COMPARISON OF SINGLE AND DOUBLE IMPACT DAMAGE ON CARBON/EPOXY LAMINATES SUBJECTED TO HYGROTHERMAL AGEING

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Abstract
This paper studies the effect of impact damage on carbon/epoxy laminates which have undergone hygrothermal ageing. Three stratifications have been chosen whereby the first layup is the classical type used in the industry and the other two are of quasi-isotropic/quasi-homogeneous properties consisting fibres orientated at ±45° and ±60°. The specimens were aged at 70°C with a relative humidity of 85% in a climatic chamber up to 2100h and impacted directly after exiting the climatic chamber. Ultrasonic C-scan was used to analyse the damage before the specimens were placed back into the climatic chamber for the second phase of ageing and the second impact test.

1 Introduction

There is a high possibility of damage occurring to composites from the time it has been fabricated up to and while the composite serves its purpose. A drop of an object, be it heavy or not, would result in damage; the extent of damage dependent on many factors such as energy, layup, impactor shape. This damage may not be visible to the human eye or may seem insignificant, although the internal effect is unknown, thus it is important that the consequences of such an incident be investigated to understand the structural effect on the composite. The probability that a new impact of such an occurrence is unlikely but possible, the extent of damage being an important contributing factor to the lifespan of the composite, thus leading to the investigation of damage caused by dual impact at the same zone.

Many studies have been carried out on the impact of composites. Such studies range from experimental to computational analysis. Davies and Zhang [1] described a method of predicting internal damage due to low velocity impact on carbon composites. Hitchen and Kemp [2] carried out an experimental investigation into the effects of layups on impact damage. Parvarateddy et al [3] researched on the resistance and tolerance to impact damage when the composite is subjected to environmental ageing. Schoeppner and Abrate [4] investigated the level of load at which delamination is propagated during low velocity impact. Shyr and Pan [5] studied the damage characteristics of composite laminates due to low velocity impact.

Although there are numerous studies on impact, not many are on multiple impacts. An example of a study on multiple impact is by Morais et al. [7], who studies the macroscopic damage by repeated low energy impacts on a carbon composite using a phenomenological equation which is found to successfully describe the behaviour of the composite and is dependent on the stacking sequence. Thus, the importance of this study is obvious due to the lack of research in multiple low velocity impact on aged composites.

2 Materials and testing methods

2.1 Material

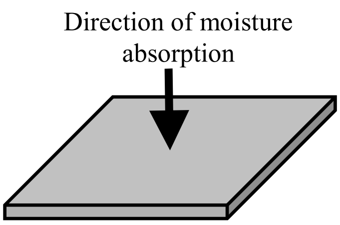
The composite specimens were prepared from a unidirectional carbon fibre prepreg (TR50S/R367-2): high tensile strength fibre and 120°C cure-type epoxy resin, supplied by STRUCTIL, France. Three stacking sequences of 24 plies were cured in a 400 mm x 400 mm mould under a hot press. The three stacking sequences, as seen in Table 1, are of the classical layup used in the industry (Aero) and the other two of quasi-isotropic/quasi-homogeneous mechanical properties with ply orientation of 45° and 60° (QIQH 45° and QIQH 60°).

Name	Ply Orientation
Aero	$[45/90/-45/0]_{3S}$
QIQH 45°	[90/0/-45/45/-45/45/0/45/90/-45/90/0/90/0/45/0/-45/90/-45/45/-45/45/90/0]
QIQH 60°	[0/60/-60/60/0/-60/0/-60/-60/60/60/-60/0/60/60/0/0/-60/0/-60/60/0/60/-60]

Table 1. Specimen stratification

2.2 Preparation of specimens

Impact plates of about 100 mm x 100 mm were cut from the 400 mm by 400 mm plate. The weak borders of specimens to undergo hygrothermal ageing treatment were covered with aluminium foil using aradite 2014, as in Figure 1, to ensure that moisture absorption occurs in the transverse direction. The dimensions and weight of the specimens were measured, and visual and ultrasonic analyses were done to ensure the quality of the specimens before ageing treatment.



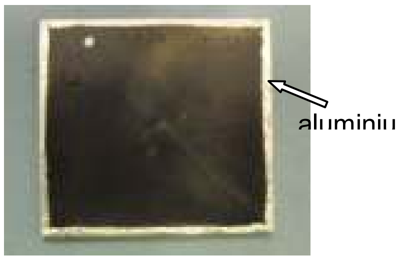


Figure 1. Moisture absorption during ageing

2.3 Water absorption test

The pre-weighed dry specimens were placed in a climatic chamber at 70°C and 85% relative humidity for duration of up to around 2000 h (i.e. 90 days) when saturation state is obtained. The weight gain was regularly measured using a high precision weight scale with an accuracy of 0.01 g and moisture absorption was calculated using the following equation [6]:

$$M_t = \frac{W_t - W_0}{W_0} \times 100(\%) \tag{1}$$

where M_t is the moisture at time *t*, W_t is the weight at time *t*, and W_0 is the initial weight before ageing treatment.

2.3 First impact test

A low-velocity impact test was carried out using a drop weight impact test machine, Instron Dynatup 9250HV, with a hemispherical impactor, of 12.7 mm diameter, at room temperature. The impact test machine is equipped with an anti-rebound system to prevent multiple impacts. The standard parameters used for the impact tests are 20J of energy using a drop weight of 4.7 kg dropped from a height of 0.44 m at a velocity of about 2.9 m/s. The impulse data acquisition software measured and recorded the impact load, velocity and deflection during impact. The damage due to impact was inspected via ultrasonic C-scan system using a 10MHz transducer in pulse-echo mode and is viewed in two-dimension, whereby the project damage area is analysed, as seen in figure 2.

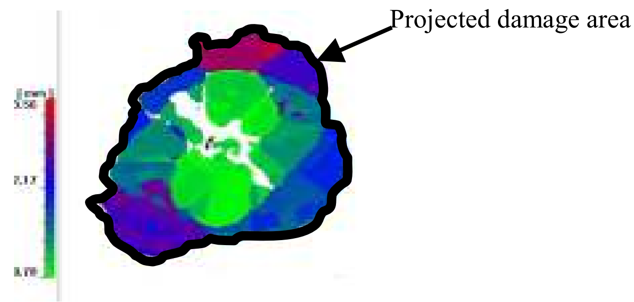


Figure 2. C-scan image and the projected damage area taken into account

2.4 Second impact test

After completing the analysis of the first impact test, the specimens underwent a second hygrothermal ageing so that the total ageing time amount to 2200 h. The weight was measured to calculate the moisture absorption for the second ageing phase and the specimen is again impacted using the same parameters. A repeated analysis is executed.

3 Results and discussion

3.1 Water absorption

Ageing results in an increase in mass due to the absorption of moisture in the composite matrix. The same trend is observed for all three stratification, as seen in figure 2, where the moisture absorbed increases linearly up to about √30 and then increases steadily up to stabilisation. The linear increase occurs at a gradient of about 0.0315 to a moisture uptake level of about 1% and a steady increase occurs thereafter up to stabilization at about 1.16%. The ageing trend is in accordance to Fick's law for all three stratification and the same evolution of mass increase is observed as all three have the same volume of fibre and matrix as moisture diffusion only occurs in the transverse direction. This trend is similarly seen in the research by Chen and Springer [6]. The diffusivity is calculated from the graph to be between the range of 1.78 and 1.86 x 10^{-3} mm²/h, as seen in Table 2. The difference between the diffusivities is 2 to 4%, therefore there is no great difference between diffusivities of the three stratifications.

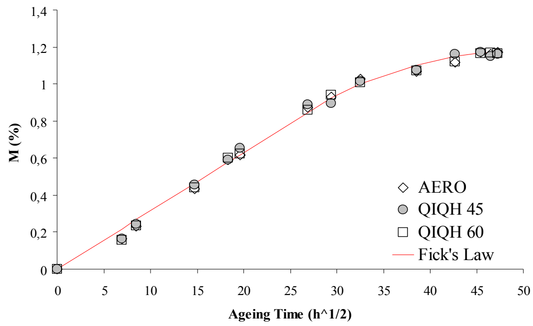


Figure 3. Moisture uptake during the first ageing phase

Stratification	k	h (mm)	M (%)	D (mm²/h)
Aero	0.0315	3.55±0.06	1.16±0.034	1.82E-03
QIQH 45°	0.0316	3.54±0.05	1.15±0,033	1.86E-03
QIQH 60°	0.0315	3.54±0.06	1.17±0,043	1.78E-03

Table 2. The calculated diffusivity of the specimens

3.2 Impact test results

The two graphs obtained from the impact test, in Figure 4, show the force versus time and force versus deflection for all three stratifications at ageing times of 1 month, 2 months and 3 months. Analysing the graphs of force versus time, it is observed that after the peak force is reached, a drop in force is observed. This phenomenon is known as the damage threshold load [4], whereby the drop in force denotes the initiation of damage. Comparing the force-time diagrams, it is observed that the specimen aged for 1 month is more brittle as there seem to be more drops in force observed in the graph. The peak force is seen to increase by 2 to 14% with increasing ageing time. The force-deflection graphs show a slight decrease in energy absorption as the area under the graph denotes the energy absorbed during impact. The maximum deflection is seen to increase with increasing ageing time, thus being more flexible due to increased moisture absorption in the matrix.

A graph of projected damage area versus ageing time, as seen in Figure 5, show a slight increase in projected damage area with increase in ageing time. The damage area is smallest in AERO, but was observed to be more constant in QIQH 45° with respect to ageing time. The greatest damage was observed in QIQH 60°, where the projected damage area is also seen to increases the most with increase in ageing time.

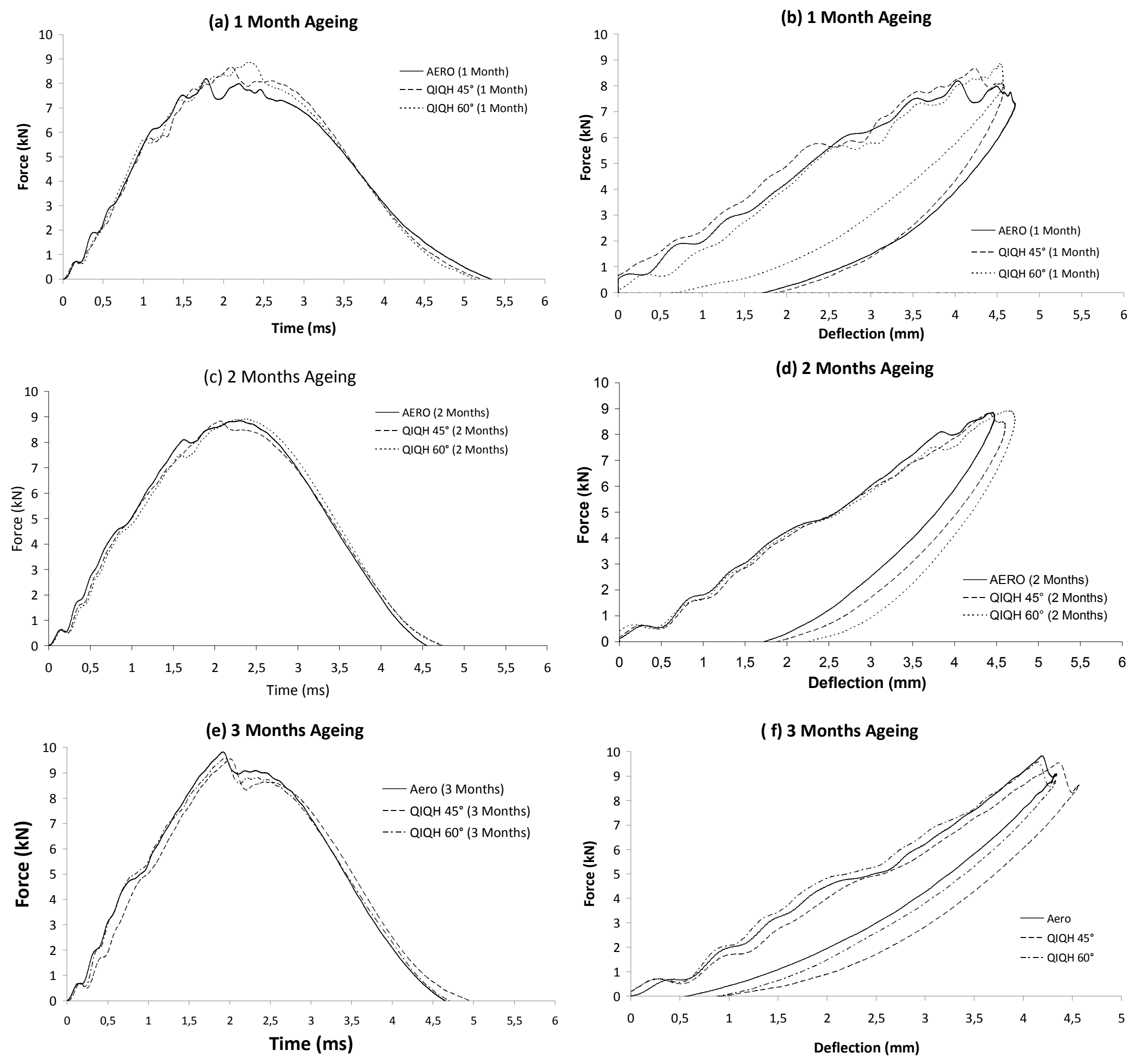


Figure 4. Force versus time and force versus deflection graphs for an impact at different ageing times

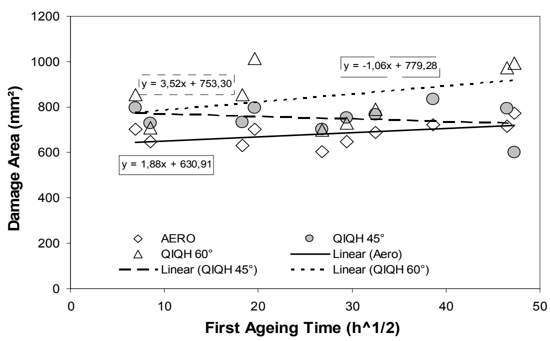


Figure 5. Damage area due to impact for all three stratifications for the first impact

3.3 Second ageing phase

After the first impact, the specimens were aged again, and a mass increase is again observed. The graphs in Figure 6 show the trend of mass increase for all three stratification with respect to the trend of the first ageing phase. The moisture absorption tends to follow Fick's law, when the specimens had not reached stabilisation during the first ageing phase. For specimens with first ageing time 2 days, the moisture absorbed during the second ageing phase is observed to increase when weighed at regular intervals for all three stratification. This occurrence may be due to the damage from the first impact which caused fissure cracks, thus enabling an increase in absorption. Specimens with first ageing phase 2 weeks, seems to have the same increment in moisture as the first ageing. The absorption is seen to decrease according to the increase in first ageing time. This is also probably due to the fact that the less the first ageing phase, the farther away from saturation state, thus the higher absorption.

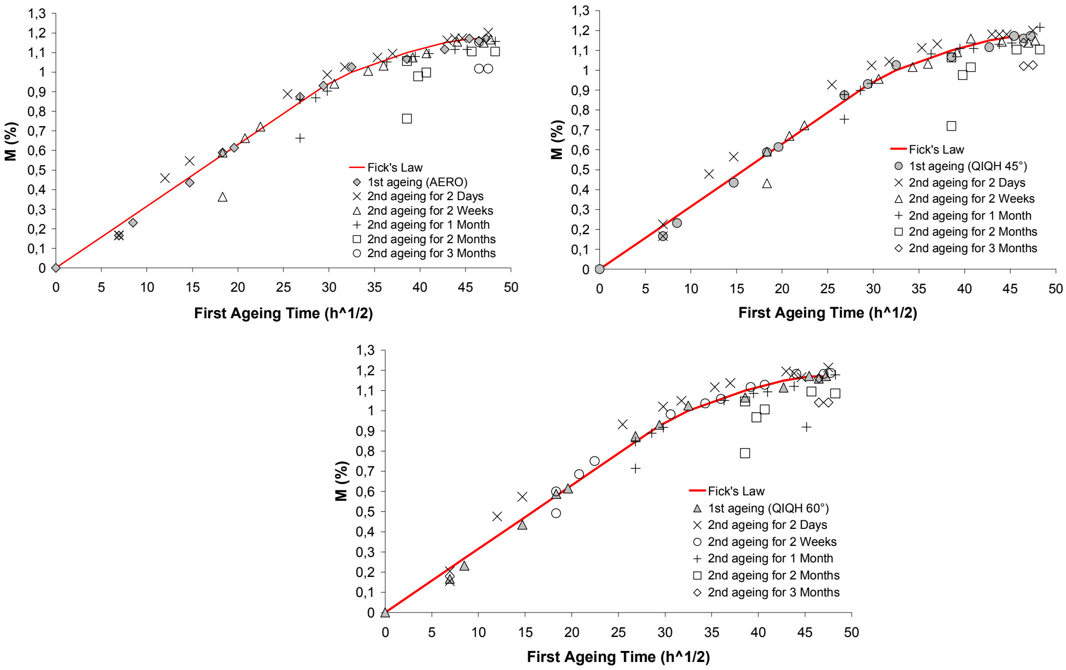


Figure 6. Moisture absorption during the second ageing phase for all three stratifications

3.4 Second impact test results

Results from first and second impacts can be observed in Figure 7, whereby the force versus time and force versus deflection can be compared for specimens which had undergone the first ageing time of 3 months. A 10 to 20% drop in the peak force is observed for the second impact, and the contact time has increased by about 10 to 20%. The drop in peak force is more significant for AERO. QIQH 60° shows a major drop in force, which probably denotes a greater damage effect due to the second impact. From the force-deflection curves, an increase in energy absorption and an increase in deflection were observed during the second impact. AERO and QIQH 60° seem to have a greater effect due to the second ageing and second impact. The results obtained are similar to the study by Morais et al [7].

Figure 8 shows the total projected damage area for damage caused by the second impact. Figure 8 (a) show that there is a slight increase in damage area for AERO and a slight decrease for QIQH 45°, whereas QIQH 60° is affected more significantly by the second ageing phase and impact, as a drastic increase in damage is observed.

When comparing the damage area between the first and second impact, as shown in Figure 8 (b), (c) and (d), there is an overall increase in damage area when comparing the first and second impact. For AERO, there is a similar increase in damage area for the first and second impact, and the increase is between 5 to 28%. QIQH 45° has a damage increase of 6 to 36%, whereas for QIQH 60°, the increase is between 5 and 43%. The damage area is more significant for QIQH 60° as the difference in the damage area trend between the first and second impact.

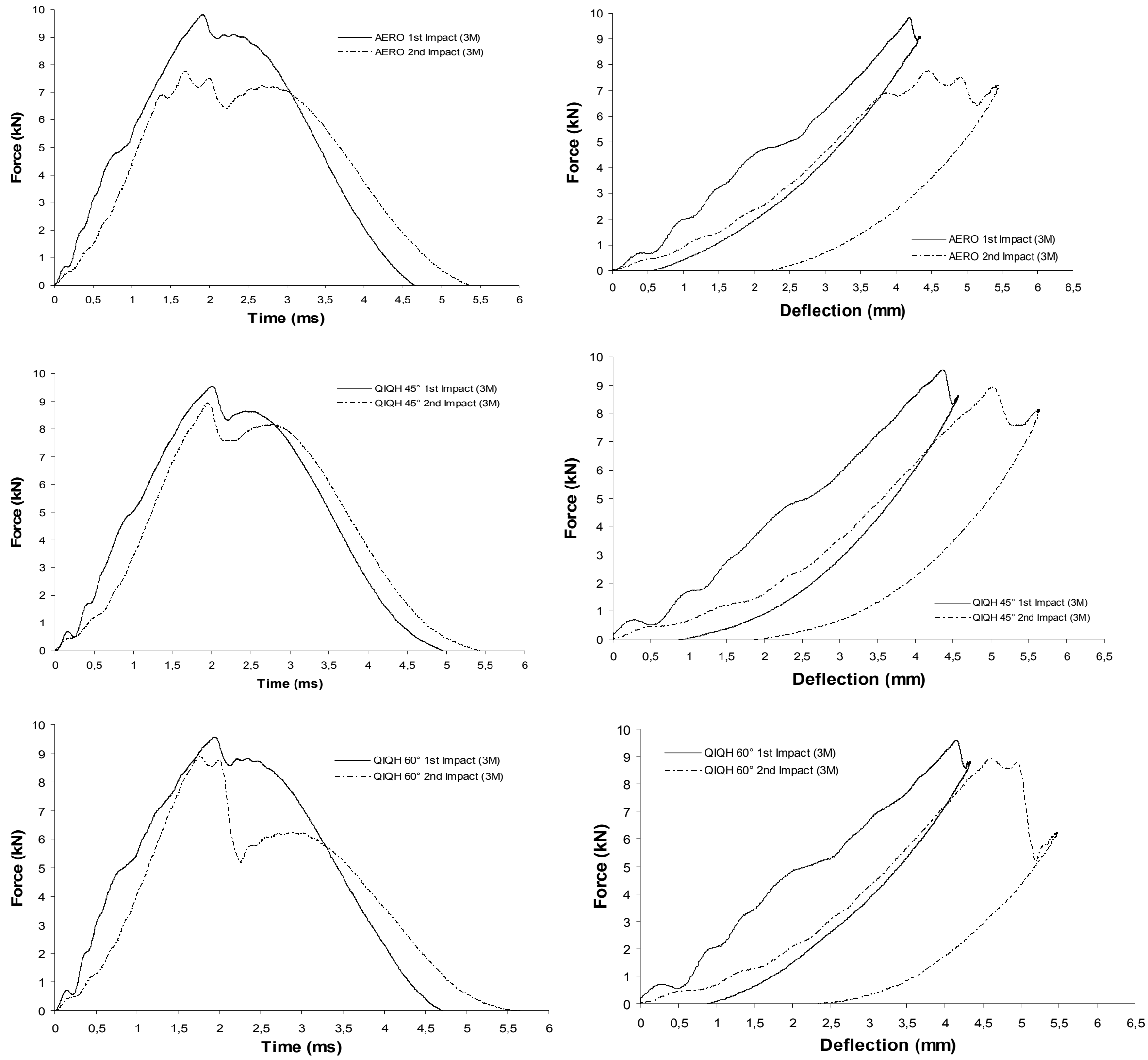
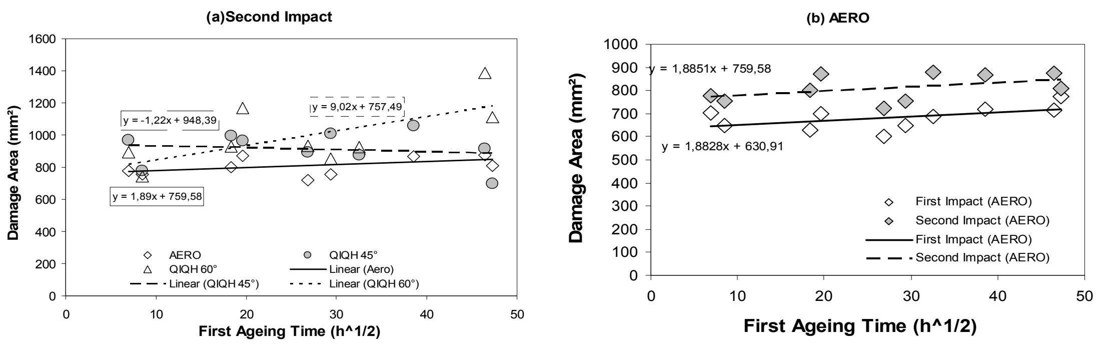


Figure 7. Comparison between first and second impact for all three stratification



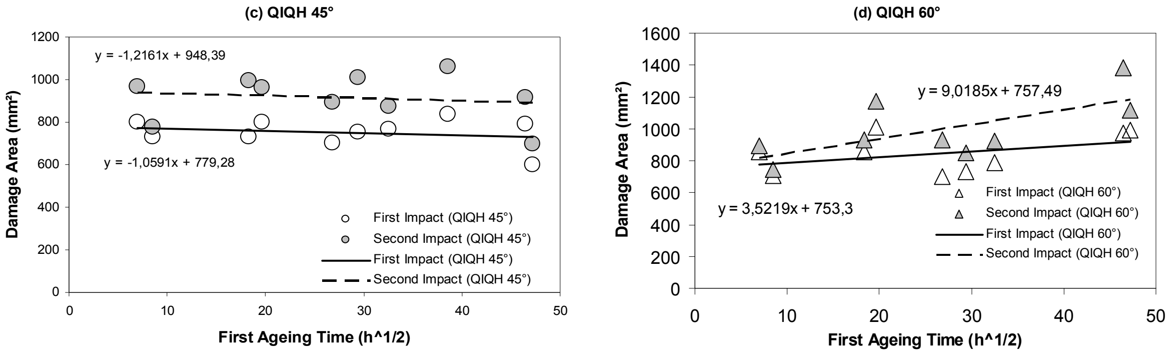


Figure 8. Projected damage area for (a) the second ageing phase for all three stratification; first and second ageing phase for (b) AERO, (c) QIQH 45° and (d) QIQH 60°

4 Conclusion

From the preliminary analysis of the effects of first and second ageing and impact on carbon/epoxy composites, it is observed that from both the first and second ageing phase, a mass increase is observed due to moisture absorption in the transverse direction of the specimen, as in accordance to previous findings by Chen and Springer [6]. The composite material seems slightly more brittle during the early stages of ageing, which is obvious in the force-time graphs where there are more delamination occurrences than when compared to the later stages of ageing even before stabilization state is achieved. The second impact is observed to have a longer contact time, less peak force and more energy absorption. The damage is constant in AERO and QIQH 45° as the same trend is observed between the first and second impact, whereby the damage is seen to increase more significantly for QIQH 60°. Since the total projected damage area is taken in this study, the relationship of cross-ply orientation to the extent of damage is not obvious, thus requiring the study of damage in three-dimension to be able to conclude the extent of damage in between plies.

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