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# Impact properties of glass fiber/epoxy composites at cryogenic environment

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ABSTRACT

Glass fiber/epoxy polymer (GFRP) composites are widely used in the aerospace engineering industry due to their high specific strength to weight ratio with non-corrosive properties, however they are very sensitive to foreign object impact. This study aims at investigating the impact response of GFRP composites at different temperature environments, which are encountered in their service at high attitude and low earth orbit (LEO) conditions. 18 GFRP samples were fabricated by vacuum infusion process and 9 of them were post-cured at 353 K for 3 h to ensure that a complete chemical reaction inside the samples was achieved. Low velocity drop weight test was performed for the samples prepared and then stored at room temperature (295 K), dry ice temperature (199 K) and liquid nitrogen temperature (100 K) conditions. The apparent damages and their size were visually examined and measured. Impact parameters such as impact load, deflection and energy absorption of each damage type were also analyzed. Besides, the post-curing effect was also studied to verify its significance to the impact properties of composites. Experimental results showed that GFRP composites at cryogenic condition exhibited smaller apparent damage and were stiffer as compared with other cases. However, they demonstrated relatively poor energy absorbability at low temperature condition. It was also found that post-curing could reduce the apparent damage and increase the energy absorption of GFRP composites.



## 1. Introduction

In the past decade, fiber reinforced polymer (FRP) composites have been widely used in different engineering industries due to their high specific strength to weight ratio, chemical and corrosion resistance and ease of manufacturing into complicated forms with less fasteners required. These composites are used mostly in primary and secondary structural components, such as wings, fuselages and cryogenic fuel tanks in the aircraft and aerospace engineering industry. In the low earth orbit (LEO) environment, where spacecrafts and satellites are located, the materials used for making their structures are always subject to extreme temperatures in the range of −170 °C to 200 °C [1]. Besides, in this environment, outgassing, atomic oxygen and ultra-violet (UV) attacks and thermal-fatigue are always the problems that cause mechanical and material degradations of composites. Therefore, carrying out continuous research and development to optimize the mechanical properties of the composites in cryogenic condition is undoubtedly essential.

Glass fibers, especially produced in a woven form, offer sufficient resistance to an object during impact with low material cost as compared with carbon fibers, which make them more attractive for many structural applications [2]. Among all different kinds of thermosets, epoxies are well-known for their outstanding mechanical properties such as resistance to micro-cracking, chemical inertness, good thermal and dimension stabilities [3]. In current aircraft and automotive composite components, epoxies are mostly used. Therefore, glass fiber woven fabrics and epoxy resin were chosen for the current project.

The mechanical properties, such as tensile and shear behavior, of glass fiber reinforced polymer (GFRP) composites at cryogenic condition were studied but very few focused on their out-of-plane properties, like impact response. Shindo et al. [4] have investigated the tensile properties of glass fiber/epoxy composites at cryogenic

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**Table 1**
Dimension and properties of GFRP samples.

| Dimensions (mm) | 100 × 100 |
|---|---|
| Mean Thickness (mm) | 1.4648 ± 4.7% |
| Mean Weight (g) | 23.311 ± 4.5% |
| Fiber mass fraction | 56.2% |

**Table 2**
Short forms of Sample Groups.

| | |
|---|---|
| **RT**: Room Temperature (295 K) | **RT-P**: Room Temperature with Post-curing |
| **DT**: Dry Ice Temperature (199 K) | **DT-P**: Dry Ice Temperature with Post-curing |
| **CT**: Cryogenic Temperature (100 K) | **CT-P**: Cryogenic Temperature with Post-curing |

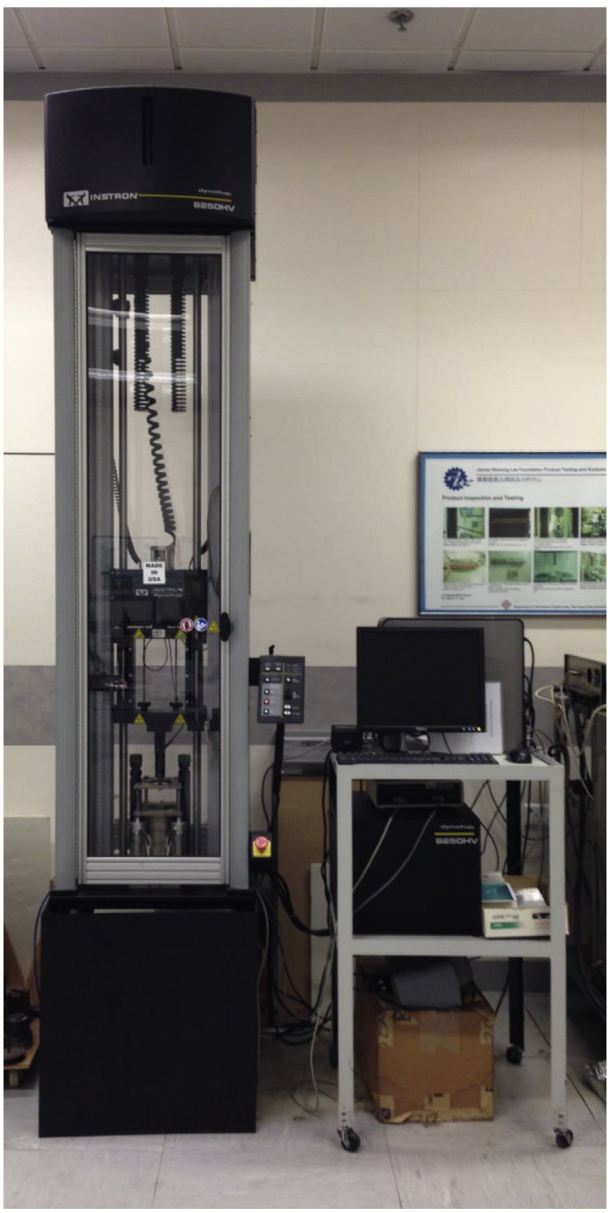


**Fig. 1.** Drop tower impact tester INSTRON Dynatup 9250 HV.

temperature and found that their Young's modulus and ultimate tensile strength increased when comparing with those at room temperature condition [4]. Miura et al. [5] experimentally studied the fracture toughness of GFRP composites under mixed-mode II/III loading, high delamination fracture toughness was found at cryogenic temperature as compared with samples conduced a similar test at room temperature environment. Dutta and Hui [6] have addressed that the performance of FRP composites at low temperature is dominated by the properties of matrix due to the increase of Young's modulus "E" and shear modulus "G" values. Based on the Timoshenko's beam theory, Ip et al. [7] have also found that the natural frequency of thick composite beams increases with decreasing the temperature, which is due to the change of their mechanical properties. The natural frequency of a structure is directly proportion to its Young's modulus.

Mathivanan et al. [8] have pointed out that impact damages were usually undetectable. At room temperature, the main failure modes identified in an impact test for woven E-glass epoxy composite laminates were delaminations, matrix cracking and fiber failures. The effect of drop height to the damage behavior of composite laminates was investigated by both Mathivanan et al. [8] and Bhushan et al. [9]. However the effect of temperature, especially at cryogenic temperature, was not considered in their works.

The influence of temperature (−50 °C to 120 °C) on the impact properties of GFRP laminates was examined by Salehi-Khojin et al. [10]. They discovered that the laminates became rigid with high stiffness at low temperatures so as their deflections in impact tests were small. Icten et al. [11] have also found that damage areas were smaller and higher perforation threshold was resulted for GFRP laminates subjected to a low velocity impact at low temperature (−60 °C to 20 °C) condition. Although some works were done to study the impact properties of glass fiber composites at low temperature environment, the lowest temperature that have been widely-investigated was down to − 60 °C only. Very limited works focused on the impact response of GFRP composites at cryogenic condition, which is down to −150 °C or even lower. In high attitude and LEO applications, impact damages in a composite structure would cause catastrophic failure and such damages may not be observed and discovered easily through neck-eyes or other external non-destructive evaluation (NDT) tools. It is thus always neglected by routine visual inspection process [12]. Therefore, designing FRP composites with good impact resistance are always a challenge to composites designers and engineers.

Normally, epoxies are not completely cured at room temperature environment, many epoxy's users have adopted the post-curing process at set temperature, which is recommended by the manufacturers to rise the degree of cure. In fact, the purpose of post-curing is to ensure a complete chemical reaction between resin and hardener to form a full cross-linking in epoxy to obtain better physical and chemical properties [13]. With post-curing, thermosets are said to be more mechanically stable and more impact resistant by absorbing more energy prior to fracture [3]. The effect of post-curing to the mechanical properties of two kinds of epoxies was studied by Carbas et al. [14]. They found that the epoxies behaved in a slightly different way with each other after treatment, the stiffness and strength of epoxies decreased after post-curing which promoted greater energy absorbability.

This study aims at investigating the low velocity impact response of woven GFRP samples at different temperature