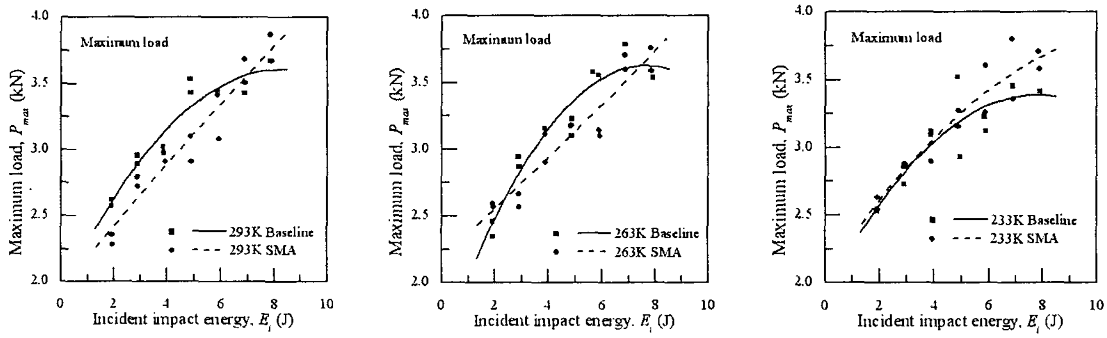


(a) Temperature: 293K

(b) Temperature: 263K

(c) Temperature: 233K

Fig. 4. Incipient energy.



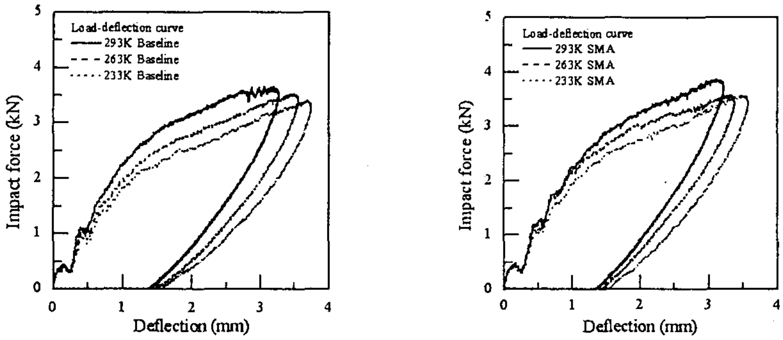
(a) Temperature: 293K

(b) Temperature: 263K

(c) Temperature: 233K

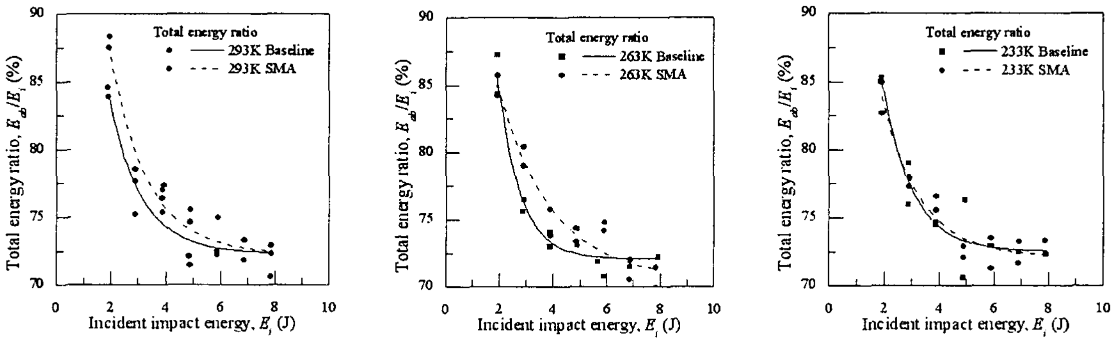
Fig. 5. Maximum force.

similar to those of incipient load. As the temperature decreases, the maximum force in SMA laminates is slightly lower at higher incident energy. But the force in baseline laminates is greatly reduced at higher energy and this behavior is more remarkably under lower temperatures. From the above results, it is inferred that the impact response of glass/epoxy laminates is governed by both the temperatures and SMA wires and also, the SMA wires play a role of reinforcement in laminates, especially under lower temperatures. In detail, at lower incident energy, the effects of temperature and SMA wires are negligible but, at higher incident energy under lower temperatures, the wires play a main role in the impact response. A similar behavior can be found on load-deflection curve in Fig. 6. Fig. 7 shows the absorbing energy



(a) Baseline laminates (b) SMA laminates

Fig. 6. Force-deflection curve.



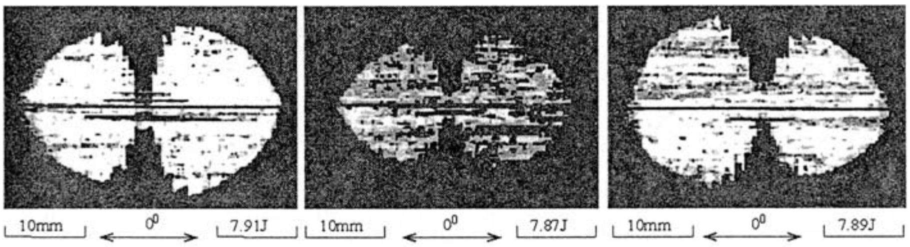
(a) Temperature: 293K (b) Temperature: 263K (c) Temperature: 233K

Fig. 7. Absorbed energy.

ratio, E_{ab}/E_i against the incident impact energy. Here, the absorbed energy was calculated through the impact force history. The ratios in both laminates are greatly decreased with increase in incident energy before reaching a plateau for all test temperatures. It appears that this behavior may be caused by the change of energy absorbing mechanism during the impact. When the laminates are subjected to the impact loading, the incident energy has been absorbed by both elastic (deflection etc.) and inelastic damage behaviors during the impact process. This energy is mainly absorbed by the elastic behavior at lower incident energy level while as the incident energy is higher, the energy absorbed elastically is saturated; the incident energy is mostly absorbed by inelastic behavior. And the absorbing energy according to laminates types exhibit a little different behavior; at ambient temperatures, the SMA laminates have absorbed the more energy than the baseline laminates but, as the temperature decreases, energy absorbed by both laminates approach almost the same level. It appears that the wires behave a discontinuity at ambient temperature: but, as the temperature decreases, the internal stress or deformation of laminates due to temperatures is relaxed by SMA wires. It means that although it is small amount, the SMA wires play a role of a stress relaxation at lower temperatures.

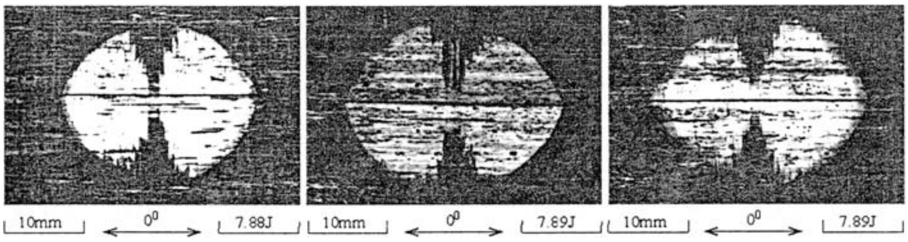
3.2 Impact damage behavior at the various temperatures

To compare the damage configurations of glass/ epoxy laminates according to embedded SMA wires, the impact tests were made at the plate center, with the energy level of about 7.9. Fig. 8 and Fig. 9 shows the typical damage states, which were observed by the SAM (scanning acoustic microscope) in baseline and SMA laminates, respectively. Here the damage was captured at the second interface from the impact point. The figures show that the impact damage for both the laminates is mainly delamination and peanut-shaped with major axis along their lower fiber orientation, the same as reported previously [1, 2].



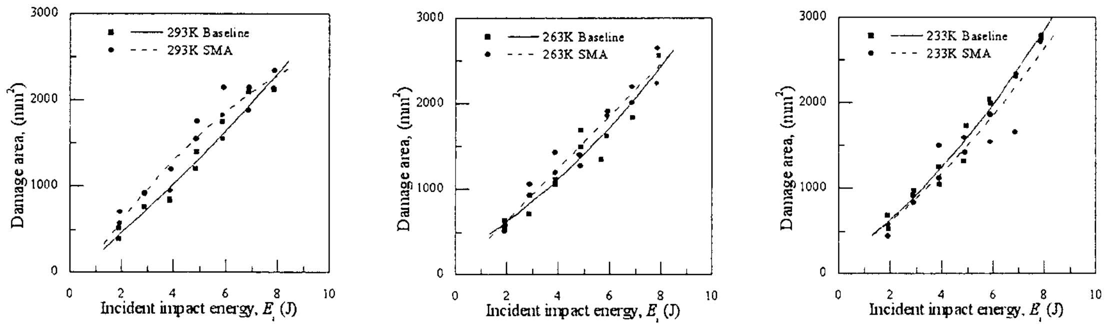
(a) Temperature: 293K (b) Temperature: 263K (c) Temperature: 233K

Fig. 8. Delamination measured by SAM in baseline laminates.



(a) Temperature: 293K (b) Temperature: 263K (c) Temperature: 233K

Fig. 9. Delamination measured by SAM in SMA laminates.



(a) Temperature: 293K (b) Temperature: 263K (c) Temperature: 233K

Fig. 10. Impact damage behaviour.

And, although there is a little difference between the damage behavior of baseline and SMA laminates, it is not clear that the effects of SMA wires as well as temperature on damage behavior are present.

For further understanding of damage behavior with SMA wires and temperature, the delamination areas obtained by the SAM, against the incident impact energy are shown in Fig. 10. From the figure, as the incipient impact energy increases, the damage areas are rapidly increased for all the laminates and temperature as expected. There is, however, a little difference between the impact damage of baseline and SMA laminates. At the ambient temperature, the damage for SMA laminates is more serious than that of baseline laminates. As the temperature decreases, however, the severity of impact damage in SMA laminates is changed. At the 263K, the impact damage behavior of SMA laminates is almost identical with the damage behavior of baseline laminates. And at the lowest temperature, the impact damage is more serious in the baseline laminate, not SMA laminates. This is consistent with the behaviors described above that although the wires behave a discontinuity at ambient temperature, the SMA wires play a role of a stress relaxation at lower temperatures.

4. Conclusions

To identify the impact response of glass/epoxy laminates with embedded shape memory alloy subjected to low velocity impact at various temperatures, the impact tests were performed at three temperatures: 293K, 263K and 233K for the baseline and SMA laminates. And then, the resultant damages were inspected through the scanning acoustic microscope (SAM) to evaluate the impact damage behavior of laminates. The following conclusions have been drawn.

Based on the impact force and energy histories, the impact resistance parameters were employed to evaluate the impact response of laminates with embedded SMA wires. As a result, the wires behave a discontinuity at ambient temperature. But, as the temperature decreases, it appears that the SMA wires play a role of a stress relaxation at lower temperatures.

The impact damage of both the laminates (baseline and SMA laminates) is mainly delamination and its configuration is peanut-shaped with major axis along their lower fiber orientation. And it has been shown that under lower temperatures, the SMA laminates have superior damage resistance compared with the baseline laminates.

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