DESIGN AND MANUFACTURING OF AN IMPACT FATIGUE TESTING MACHINE FOR FIBRE REINFORCED PLASTICS

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1 Introduction and Background

Fibre reinforced plastics (FRP) are now utilized in various areas such as aerospace, buildings, sports equipment and cars due to its light weight and high strength. Thus the parts of composite structures are subject to many types of loading. So far, a large amount of research into the strength of FRP has been done, especially behavior of FRP subject to tensile, compressive loading and high-energy low-cycle impact. However, composite materials and components are often exposed to low-energy high-cycle impact (Bird strikes on the wing of aircraft, the hydrogen tank in fuel cell cars hit by bouncing pebbles from the road, for example.) This means the impact fatigue durability of composite materials is quite important.

There is some literature related to impact fatigue durability [1-7]. These articles deal with the behavior of composite materials after impact. These results might be helpful for evaluating the endurance of composite materials, but still they are not enough to examine the impact fatigue durability. The number of impact cycles in the articles is limited to below 10^5. An endurance limit of composite materials has not been clarified.

Azouaoui et al. [8,9] have manufactured an impact fatigue testing machine and conducted high-cycle impact fatigue tests which have shown the endurance limit of glass/epoxy cross ply laminates. The maximum number of impacts was 572,018 in the tests. They examined the effect of the number of impacts on the residual stiffness of GFRP plates.

To clarify the effect of the number of impacts on the residual stiffness of CFRP is also important, but has not been done yet. This investigation would allow CFRP parts to be designed more efficiently.

In this paper, an impact fatigue testing machine was designed and manufactured to perform high-cycle impact fatigue tests in order to examine the impact fatigue durability of CFRP. The machine can hit a CFRP specimen with the same impact energy at each impact because the hammer is controlled in a way which allows it to swing freely during a collision such that it hits the specimen by force of inertia. This is a better way to deliver impacts to the specimen when evaluating the impact fatigue strength of specimen.

2 Machine Concept

To investigate the fatigue durability of CFRP on high-cycle impact, impact fatigue tests need to be carried out. The impact fatigue testing machine in this paper was used for these tests. The specimens subjected to the impact fatigue tests are CFRP plates which are struck by the machine.

The requirements of the impact fatigue testing machine are;

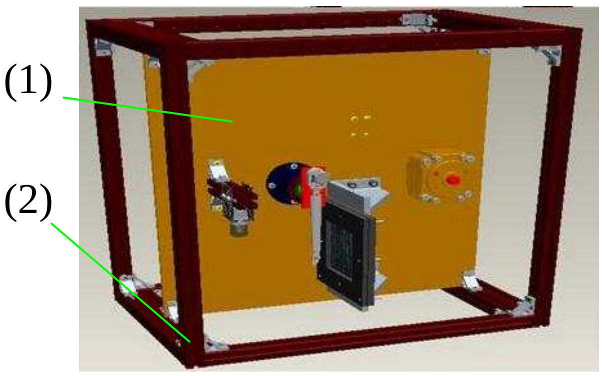
(1) Impact caused by force of inertia (not caused by forced action of the hammer)
(2) Wide range of impact energies
(3) Adequate strength and endurance for impact fatigue tests
(4) High impact cycle frequency

The impact on the FRP specimens must be caused by inertia of the hammer because a hammer which is given forced displacement cannot hit specimen with the same impact energy every time; as the specimen deforms, the impact condition would reduce. The range of impact energies needs to be wide so that the specimen can be subjected to a variety of impact conditions. It is essential for the machine to have enough strength to perform high-cycle impact fatigue tests. A fatigue test usually takes a large amount of time. Therefore the frequency of impact cycles needed to be high. Considering these requirements, a system which included a pendulum actuated by rotary pneumatic actuator was chosen for the impact fatigue testing machine. The pendulum hits the specimen by force of inertia via a solenoid valve with a normally exhausted flow configuration (Fig.2.(4)). A wide range of impact velocities can be obtained by connecting the shaft of the rotary actuator and that of the pendulum with a chain belt and various sizes of sprockets.

3 Machine Configuration

3.1 Structural Components

3.1.1 Impact Apparatus



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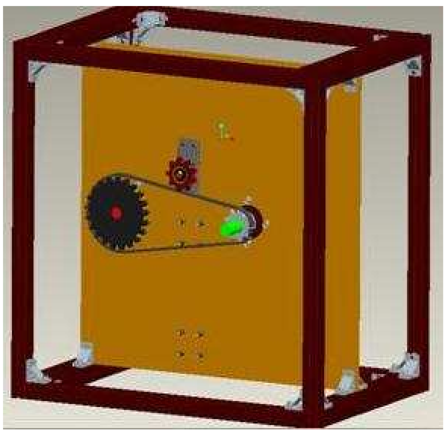

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Fig.1. Impact fatigue testing machine

The impact apparatus (Fig.1.) is characterized by the chain and sprockets system. This system increases the rotational velocity of the pendulum. The maximum impact velocity is up to 9.0m/s and the maximum cycle frequency is 3.5 Hz. The pendulum is a bar made of steel weighing about 0.40kg.

3.1.2 Pneumatic System

The layout of the pneumatic system is shown in Fig.2. The pneumatic components used are an air compressor (1), filter regulator (2), 5port 3way solenoid valve (3), speed controllers (4) and rotary actuator (5). The pendulum is accelerated towards the specimen before an impact. Shortly before, during and shortly after an impact, the solenoid valve exhausts air in the rotary actuator so that the pendulum swings freely. After an impact, the pendulum moves away from the specimen.

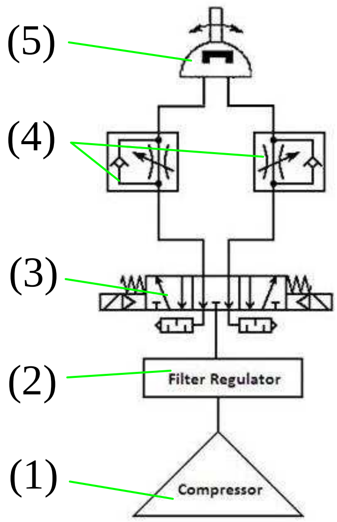

Fig.2. Pneumatic system layout

3.1.3 Specimen Holder

The Specimen holder has been designed to accommodate a specimen measuring 150mm x 150mm and consists of two large flanges as shown Fig.3. It was laser cut from steel, with the back plate being thicker than the front, to withstand the repeated impact force.

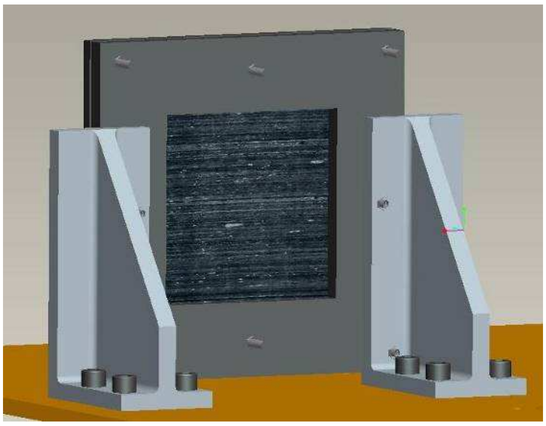

Fig.3. Specimen holder

3.1.4 Base Plate and Framework

The base plate (Fig.1.(1)) is a steel plate of dimensions 750mm x 750mm x 12mm. The purpose of the base plate is to attach all of the mechanical components in a vertical configuration. This configuration allows for the electronics to be placed on the other side of the plate, thus reducing the possibility of interference from electrical wiring. The outer frame (Fig.1.(2)) was assembled from aluminum alloy components. The machine is constructed from these components to create a 800mm x 800mm x 800 mm box frame. Each beam is connected together using aluminum brackets. The beams have a cross-section of 60mm and include slot sections that create a sliding interface for moveable rails.

3.2 Measurement System

The impact fatigue testing machine measures three parameters during tests;

(1) Number of impacts
(2) Impact velocity
(3) Displacement of the specimen

The Impact number is measured by counting the on-off switching of the solenoid valve. Two photo interrupters are set just in front of the specimen to measure impact velocity. A displacement transducer is behind the impact point of the specimen measures displacement of the specimen. These test parameters are recorded at each impact event using a LabVIEW program.

4 Operational Test

4.1 Specimen and Test Method

The material used in this paper was epoxy matrix reinforced by carbon fibres (CFRP), TR352G125S (supplied by MITSUBISHI RAYON CO .,LTD.) The stacking sequence of laminates was $[0/+45/-45/90]_{2s}$. The size of the specimen was 180mm x 180mm. The thickness was 2.0mm. An operational test was carried out with the impact velocity set to 6.0m/s and a steel plate was put on the surface of the specimen in order to protect it from excavation.

4.2 Results and Discussion

The machine (Fig.4.) performed 130,000 impact cycles. Excavation was observed on the surface of the steel plate but not noticeable on the surface of the CFRP specimen (Fig.5.) Impact velocity was stable at 6.0m/s during the test. The displacement of the specimen was recorded. Since the machine operates correctly, it is possible to evaluate the impact fatigue durability of CFRP specimens. A compression or tension test of the specimen after a fatigue test will show the residual strength of the specimen. Transverse cracks and delamination can be investigated microscopically like the way Ogihara et al.[10] did. Recorded data of the displacement of the specimen will indicate the residual stiffness of it during the test.

Fig.4. The machine during the test

Fig.5. The specimen after the test

5 Conclusion

The developed impact fatigue testing machine was able to perform 130,000 impact cycles, and this means the machine can endure high-cycle impact fatigue tests. The number of impacts, the impact velocity and the displacement of the specimen were measured during the operational test. The results of the test indicated that the machine is capable of evaluating the fatigue durability of CFRP specimens subject to high-cycle impact.

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