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LOW VELOCITY IMPACT PROPERTIES OF POLYPROPYLENE ~~(PP)~~ HONEYCOMB CORE SANDWICH STRUCTURE WITH GLASS FIBER REINFORCED PLASTIC (GFRP) LAMINATED FACESHEET

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ABSTRACT

The low velocity impact response of thermoplastic honeycomb core from polypropylene (PP) laminated with non-metallic facesheet made from glass fiber reinforced plastic (GFRP) has been investigated by conducting drop weight impact test characterize with different drop heights displacement. Drop weight test was performed and average data was collected for each specimen, which is also included maximum impact force, impact energy, impact damage area, and time were evaluated and compared. The experimental result found that the energy absorbing effectiveness factor increases with the increasing of the impact energy. Same goes to the increasing of the impact force, it were also increasing the impact energy, respectively. A consequent damage was inspected visually and obvious when the impact energy is high, the energy absorbed by the specimen also high and hence, propagation of the impact damage area was also increased. Therefore, the significant mark of indented will be displayed clearly on the damage area mostly on upper facesheet.

Keywords: Low velocity impact, composite sandwich structures, honeycomb core, drop weight, energy absorption.

INTRODUCTION

Sandwich structures provide an efficient method to increase bending rigidity without significant increase in structural weight. Besides the perfect bending resistance and stiffness, high corrosion resistance, low thermal and acoustic conductivity are the major advantages of theses system over monolithic materials. Due to these excellent properties, composite sandwich structures are widely used in the aerospace, marine, aeronautics, and automotive industries [1]. When two layers of material are separated by another material they make a sandwich. Composite sandwich structures usually consist of two high stiff thin layers of composite separated by relatively soft and low density core material [2]. Commonly used materials for skins or facesheet are composite laminates and metals such as steel, stainless steel, aluminum, and fiber reinforced polymer material [3]. While, cores are made of metallic and non-metallic such as thermoplastic honeycomb, web, balsa or foam, corrugated [4]. Each element plays and important role in providing strength and resistance towards damages. The facesheet in the sandwich resist in-plane and bending loads. The core separates the facesheet to increase the bending rigidity and strength of the structures and transfers shear forces between the face sheets [5]. Also helps to stabilize the facesheets and defines the bending stiffness and out-of-plane shear compressive behavior [6]. However, sandwich structures are mainly exposed to variety of causes that can minimize their behavior especially under low velocity impact loading. This behavior can be explained by several mechanisms such as fiber breaking, crack propagation, debonding of the facesheet from the core and delamination in the facesheet after impact. Impact damage in sandwich structure may arise due to poor resistance to localize impact loading, which can cause permanent damage and reduce the capacity to bear load leading to premature failure to the sandwich structures [7].

All Sandwich construction provides efficiently by utilizing the material used for each component up to its ultimate limits [8]. It's getting wider as this structure has excellent stiffness to weight ratios [9]. It enhances the structure flexural and bending rigidity without adding substantial weight, which is leading to weight reduction and fuel consumption [3]. So, it gives more advantages as compared to monolithic material. Besides, they also have high structural crashworthiness because they are capable of absorbing large amounts of energy in a sudden collision [10]. Nowadays, various combinations of core and face sheet materials are being studied by researchers worldwide in order to achieve improved crashworthiness [10].

A number of studies have been carried out to investigate the impact response of sandwich structures. Zheng *et al*. [11] studied quasi-static perforation and low velocity impact test by using a material test system and a drop weight machine, respectively. The load and displacement response, energy absorption and energy absorbing effectiveness of sandwich panels are obtained and compared for quasi-static and impact test. Followed by Ramesh, Saraswathy, *et al*. [12] investigated the low velocity impact response of aluminum honeycomb sandwich panels. Results of their experiments showed that variation in core thickness of aluminum honeycomb core does not show any significant change in energy absorption capacity of the sandwich panels but it increases the time taken to reach peak energy which is desirable for many applications like automobile bumper. Daiva, *et al*. [13] performed experimental investigation of deformation behavior of sandwich structures with honeycomb core in the case of quasi-static and dynamic loading in this study. During the study, the composite are made non-metallic materials. Currently, most of scientific studies only showed the simulation of the impact phenomena and

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impact behavior of studied material under different loading conditions. Therefore, the aim of this study is to investigate the properties of composite sandwich structure with non-metallic facing made from glass fiber reinforced plastic (GFRP) and thermoplastic honeycomb core made from polypropylene (PP) for it can be used to improve the impact performance and resistance towards impact damage under several drop height of indenters.

METHODOLOGY

Materials properties

The composite sandwich structures made of glass fiber reinforced plastic (GFRP) and epoxy resin with a polypropylene (PP) honeycomb core was investigated in this study. Code of honeycomb used PP8RT40F indicates that the core is made from polypropylene (PP), were supplied in sheet form of large flat panels with 7 mm wall-to-wall cell sizes and both hexagonal sides of the core are laminated with 40 g/m^2 non-woven polyester tissue by Qingdao Polycore Technology Co., ltd. A thickness of 30mm was investigated in this study with the density of 80 kg/m3. The face sheet used in the composite sandwich structure was 1.0mm thick glass fiber reinforced plastic (GFRP) consists of 920 kg/m^3 density, with excellent thermal resistance characteristics and lightweight. The adhesive consist of epoxy resin with hardener were used to bond together both facesheets and core element; the composite sandwich structure ready to be tested after 8 hours of curing process in room temperature. The properties of the core and the facesheet materials are presented in Table-1.

Table-1. Properties of sandwich structure component.

Properties	Core materials	Face sheet Materials
Density (Kg/m^3)	80	920
Elastic Modulus (Gpa)	1.02	3.5
Shear strength (Mpa)	0.53	-
Compressive Strength (Mpa)	2.05	-

Specimen fabrication

In this experiment, the given dimension for the specimens is follow according to ASTM D5628 standard. The specimen for the low velocity impact test was cut in rectangular shape with 60 x 200 mm^2 dimensions with 30mm of thickness by using jigsaw cutting machine as shown in Figure-1. Sandwich structures were fabricated by using hand lay-up method as shown in Figure-2. Prior to cure the sandwich panel was primed using the araldite epoxy adhesive primer. The cure was performed in room temperature and normal pressure was applied to the panels in order to make sure the adhesive were uniformly distributed on the surface where the core and facesheet interface.

Figure-1. Cut the honeycomb into 60 x 200 mm^2 dimension.

Figure-2. Hand lay-up process for drop weight test specimen.

Test method

Impact test were conducted using a 2.1 kg instrumented drop weight impact machine with 12.5 mm diameter hemispherical nose indenter, as shown in Figure-3. The specimens were tested at different drop heights release from 0.2 m up to 1.0 m. By varying the drop height, the impact energies can be determined. The impact force was measured using Kistler 9333A piezo-electric load cell located above the indenter. The variation of time was recorded by dedicated computer respectively. During the impact test, specimens were supported on two 12.5 mm diameter of stainless steel cylindrical movable support. Test on the sandwich panels was based on 30 mm thick core with 60 mm wide specimen supported over 156 mm span estimated according to ASTM D5628-10 drop weight test standard. For average purpose, three specimens of each drop height were tested as to obtain the accuracy of the results. The energy absorption of the structures was computed by multiple the mass of indenter, gravitational force and height of drop weight.

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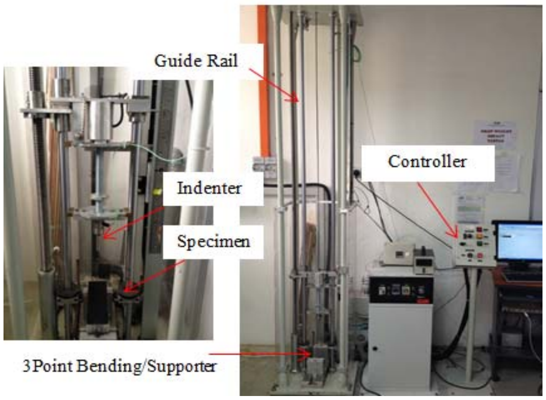

Figure-3. Drop weight impact machine.

RESULTS AND DISCUSSION

Impact properties of the sandwich structure

As illustrated in Figure-4, it shows the average of maximum impact force versus impact energy and impact damage area experience impact test on five different drop weight height varied between 0.2m, 0.4m, 0.6m, 0.8m, and 1.0m. Based on the figure, it clearly visualize that when the impact force increase it will increasing the impact energy. This means that, by increase the height of the drop weight displacement, it will affect by increasing the impact force under impact loading since the more higher drop weight is took place, the composite sandwich structure was able help to absorb the impact energy which also resulting in damage initiation across the sandwich panels [14]. To be clearer what is meant, Equation.1 describes the correlation between the impact energy and the drop weight height response to the sandwich panels.

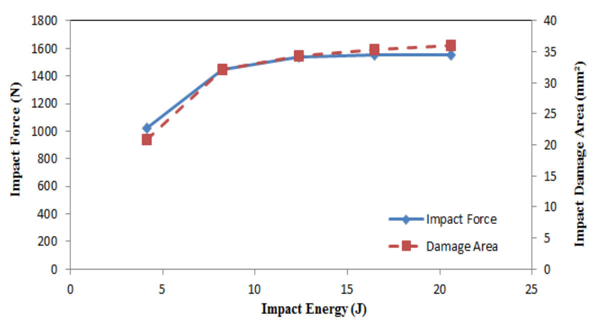

Figure-4. Effect of impact energy (drop heights) on the maximum impact force and impact damage area for core thickness = 30mm.

$$E = mgh \tag{1}$$

Where E is represent the impact energy, m is the mass of indenture, g is the gravitational force, and h is the drop heights. As mentioned before, by increase the height of the drop weight displacement, it will affect by increasing the impact force and hence, the impact energy absorption on the sandwich panels also increases. Increased the energy absorption is also initiation and development of damage or crack propagation on sandwich panels [15]. Based on observation, when the impact energy is low, the panel is only partially dent and most impact energy is absorbed by the sandwich structure, so the energy to maximum load or to failure is approximately equal to the impact energy [16]. As the impact energy continues increases, full dent take place and some kinetic energy may remain in the impact mass, as seen in Figure-4. Based on the observed results, the maximum impact force increased gradually in the composite sandwich structure from 0.2 to 1.0 m with 0.2 m as the lowest which was 1018.667 N. Then, it increased to 1444.333 N for 0.4 m. Again, the force further increased to 1535.333 N, 1550.667 N, and 1551 N for 0.6 m, 0.8 m, and 1.0 m. Hence, the maximum impact loading that the sandwich structural can withstand is 1551 N at height of 1.0 m.

In additional, energy absorption effectiveness factor gradually increases with the increasing of the impact energy and the failure are more concentrate at the localized area underneath of the indenter and leave dent marks and hence, suffering from crack propagation and de-bonding between the face-sheet and the core. The damage occurred illustrated the condition of the structure under impact that causes the panels reduce its load bearing capacity. From the figure, it can be observed that as the impact energy increased, the impact damage area also continues increased along the impact energy. From the result observed, the lowest drop height weight exhibits localize damage only incriminate at the facesheet surface. At the lowest drop height, the facesheet are thick and stiff enough to withstand the impact and bending load against it, and the core is rigid enough to withstand shear stress from the impact, and only small dent mark were occurred seen on the top facesheet. The observation also shows that by increased the drop height displacement, the core was suffered from the shear load that consequent from the high impact force comes from the indenter and transform it into permanent damage and hence, propagate crack and delamination between the facesheet and the sandwich core, and dented mark obviously seen at the area where indenter hits.

Effect of maximum impact force under time response

The maximum impact force and time curve behaviour for composite sandwich structures at five different impact loading levels were shown in Figure-5 which also indicate as force-time history. The impact force and time response of five impact events exhibit similarity in trends with a complex series of peak, where overall curves can approximately divided into two parts at the maximum impact force [15].The first part is pre-dominantly related to damage initiation. The force is increase linearly at the beginning of loading, it indicated the purely elasticity response of the specimen, and no damage is expected to occur if the impact loading stopped at this stage.

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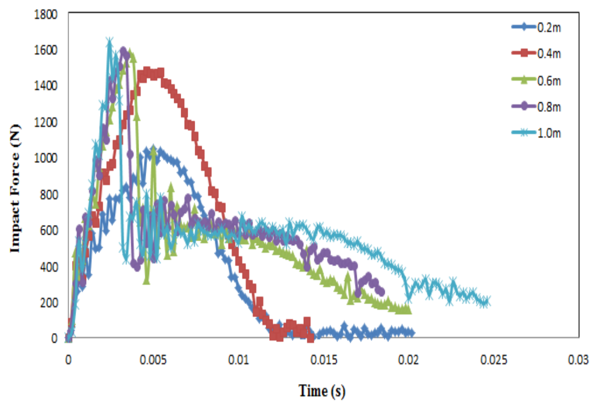

Figure-5. Maximum impact force and time curve behaviour for composite sandwich structure under drop weight impact test.

When, the impact loading in further increased, there are significant damage initiation regions, where occurs at different load in different time. Then, the second part is mainly associated with damage propagation in which the force has a monotonically decreasing with increasing the time. The impact force and time traces similar to those in penetration impact testing but implications are fundamentally different. In the case of penetration impact, load drops are associated with major damage propagation. Hence, non-penetration impact test, the load drops are associated with both elastic and plastic deformation. The indenter bounces upwards from the specimen surface due to elastic collision [15]. On the behalf of the results obtained, the maximum impact force increased gradually from 1048 N at 0.2 m to 1637 N at 1.0 m of drop heights respectively with the time response.

Failure mechanism under drop weight impact test

The impact damage of low velocity impact have shown in Figure-6, where circular mark of impact area was seen under seen under microscope with 50x magnification on the impacted side at center of the sandwich structure facesheets. Based on the observation, we can visualize that the higher drop weight of the indenters released and impacted the sandwich facesheet, the impact damage area seen more clearly and suffered from indent damage on the facesheet and hence, reduced more load bearing capability for the structure. The results was supported by the previous studies, it has been shown that low velocity impact may significantly reduce the load carrying capability of a composite structure by as much as 50% of reduction [17]. On the behalf of the results obtained, at the 1.0 m of drop weight height give significant of indentation damage on the facesheet panels with 36.1 mm^2 of impact damage area. Compared to the 0.2 m of drop weight height, where only give 20.9 mm^2 of impact damage area.

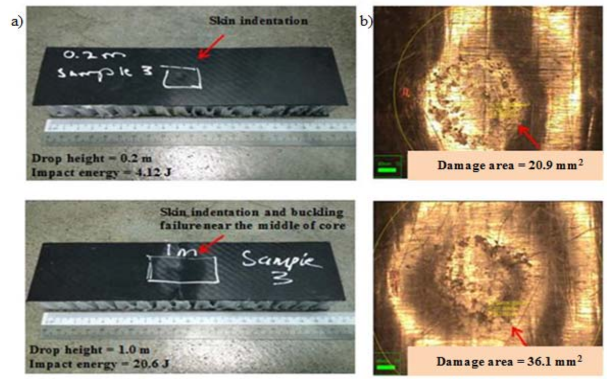

Figure-6. Damage characteristic drop weight impact test by (a) visual inspection, (b) microscope with 50 x magnifications.

CONCLUSIONS

The behaviour of thermoplastic honeycomb sandwich core made from polypropylene (PP) laminated with non-metallic facesheet made from glass fiber reinforced plastic (GFRP) was investigated under drop weight impact test. Based on the experiment, results found that the impact force increases with the indenter displacement up to a first peak force point associated to the failure of the upper facesheet. Afterward, the force suddenly drops to a valley and then small increase took place with the thermoplastic core crushing and distributed the impact until the lower facesheet fails and the specimen loses its load carrying capacity. It also was found that the energy absorbing effectiveness factor increased with the increasing of the impact energy. Same goes to the increasing of the impact force, it were also increasing the impact energy, respectively. When the impact energy is high enough, the energy absorbed by the specimen in impact test is higher and hence, propagation of the impact damage area was also significantly increased. From the result and discussion concluded that the higher drop weight displacement took place, the higher impact force and energy the specimen will absorbed. The significant mark of indented will be displayed clearly on the damage area, especially in sandwich facesheet.

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