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# STUDY ON DAMAGE MODES OF A SANDWICH PANEL IMPACTED REPEATEDLY

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## ABSTRACT

This paper describes an experimental investigation for determining the damage modes under low energy impact-fatigue of sandwich panels consisting of aluminum skins supported by honeycomb core made of aluminum. Square samples of 125mm by 125mm sides and 10mm thickness (skin of 0.6mm and 8.8mm of core) were subjected to impact fatigue loading using a testing machine at four different energy levels (2J, 3J, 5J and 7J). The square plates are clamped in a fixture system over a 100mm diameter hole. Three different diameters of impactor head (15mm, 25mm and 35mm) are used to study their influence on life duration of the sandwich plates. Some parameters such as impact number, damage area at impact face and development of cracks were evaluated and compared. The experimental results showed that impact fatigue responses and damage mechanisms of sandwich panels were affected significantly by the energy level and impactor diameter.

**Keywords:** aluminum sandwich panels, honeycomb core, damage, repeated impact, impact energy, impact fatigue life.

## INTRODUCTION

Sandwich panels made of stiff face sheets and compliant low density core materials result in high stiffness lightweight structures having good mechanical properties and energy absorbing capacity. There is a lot of interest in sandwich structures particularly in applications related to aerospace, automobile industries, energy, and marine technologies. As the range of applications expands, there is increased need to understand the behavior of sandwich structures under a wide range of loading conditions and environments. This poses special challenges to experimental mechanics in characterizing the loading and deformation and failure response of sandwich structures (Ravichandran, 2012). The understanding of their behavior under impact conditions is extremely important for the design and manufacturing of these engineering structures since impact problems are directly related to structural integrity and safety requirements.

Sandwich structures can experience low velocity impact both during manufacturing and during service. Such sandwich structures offer potentially good damage-tolerance, since the core can absorb impact energy by local plastic deformation whilst still affecting enough overall support to prevent high local bending strains in the skins (Besant, 2001).

Several works were performed to identify the damaging modes in sandwich structures subjected to low energy impact (Foo, 2008, Paik, 1999, Crupi, 2012, Aktay, 2005, Jeon, 2012). The damages are generally induced in the impacted skin, and in the core and in the impacted skin-core interface. Moody and Vizzini (2002) have demonstrated that under impacts of very low energy levels, the impactor deflects the surface and the skin rebounds.

There was no visible damage to the panels; however, the cell walls of the core were crashed. Higher energy impacts cause the skin to have a permanent indentation at the impact site.

However, several experimental works, aiming to better understand the different damage mechanisms under impact of sandwich structures, have shown that skin damage develops linearly with incidental energy, until a maximum value is reached (Plam, 1991, Gottesman, 1987).

The damage of the core, in addition to cracking, fracture can occur by buckling of cell walls (honeycomb core). Finally, the authors (Tomblin, 2002) reveal that debonding is the main physical mechanism responsible for the rupture of the interface.

However, less work has been performed on sandwich panels impacted repeatedly. Then, the aim of this work is to describe an experimental investigation for determining the damage modes under low energy impact-fatigue of sandwich panels consisting of aluminum skins supported by honeycomb core made of aluminum.

## EXPERIMENTAL PROCEDURE

A series of impact-fatigue tests were conducted on sandwich panels consisting of aluminum skins with aluminum honeycomb core. Square samples (Fig.1a) of 125mm by 125mm sides and 10mm thickness (skin of 0.6mm and 8.8mm of core) were subjected to impact-fatigue using a testing machine (Fig.1b) at four different energy levels (2J, 3J, 5J and 7J). For more details refer to the work of Azouaoui (2010, 2007). The square plates are clamped in a fixture system over a 100mm diameter hole (Fig.1c). Three different diameters of impactor head (15mm, 25mm and 35mm) are used to study their influence on life duration of sandwich plates.

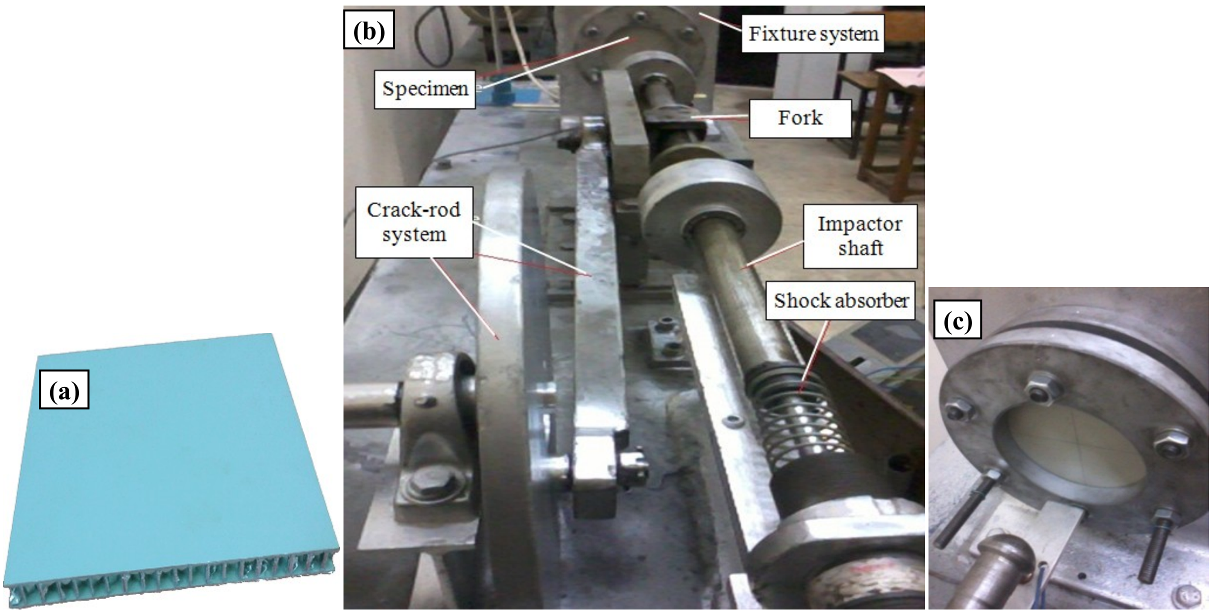


Fig.1 Specimen (a), impact-fatigue machine (b) and fixture system (c)

The material properties of the skins and core materials are given in tables 1 and 2.

Table 1 Material properties of the aluminum honeycomb core

| Property | value |
|---|---|
| **Density [kg/m$^3$]** | 82 |
| **Through-thickness Shear modulus [MPa]** | 430 |
| **Through-thickness Shear strength [MPa]** | 2,4 |
| **Compression strength [MPa]** | 4,5 |

Table 2 Material properties of aluminum skin

| Property | value |
|---|---|
| **Young modulus [GPa]** | 70 |
| **Tensile strength [MPa]** | 367 |
| **Elongation to failure (%)** | 13 |

## RESULTS

In this experimental part we are interested in the influence of impactor diameter on impact-fatigue life duration of sandwich plates. The results show that under same impact energy, the number of impacts to rupture (perforation) increases with diameter of impactor. These results are probably due to the load distribution at the contact between impactor and sandwich panel, one can say when the sample impacted by an impactor of large diameter, the pressure distribution will be distributed over a large surface, which improves the service life comparatively to an impact with an impactor of small diameter. The estimate of the damaged area to the specimens is done by delimiting the area of damage by the calculation of a circular area including the damage. This is due to the fact that the actual surface is complex to assess. This approach is already used by Fan et al. (2011).

Fig.2 shows the damaged area (perforation) on the impacted face, for three impactors of different diameters (15mm, 25mm and 35mm), relatively to an impact energy of 3J.

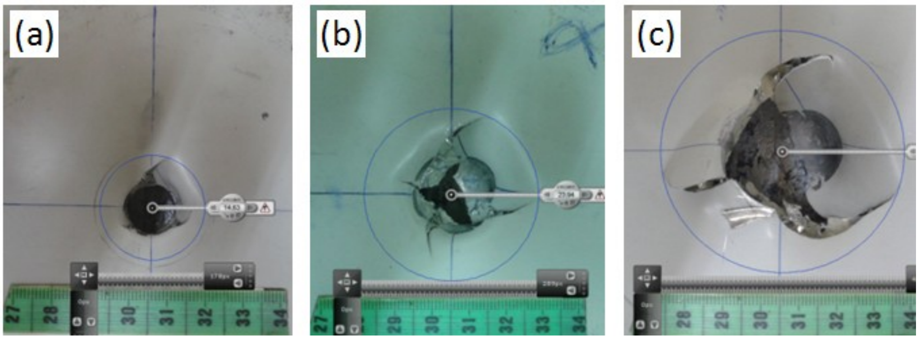


Fig.2 Estimated damage area for different impactors of different diameters
(a) Ǿ=15mm, (b) Ǿ=25mm, (c) Ǿ=35mm

The use of three impactors of different diameters reveals a dimension of damage and a number of impacts to failure increasing with diameter, as shown in Fig.3 and Fig.4.

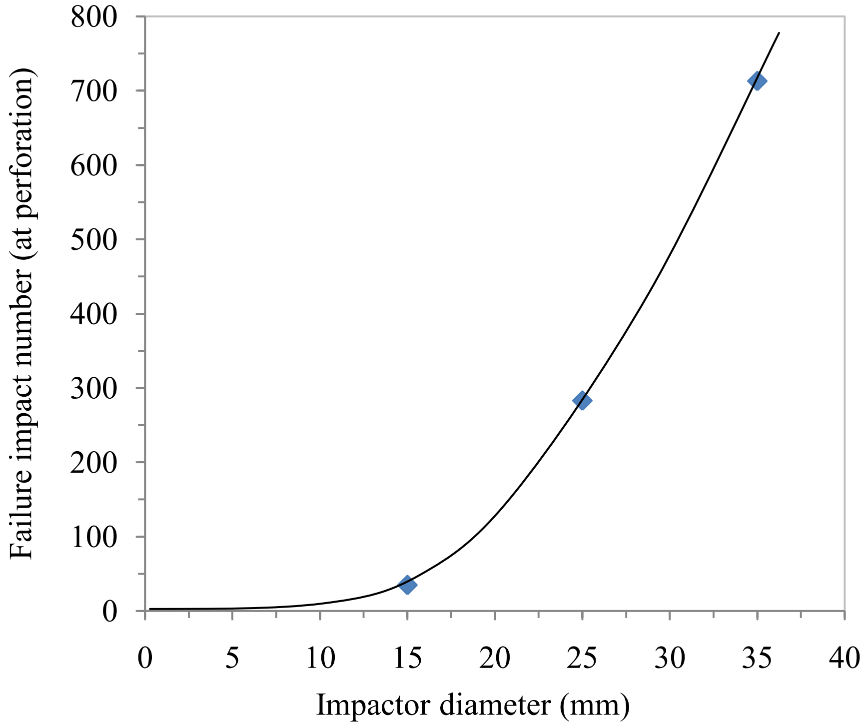


Fig.3 Failure impact number vs projectile diameter (impact energy of 2J)

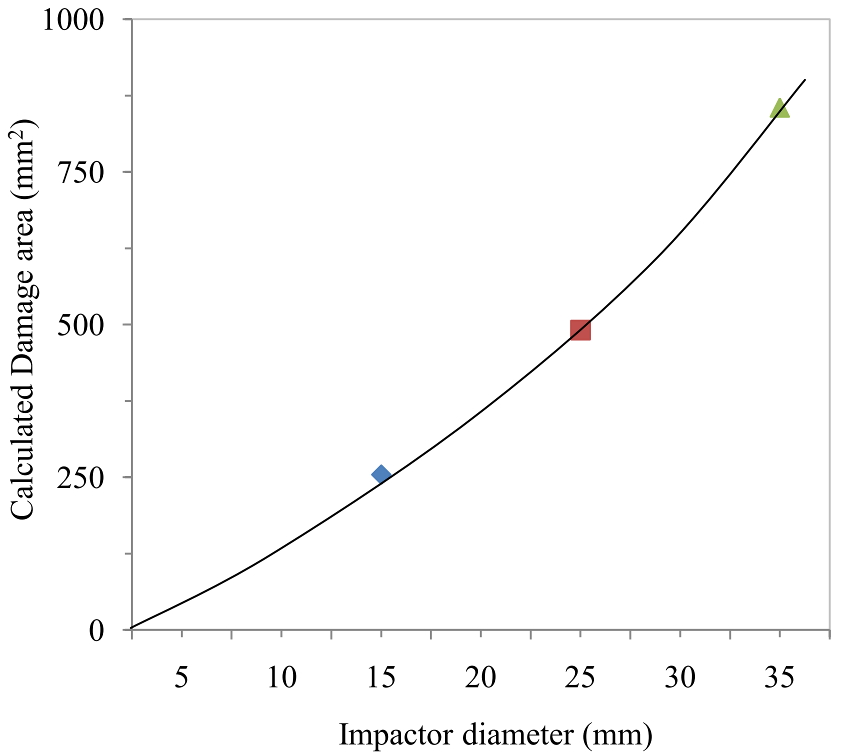


Fig.4 Calculated damage area (skin front face) vs projectile diameter (2J)

Fig.5 shows different pictures taken during impact-fatigue tests under impact energy of 2J. A hemispherical indentation clearly visible on the impact face indicates that impact causes a permanent deformation of the skin of the sandwich, in addition to the crushing of the core. Beyond 18,000-20,000 impacts, three cracks initiate in the upper skin in three different places. When Nida cells cede, under the point of impact, the perforation occurs fairly quickly, tearing the skin below.

The damage modes inventoried are: localized buckling of the core, the core cracking, permanent indentation under the point of impact, cracking of the impacted skin, debonding of the skin-core interface.

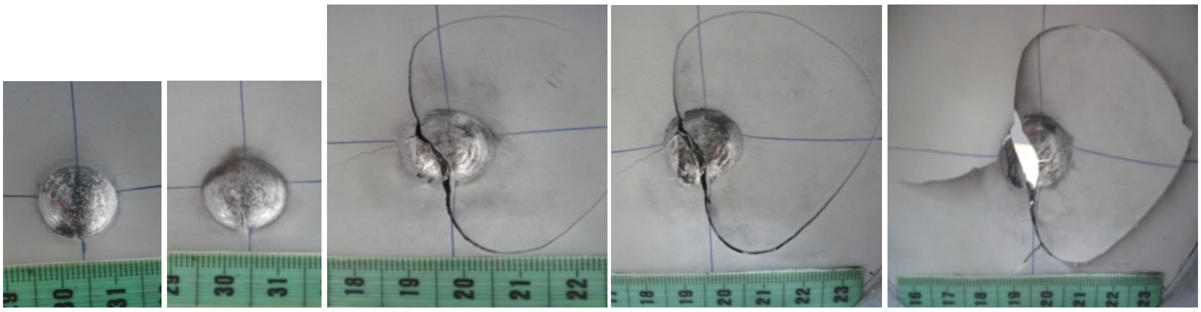

Fig.5 Front face at 8,000 - 12,000 - 20,000 - 28,000 and 30,986 impacts (2J)

The comparison of damage area, represented by the “footprint” left by the impactor on the impacted face (crater shape), for the same number of impacts, brings up the undeniable effect of impact energy on the damaging of sandwich panels (Fig.6).

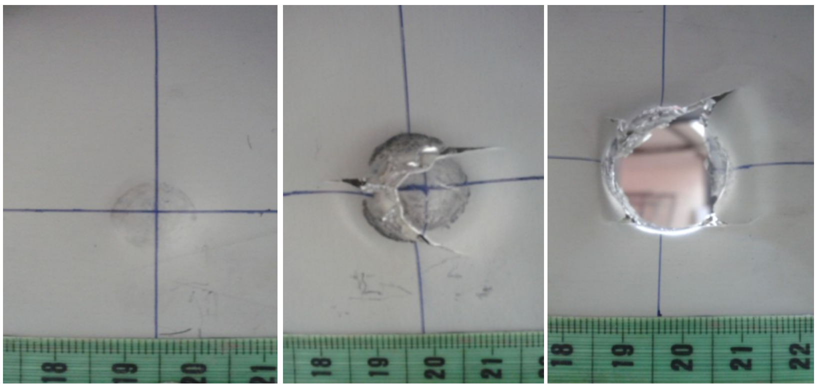

Fig.6 Impacted face under 3J, 5J and 7J (number of impacts: 10)

The evolution of calculated damage surface based on the number of impact is manifested in two phases: a first zone of acceleration of damage (the early impacts) and a second phase of slower damage, until failure (Fig.7). For the lowest energy, this development is in three phases: the two phases listed above, followed by a third phase of accelerated damage until perforation (Fig.8). Damage to the upper skin is manifested by the initiation and growth of three cracks whose lengths increase with the number of impacts, following curve paths (Fig.9). It should be noted that cracks numbered 1 and 2 propagate until they meet each other at the same point.

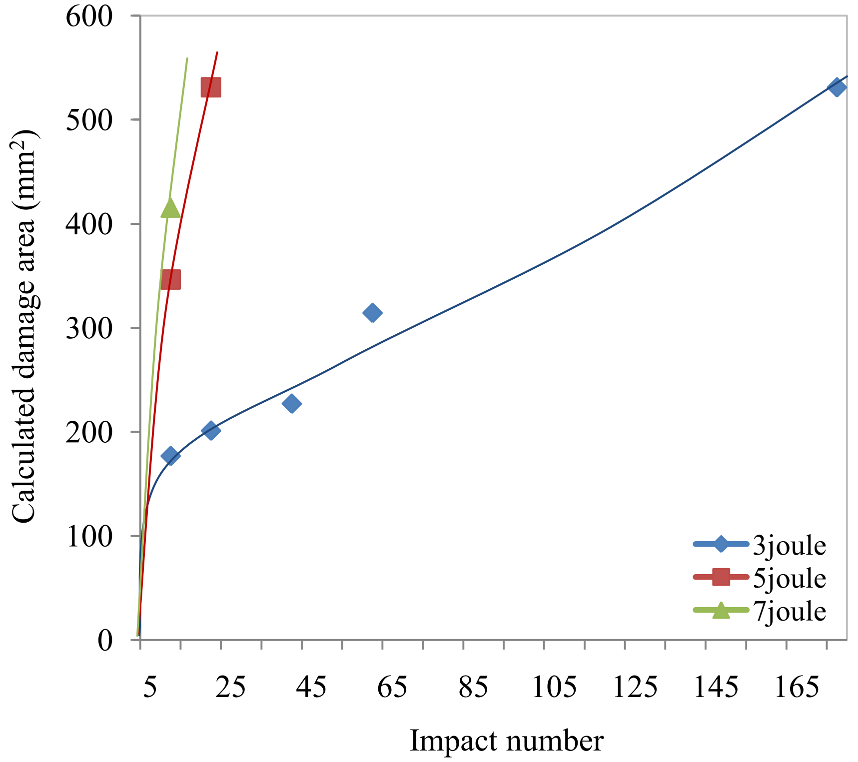


Fig.7 Evolution of calculated damage area with number of impacts under different energy levels 3J, 5J and 7J

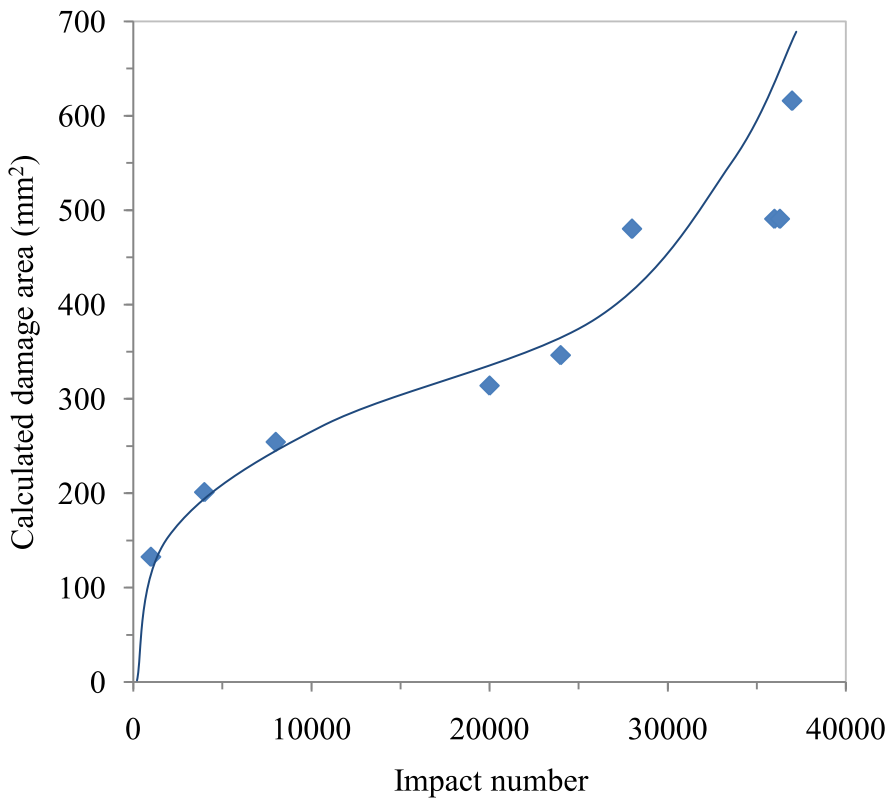


Fig.8 A three phase evolution of damage area in function of number of impacts under an energy level of 2J

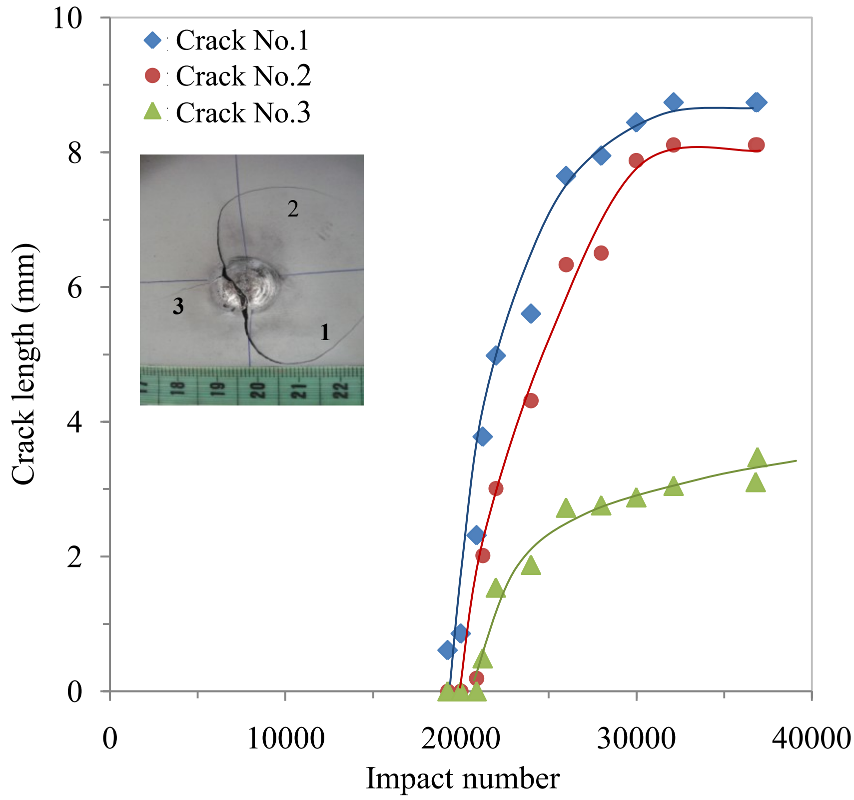


Fig.9 Crack length (three cracks numbered 1, 2 and 3) vs impact number (2J)

One can easily see that the plotting of the curve representing impact energy in function of number of impacts to failure shows a characteristic curve of classical fatigue loading (Fig.10).

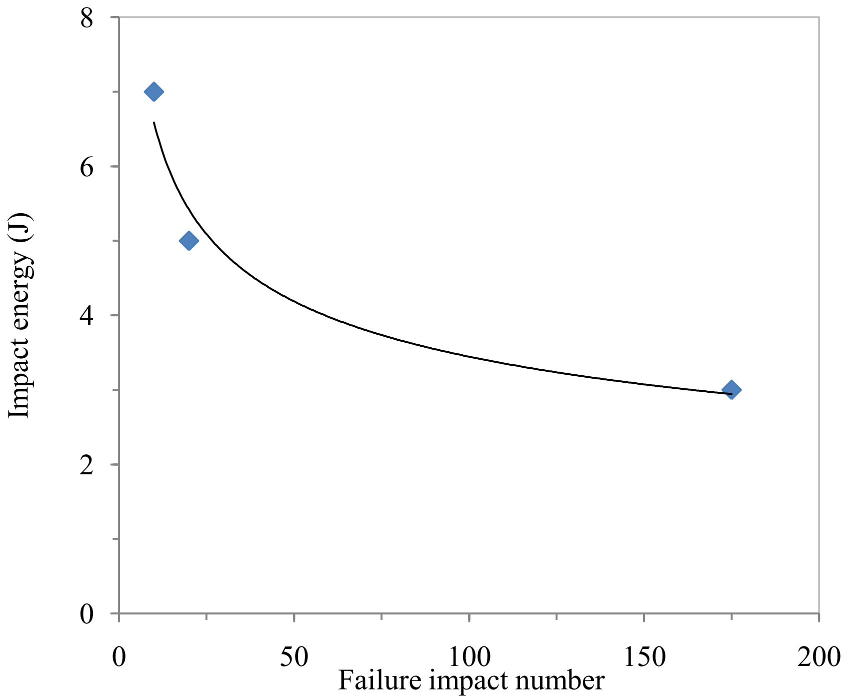


Fig.10 Impact energy versus failure impact number

## CONCLUSION

Damage occurs by a slight indentation located at the upper skin, followed by a crater, characteristic of impact-fatigue test using a hemispherical impactor. The dimension of the crater increases with number of impacts and diameter of the impactor. After a number of impact (about 19,000 impacts for energy of 2J), three cracks initiate and propagate rapidly on the upper skin of the sandwich.

The influence of the impact energy (2J, 3J, 5J, 7J) is clearly demonstrated. Indeed, the highest energy levels cause earlier the perforation of sandwich plates, at a smaller number of impacts. On the other hand, it was noted that the impact energy has a significant effect on the damage strength of sandwich structures, more impact energy is low and more damage area is high. This is tantamount to a greater consumption of energy available by damage and not by perforation. This energy balance is reversed when energy becomes more important.

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