EFFECT OF LOW TEMPERATURE ON IMPACT BEHAVIOR OF COMPOSITE SANDWICH STRUCTURES

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ABSTRACT

Global climate changes in the world are causing the arctic region to experience a severe shrinkage and reduction in the amount of ice. This change led to the opening of new seaways in the arctic region thus creating shorter passages for marine transport. A fundamental understanding of arctic low temperatures effects on the mechanical and physical properties of naval structures and materials is important. Marine operations in arctic region make it susceptible for ice to collide with structure surfaces, which can be described as low-velocity impact event. The problems associated with low-velocity impact are directly related to structural integrity and safety requirements. In this work, low-velocity impact of composite sandwich structures is experimentally investigated at four different temperatures (23°C, 0°C, -30°C, -70°C), and two different impact energy levels (5J, 10J). In order to study the effect of low temperature on impact behavior and damage response of composite sandwich structures, low-velocity impact tests are carried out, by means of instrumented drop tower machine (INSTRON CEAST 9350). The results show that, at very low temperature (-70°C) clearly visible damages occur on both sides of the composite sandwich specimens. At -30°C and 0°C, the composite sandwich structure specimens also show visible damages but they are less severe than the damages at -70°C. However, at room temperature (23°C) the specimens experience less damages on both sides of the specimens compared to low temperature conditions. This implies that the maximum strength is reduced at low temperature. Moreover, results show that face sheet absorbs less impact energy at low temperature, which similarly implies that it is easier to penetrate the specimen’s face sheet with decreasing temperature. At room temperature, the face sheet absorbs a considerable amount of energy before failure, while the foam core absorbs the remaining energy with a less evident extension of damage.

1 Introduction

Carbon Fiber reinforced composites sandwich structures are increasingly used in different engineering applications including aerospace, marine and construction. A sandwich structure consists of high specific stiffness facesheet layers, and a thick layer of lightweight core. Because of this unique design of sandwich structures, the facesheets carry bending and in-plane loads safely, while the core layer carries the transverse shear. The urge for designing light weight aerospace structures with high strength and stiffness lead to the use of carbon fiber composite sandwiches since they provide the demanded properties. However, composite sandwich structures are susceptible to impact damages which can cause significant reduction in the mechanical properties and ultimately structural failure. The causes of impact damages are various, for instance, tools dropping on the structure’s surface may induce impact damage, and also, debris hit aerospace surfaces during takeoffs and landings. In arctic naval structures, impact damages mostly take place as the ice particles collide with outer surfaces of the marine structures. The aforementioned damages are associated with low-velocity impact which typically has velocity less than 10 m/s [1]. Although impact damages could be very little or even non visible, depending on the impact velocity level, the damages might initiate some matrix cracks and core failures, these damages are known as barely visible impact damages (BVID). Studying BVID is crucial, since in the impact event, impact energy is dissipated through different damage mechanisms including separation of facesheets layers and layers micro-cracks. Moreover, energy is dissipated in
the form of delamination, which takes place within the facesheets. Energy is also dissipated in the form of core crushing and debonding between core layer and rear facesheet layers [2]. Many studies in the literature have been done regarding the impact behavior and damage mechanisms on sandwich composite structures, considering the dominant parameters in the impact behavior. Raju et al. [3] investigated the effect of impactor diameter on the damage mechanisms of Carbon/epoxy/Aluminum honeycomb sandwich structures. They concluded that using a smaller impactor diameter resulted in some matrix cracks and fiber fracture, while using larger diameter produced severe core crushing. Liu et al. [4] studied the effect of impactor geometry on CFRP with hybrid corrugated Aluminum core sandwich structures. They conducted experimental and numerical low-velocity impact tests for three different impactor geometries, conical, hemispherical and flat. The results of the aforementioned work revealed that sharper geometries require higher energy level. Moreover, the different damage mechanisms such as matrix damage, delamination and core buckling depend on the impactor shape. The indentation response of GFRP/Polyester facesheets and PVC foam core was investigated by Shaueib and Soden [5], they found that doubling facesheets thickness doubled failure load, while doubling core thickness increases failure load slightly. Daniel et al. [6] investigated impact behavior on unidirectional and woven carbon/epoxy and woven glass/vinylester composites laminates and four types of different densities PVC foam cores. They tested different energy levels ranging from 8J to 108J and it was observed that the impact failures mainly depend on the impact energy levels and the characteristics of the core layer. Furthermore, different damage mechanisms were associated with changing energy levels. In particular, they showed that at low energy, the panel damage was elastically recovered. Medium energy levels caused core crushing and permanent indentation, while high energy levels caused facesheets delamination and debonding from the core layer. Hazizan and Cantwell [7] studied the rate of sensitivity of facesheets and 11 types of foam core, they found that the cross head displacement rate has negligible role on the elastic modulus for all tested samples. In addition, they concluded that the elastic impact behavior of composite sandwich structures can be predicted using a dissipative energy-based model. Although many studies were conducted to study impact behavior on sandwich composite structures, only few of them considered the effect of changing test temperature. Salehi-Khojin et al. [8] investigated the impact behavior of Kevlar/hybrid carbon factsheets with urethane filled honeycomb core at different temperatures ranging from 150°C to -50°C. They concluded that the damages were tremendously influenced by the test temperature, the highest damage area and greatest fiber damage occurs at -50°C, and also the damage size is reduced as we increase the test temperature. Erickson et al. [9] studied the effect of temperature on glass fiber reinforced with two different types of honeycomb cores at different temperatures and different energy levels. Their results revealed that the temperature change drastically affect the peak damage force and the percentage of the impact energy absorbed by the specimen. In our work, low-velocity impact of composite sandwich structures in arctic condition is experimentally investigated at four different temperatures (23°C, 0°C, -30°C, -70°C), and two different impact energy levels (5J, 10J). The main objective of this work is to study the effect of low temperature on impact behavior and damage response of composite sandwich structures. Impact tests are conducted on Carbon fiber facesheet with Polyvinyl Chloride foam sandwich panels using drop tower machine (Instron ceast 9350). Low temperature effects on the maximum damage force and amount of energy absorbed are studied in this work.

2 Experimental procedure

The sandwich composite specimens of 150×100×7mm dimensions are subjected to drop tower impact test using Instron ceast 9350 drop tower with 16mm diameter hemispherical head and a constant impactor mass of 3.482 kg. As shown in Fig. 1, the test machine is equipped with an environmental chamber which is capable of providing excellent range of test temperatures (-70 to 150°C). The specimens are fully clamped inside the environmental chamber, they are placed on a round hollow support frame of 76 mm diameter. All samples are impacted with the same impacting mass, thus a different impact heights are used to achieve the two different energy levels. For each energy level and test temperature at least two samples are tested to verify the correctness of the system measurement. For low temperature tests, specimens are kept inside a freezer for twenty four hours before taking them to the environmental chamber. Inside the environmental chamber, each sample is
cooled for twenty minutes before the impact test using a liquid nitrogen tank. A sensitive sensor was attached to the impactor to measure the speed, contact force and contact period. The data of this variables are recorded via a data acquisition system (DAS64K).

![Experimental setup of Instron Ceast 9350 drop tower.](image)

**3 Results and Discussion**

The experimental results recorded from the data acquisition software are analyzed and categorized into two main parts as follows.

**3.1 Effect of temperature on maximum damage force**

Force impact history curves are analyzed to understand the dynamic behavior of composite sandwich structures during the impact event. The effect of temperature on the maximum load is studied at 10 J and 5 J, Fig. 2 shows that at 10 J for all temperatures the graph starts with a linear behavior representing the stage at which the initial contact between the impactor and the specimen occurs. At a specific point on each graph, all curves experience the initiation of the panel damage following by a sharp decline on each curve indicating a tensile failure of the carbon fiber front facesheet layer. Tensile failure in carbon fiber sandwich composites takes place in form of delamination, fiber breakage and penetration of the layers. By comparing the tensile failure points for all temperatures, we can observe that at low temperature tensile failure occurs at a lower value of the correspondent damage force implying that at low temperature the maximum strength of the panel is reduced. After the damage of the front facesheet, the damage force increases while the impactor is perforating through the core layer causing shearing and crushing failures. The damage continues till the curve reaches a second damage peak then sharply declines for low temperature cases (0°C, -30°C,-70°C), and less sharply for room temperature. The aforementioned peak represents the damages of the back facesheet which take place as matrix damages and whole panel penetration. By comparing the damage force of the back facesheet, we observe that the lower test temperature we use, the lower damage value we obtain. Fig. 3 shows the results at 5 J, we can observe in the beginning, the panel
damage initiation following by tensile front facesheet tensile damage as well as core layers crushing. The results at low temperature shows lower value for the front facesheet damages compared to room temperature. A major difference between the two energy level is that 5J graphs do not experience sharp reduction at the back facesheet, hence there is no visible back facesheet damage since the amount of impact energy is inadequate to cause panel penetration.

Figure 2: Effect of temperature on damage force at impact energy of 10 J at 
(a) 23°C, (b) 0°C, (c) -30°C, (d) -70°C.

Figure 3: Effect of temperature on damage force at impact energy of 5 J at 
(a) 23°C, (b) 0°C, (c) -30°C, (d) -70°C.
3.2 Effect of temperature on absorbed energy

Fig. 4 illustrates the effect of temperature on the absorbed energy at total impact energy of 5 J, it shows the energy required to penetrate the front facesheet denoted by “Ep”, the total impact energy denoted by “I.E” -which is slightly more than 5 J because of the energy added due to the global deflection of the sandwich panel- and the total amount of energy absorbed by the sandwich panel which is denoted by “Eabs”. Also, we can measure the amount of the energy that returns back to the system after the impact event, simply by subtracting “Eabs” from “I.E”. Furthermore, energy-time curves also delineate the function of the face sheet material “carbon/fiber epoxy” and the Polyvinyl Chloride (PVC) foam core during the impact test. At low temperature, PVC core is observed to absorb most of the damage energy by foam crushing mechanism. Carbon/fiber epoxy face sheets absorb less energy, due to reduced material strength. At room temperature, the face sheet absorbs a considerable amount of energy before failure, while the foam core absorbs the remaining energy with a less evident extension of damage.

Figure 4: Effect of temperature on the amount of the absorbed energy at 5 J
(a) 23°C (b) 0°C (c) -30°C (d) -70°C.

4 Conclusion

The effect of low temperature on impact behavior of carbon/fiber with PVC has been investigated experimentally using Instron Ceast 9350 drop tower machine. Specimens are tested at four different temperature (23°C, 0°C, -30°C,-70°C) and two energy levels (5J, 10J). The results show that at low temperature higher damage force for both 23°C and 0°C in comparison with -30°C and -70°C, which implies that the maximum strength is reduced and it is easier for damage to occur at low temperature. Furthermore, at low temperature, less amount of energy is required to damage the specimen.
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