EFFECT OF FLUID STRUCTURE INTERACTION ON COMPOSITE STRUCTURES UNDER IMPACT

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Abstract

This study investigated the effect of Fluid-Structure Interaction (FSI) on dynamic response and failure of polymer composite structures subjected to impact loading. Using a uniquely designed vertical drop-weight testing machine, three impact conditions were examined: dry impact, air-backed wet impact and water-backed wet impact. The study showed that the FSI effect on polymer composite structures is so critical that impact force, strain response, and damage size are generally much greater with FSI under the same impact condition. As a result, damage initiates at a lower impact energy condition with the effect of FSI. This means negligence of the FSI effect on polymer composite structures results in non-conservative analysis and design. Besides, it was noticed that the damage location changed for sandwich composite beams with the effect of FSI.

1 Introduction

There are two types of coupling between fluid and structure. One is a unidirectional coupling while the other is a bidirectional coupling. When a polymer composite structure interacts with water, it is a strong bidirectional coupling because both media influence on each other significantly. [1-4] This is because both media have comparable densities. As a result, it is important to understand the dynamic response and the resultant failure of polymer composite structures under water. As polymer composite structures are used increasingly for marine applications, the FSI effect should be properly understood and reliably predicted. The present study investigated the FSI effect on fibrous laminated composite plates as well as sandwich composite plates by comparing their dynamics behaviors and failures when the same structure was impacted in air or in water, respectively. The next section describes the experiment followed by results and discussion. Finally, conclusions are provided.

2 Experiments

Both laminated fibrous composite plates and sandwich composite plates were tested. The laminated composites were constructed of E-glass or carbon fiber woven fabrics using the vacuum-assisted resin transfer molding technique. Sandwich plates were made of E-glass woven fabric skins and the balsa core. Every composite specimen had a test section of 30.5 cm x 30.5 cm (12 in. x 12 in.) with all clamped edges. Each composite plate was clamped onto the vertical impact testing machine which was placed inside the anechoic chamber with a proper support as shown in Fig. 1. The anechoic tank was not filled with water for the dry impact testing while the tank was filled with water for the wet impact testing. For one series of wet impact tests, a water-tight bucket was attached to the composite plate side which is opposite to the impact rod so that there was no water between the composite plate and the bucket. This test is called air-backed wet impact. Without the bucket, the test called water-backed wet impact. The same impact loading conditions, i.e. the same weight and height of the free-drop impactor, were applied to the dry and wet impact testing so as to compare the behaviors among the dry and wet cases. For the wet impact testing, the impactor was prevented from entering the water in order not to disturb the still water. As a result, an intermediate impact rod was located between the impactor and the composite plate. The one end of the intermediate rod was exposed above the water level so that the impactor could strike it. The other end was just a small distance away from the plate so that the travel distance of the intermediate rod would be minimal during the impact testing. Besides, composite samples were properly waxed to prevent water intrusion into the samples without affecting their material properties.

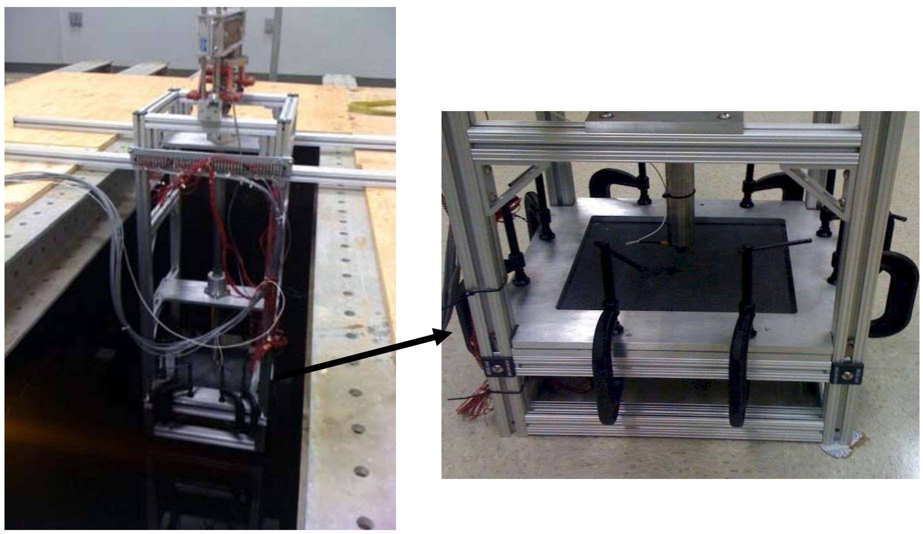

Figure 1. Impact machine lowered into an anechoic water tank

3 Results and Discussion

The first set of tests was conducted using a carbon-fiber composite plate. These tests were focused on their dynamic responses without resulting in any damage or failure. Three different impact cases (dry, air-backed, and water-backed wet impacts) were compared in Fig. 2 with the same impact loading condition. Because there was no damage in the composite plate, the same plate was used for all three cases. This removes any potential variation from one sample to another in comparing three different impact cases. The results show that the wet impacts yield much greater impact forces than the dry impact for the same impact loading condition. This results from the added mass effect in water. The composite structure moves in water with a larger inertia because of the added mass effect. This results in a greater contact force between the impact rod and the specimen.

Strain gage rosettes were attached to every composite plate on the opposite side of the impact as shown in Fig. 3. Comparisons of the strain data among three different impact cases indicated that the FSI effect is not uniform over the composite plate. One location has a greater effect than another location. In other words, the difference of strain data among the three different impact cases varies from location to location. For example, the gage location

#4 in Fig. 3 shows significantly different strain responses between the dry and wet impact cases. The wet impact resulted in much greater strains. On the other hand, strain gage at location #3 shows a less difference as plotted in Fig. 5.

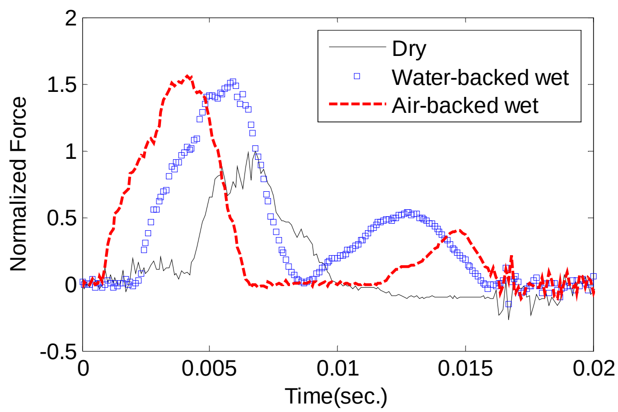

Figure 2. Impact force-time plots for carbon composite plate without damage

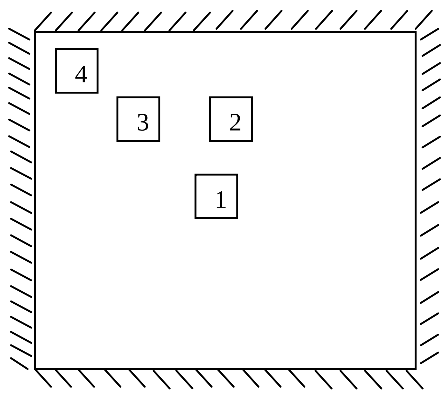

Figure 3. Strain gage locations on composite plate

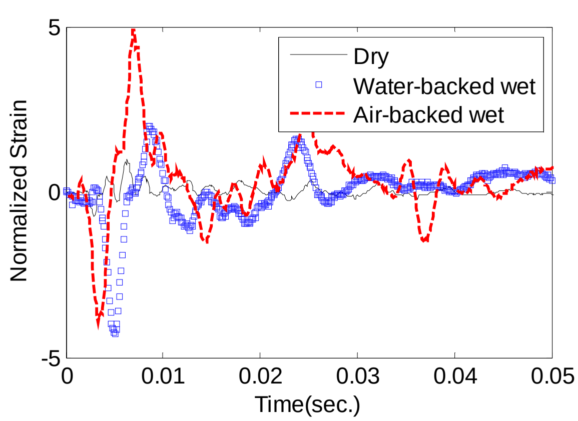

Figure 4. Strain-time plots at gage location #4 for carbon composite plate without damage

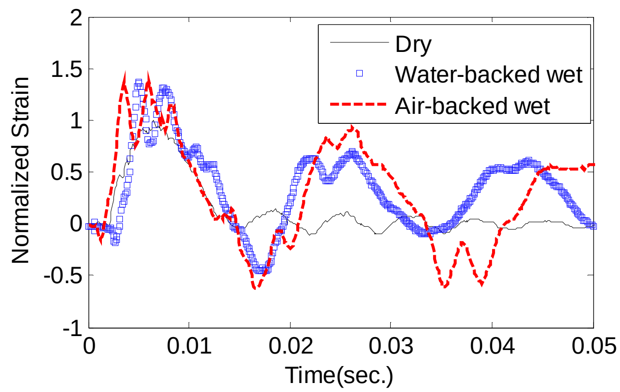

Figure 5. Strain-time plots at gage location #3 for carbon composite plate without damage

Because carbon-fiber composite plates were quite strong, they did not fail unless the impactor mass and/or height were increased significantly. This requires a modification of the impact testing machine. Instead of such a modification, E-glass fiber composite plates were used to compare damage between dry and wet impact cases. Besides, E-glass composites are translucent so that some internal damage/failure could be detected with naked eyes. To compare damage, the same composite plate could not be used for each testing because there was already damage occured in the sample. Therefore, different plates were used for dry and wet impacts, respectively. This introduces some variation from one sample to another. In order to minimize the variation, multiple samples were tested for the same impact case and their results were also compared.

The E-glass composite plates were impacted using one selected impactor mass by increasing the impactor height sequentially. The initial impact height was selected low enough not to cause any damage to the composite plate. The impact testing was conducted twice at the same impact height and their responses were compared and inspected for damage. All tested composite plates gave almost the same force and strain response at the same impact height as well as no noticeable change in damage state. This suggested that damage initiation or growth occurred as the impact height was increased to the next level. The air-backed testing made it difficult to inspect damage occurring on the opposite side of the impact because of the attached air bucket. Hence, only water-backed impact was conducted to be compared to the dry impact.

Figure 6 plots the impact force-time history as the drop height is increased. At the drop height of 7.6 cm which did not yield any damage, the wet impact resulted in a slightly larger force than the dry impact. Comparing this to Fig. 2 shows a very large contrast. One reason is the E-glass composite was impacted at much lower drop height and with a less weight than the carbon composite. As the impact energy becomes lower, the dynamic response of the composite structure is less. This results in a less FSI effect on the E-glass composite plate. The E-glass composite had damage initiation and growth at a lower drop height under wet impact than dry impact. The damage occurred at the center of the plate coincident with the impact location. However, the major damage occurred at the opposite side of the impact. Once there is damage at the center, the plate loses local stiffness at the site. This resulted in lower impact force for the wet impact as shown in Fig. 6 for larger drop heights. Figure 7 compares the strain-time history at gage location #3 between the dry and wet impacts as the damage grows along with the drop height. As damage grows, the strain response changes significantly for the wet impact. The peak strain due to the dry impact becomes closer to that under wet impact as the damage (i.e. drop height) increases.

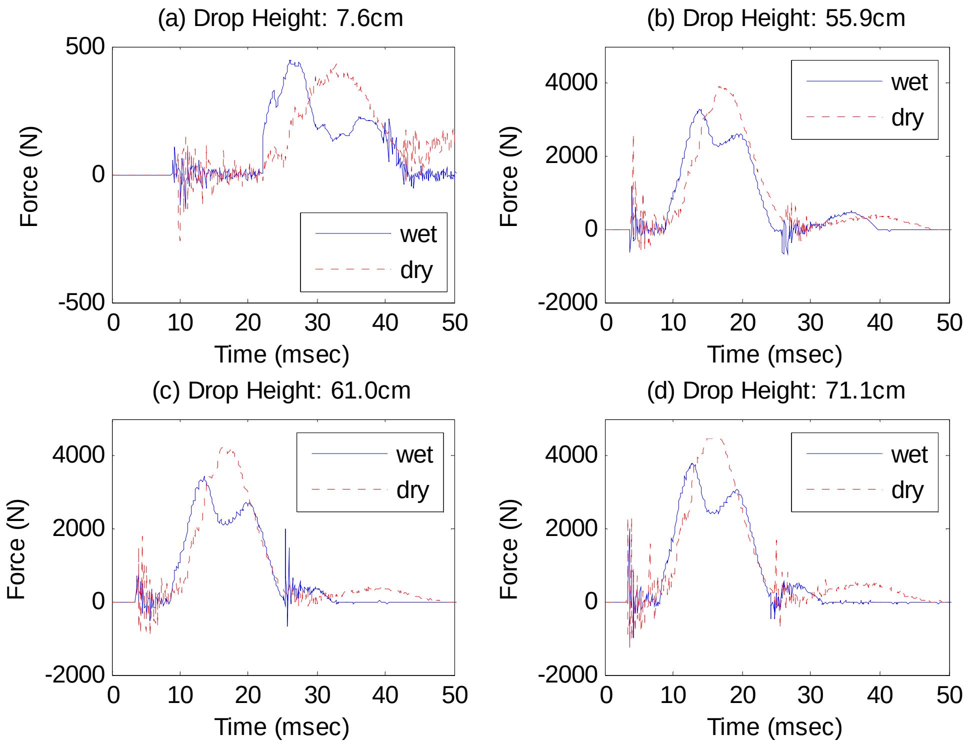

Figure 6. Impact force-time plots for E-glass composite plate with increasing drop height

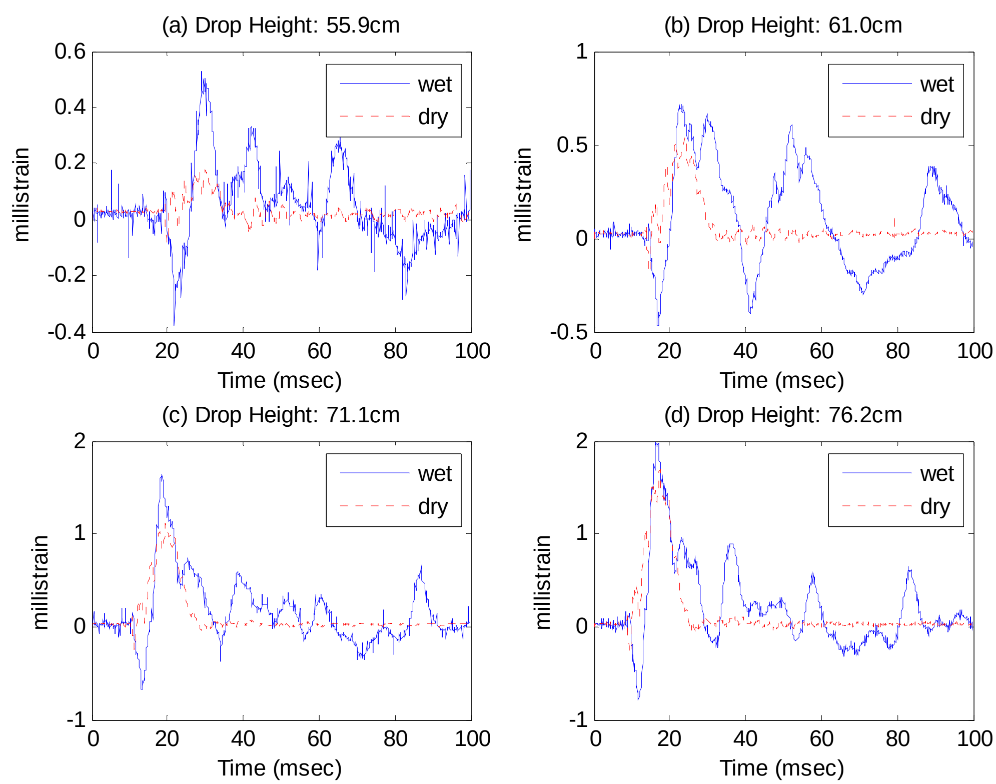

Figure 7. Strain-time plots at gage location #3 for E-glass composite plate with increasing drop height

Progressive damage as a function of the applied peak impact force is compared in Fig. 8. Because the damage has almost a circular shape, its diameter is plotted in Fig. 8 for both dry and wet impacts. The figure shows that wet impact results in damage at a lower impact force than dry impact.

The added mass of FSI also affected the vibrational frequency of the composite plate. As a result, the frequency of the wet response is much lower than that of the dry response. The vibrational frequencies were computed from the strain-time histories and the results are compared in Table 1. The wet frequency is significantly reduced to 30% of the dry frequency. Such a large reduction occurs because the water density is compatible to the composite density.

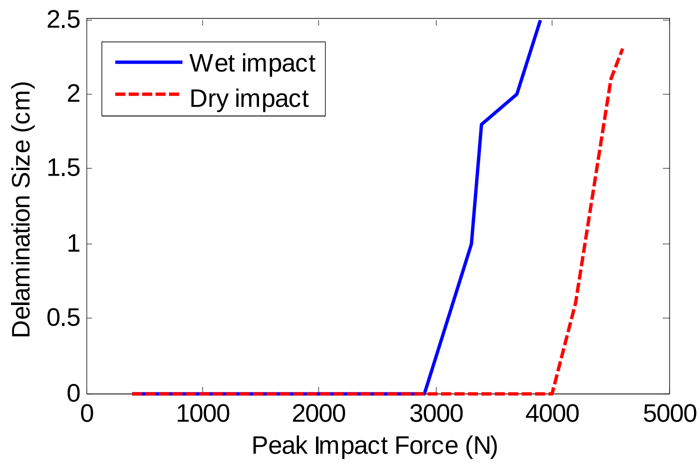

Figure 8. Comparison of damage sizes between dry and wet impacts of E-glass composites

Sandwich composite plates showed similar results qualitatively as the E-glass composites. Figure 9 shows the comparison of the damage size between the dry and wet impacts under the same impact loading condition. Wet impact resulted in much larger damage than dry impact. All those results suggest that the wet impact is more critical to the composite structures than the dry impact.

(a) Dry Impact (b) Water-backed Wet Impact

Figure 9. Comparison of delamination sizes between dry and wet impacts of sandwich plates

	Dry Impact	**Wet Impact**
Freq. (Hz)	600	185

Table 1. Comparison of vibrational frequencies of strain responses between dry and wet impacts

4 Conclusions

The effects of FSI on polymer composite structures are significant, and those effects are not uniform over the composite structures. Some locations have greater effects than others. Analysis and design of composite structures in contact with water requires including FSI effects. Otherwise, the results would be non-conservative yielding pre-mature failure of the structures.

References

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