INFLUENCE OF STACKING SEQUENCES ON IMPACT DAMAGE OF PRE-STRESSED ISOTROPIC COMPOSITE LAMINATES

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Keywords: *Impact, laminates, stacking sequence, damage*

Abstract

The aim of the present study is to show the influence of uniaxial tension on impact damage sustained by composite laminates.

Three specific stacking sequences were evaluated. Two of the sequences give quasi isotropic and quasi-homogeneous behaviour; the third is a classic lay-up being quasi isotropic for in-plane stress but anisotropic in bending.

Specimens were simultaneously tensioned and impacted. The damaged areas were ascertained using ultrasonic C-scans. It was observed that the extent of damage increased significantly with increasing tensile load. Furthermore results show that both load direction and stacking sequences affect the amount of delamination between layers.

Overall results indicate the important role played by bending properties in the impact damage signature of composites.

1 Introduction

Composite structures are likely to receive accidental impacts during fabrication and maintenance from falling objects which may damage them. However the most damaging impacts occur when the structures are in service under working stresses. Although the damage may not be spectacular it will lead to a weakening then to early failure of the structural element concerned [1].

The parameters that determine the impact damage response of a structure are many and varied but it is convenient to group them into three main categories; materials parameters (types of fibre and resin, lay-up; structural parameters (size and shape, boundary conditions) and loading parameters (type, associated energy, environmental conditions) [2].

This study examines the influence of applied tensile load on the type and the extent of impact damage. It follows on from previous work that showed the importance of the role of bending strength on the post impact damage morphology of carbon epoxy material.

Three types of lay-up were chosen for this study, two of which give isotropic properties in both in-plane and bending and the third being in-plane isotropic and anisotropic in bending.

Results are analysed to explain the influence of pretensionning levels and orientations, the bending properties and the lay-up on impact damage response in composite materials having identical mechanical properties.

2 Materials and lay-up

All specimens were laid up using high modulus carbon fibres and epoxy resin (NCHM 6376 resin and M40J fibres, Structil France). Main mechanical characteristics are presented in Table 1 below

Table 1: Experimentally derived mechanical properties of UD ply

E11 (GPa)	E22 (GPa)	G12 (GPa)	ν12	Xt (MPa)	Yt (MPa)
103	7	3.1	0.34	2000	44

Composite plates 400x400 mm, thickness 4.8 mm were made using hot-pressing conditions recommended by the materials supplier (2h at 125 °C under 7 bars). All plates had 24 layers of UD materials orientated as shown in Table 2.

Table 2: Specimen lay-ups used in this study

Ref	Stacking sequence
A	[90/0/-45/45/-45/45/0/45/90/-45/90/0/90/0/45/0/-45/90/-45/45/-45/45/90/0]
B	[0/60/-60/60/0/-60/0/-60/-60/60/60/-60/0/60/60/0/0/-60/0/-60/60/0/60/-60]
C	$[45/90/-45/0]_{3S}$

By using the polar method for predicting materials properties, it is relatively straightforward to choose different stacking sequences that give the same mechanical properties [3] provided the number of layers is sufficiently high. Specimen type A (Table 2) is quasi-isotropic and quasi-homogeneous (QIQH) with no coupling effect, the elastic behaviour being equivalent to that of an isotropic material.

Specimen type B is also defined as QIQH with no coupling effect but with only 3 distinct fibre orientations.

Specimen type C is less balanced than the first two with pronounced in plane anisotropy and an almost perfect isotropy in bending. The type C sequence was included in this study as it is widely used in the aircraft industry and is referred to as being quasi-isotropic although this is only strictly true in-plane.

This sequence is differentiated by the fact of having 45° fibre orientations on the outside surface which is considered to give better impact resistance [4].

Figure 1 shows the polar diagrams (moduli) of the three stacking sequences using a normalised scale. For type A specimens the elastic behaviour is identical to an isotropic material having a Young modulus of 39 GPa and a Poisson' ration of 0.32.

The main values obtained from the analysis, flexural and in-plane moduli and their angles are presented in Table 3.

Actual test specimens, 60 mm wide by 165 mm long, were cut from the plates using a diamond wheel. Aluminium end tabs 62 mm x 35 mm x 2.5 mm were bonded to the specimens prior to testing.

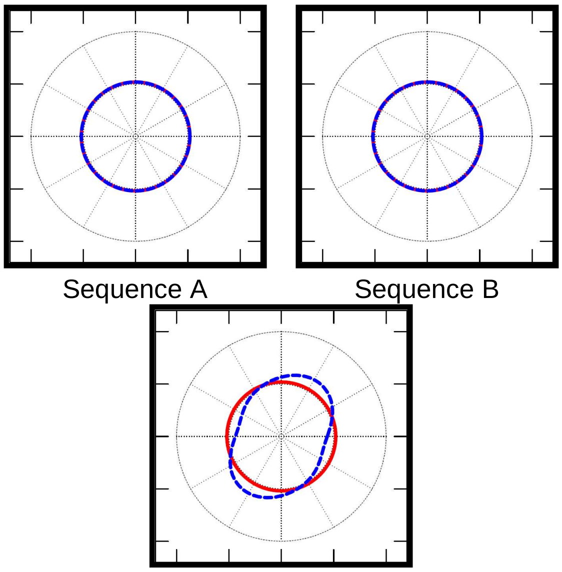

Figure 1: Polar diagrams presenting moduli of each of the stacking sequences used in this study

Table 3: Calculated values of in plane flexural moduli for the three stacking sequences used in this study

Seq.	In plane stiffness min (angle)	In plane stiffness min (angle)	Bending Stiffness max (angle)	Bending Stiffness min (angle)
A	39,2 MPa (-)	39,2 MPa (-)	39,2 MPa (-)	39,2 MPa (-)
B	39,2 MPa (-)	39,2 MPa (-)	39,2 MPa (-)	39,2 MPa (-)
C	39,2 MPa (-)	39,2 MPa (-)	48,3 MPa (53°)	30,5 MPa (168°)

3 Impact testing and damage assessment

The apparatus used in the experiments consists of a horizontal load frame of 5 tonnes capacity fitted with conventional tensile jaws. An existing drop test rig was modified so as to be able to impact the specimens without interfering with the jaws. The impactor cradle with 20 mm diameter nose weighs 2.625 kg (Fig.2). Theoretical impact energy wavaried by adjusting the drop height.

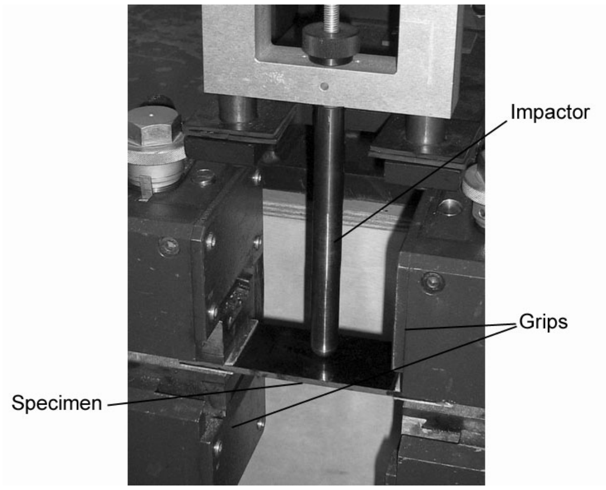

Figure 2: Testing apparatus

The extent of damage was assessed using immersed C- Scan analysis with a 10 MHz transducer by measuring the acoustic signal attenuation and also flight times of the acoustic impulses. Signal attenuation measurements are useful in measuring the distance the crack front has travelled from the point of impact whereas flight time measurements enable the positioning of the damage through the material thickness. In this study, the test parameters used where based on earlier work which examined impact damage on un-tensioned carbon/epoxy specimens. Figure 3 is an illustration of the type of damage encountered with our specimens, which shows the influence of material bending properties on the type and extent of impact damage as a function of impact energy level.

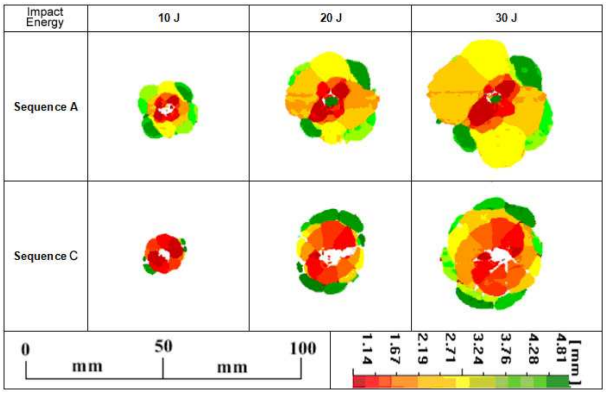

Figure 3: Damage morphology for different sequences and three energy levels

Thus, in the present study, it was possible to choose an impact energy value that was capable of inflicting a sufficient amount of damage so as to be readily detected while at the same time avoiding any interaction with the free edges of the specimens; this value was fixed at 20 J. The maximum tensile load applied was 45 kN which corresponded to about 70 % of the breaking stress of the first ply for each stacking sequence, hence avoiding any tensile degradation of the material before impact.

4 Results and discussion

The results are presented in Figures 4, 5, and 6 for the range of tests carried out ; three stacking sequences impacted under four imposed tensile loads (three tension loads and zero load) and in two specimen orientations. For each point on the graphs three specimens were tested; standard deviation did vary a little with stacking sequence but the results fell within a narrow band around 0.15.

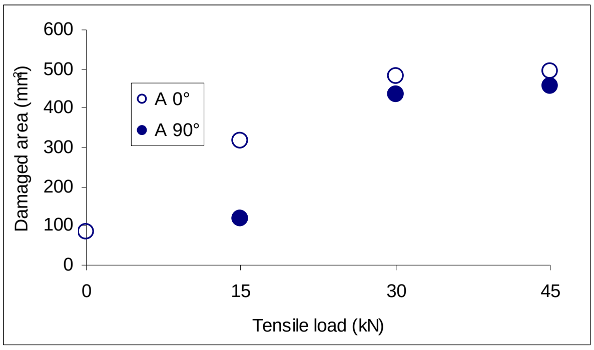

Figure 4 : Damage area versus tensile force (Sequence A)

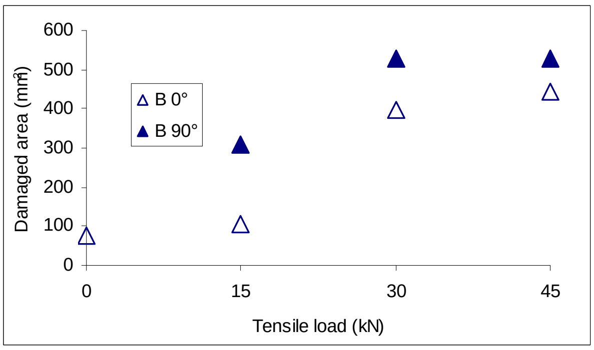

Figure 5 : Damage area versus tensile force (Sequence B)

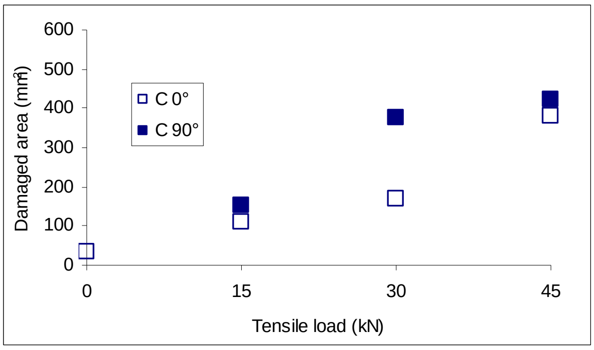

Figure 6: Damage area versus tensile force (Sequence C)

As damage zones were small for zero load specimens then only the 0° orientation was tested.

From Figures 4 to 6 it can be seen that overall behaviour is similar for the three types of stacking sequence. All specimens show increased vulnerability to impact damage once they are under tension; damage area is increased over five times for the highest tensile load. Although not enough experimental data is available to substantiate a definite value, the results seem to suggest that there could be some threshold value of tensile stress that would encourage delamination propagation, probably less than that equivalent to the 15 kN load. By the same token doubling the applied stress more or less doubles the damage area whereas tripling the applied stress does not increase impact damage. This infers that there is some single stress-induced damage mechanism.

4.1 Influence of the load direction on delamination propagation

Figure 7 groups the C-scan results obtained for the three stacking sequences after impact at 20 J under a 45kN load in both 0° and 90° directions. It would seem that there is little directional effect with the sequences chosen, with B and C only showing a slight tendency of "drawing out" the impact damage in the load direction.

It has been shown that tensile loading has the effect of increasing the impact force [5]. Other studies have shown strong correlation between this increased impact force and the extent of the delaminated zone. In view of these findings and the results observed in this study it would seem that the threshold tensile stress mentioned above was achieved but that applied loads were insufficient to trigger the impact load amplification effect.

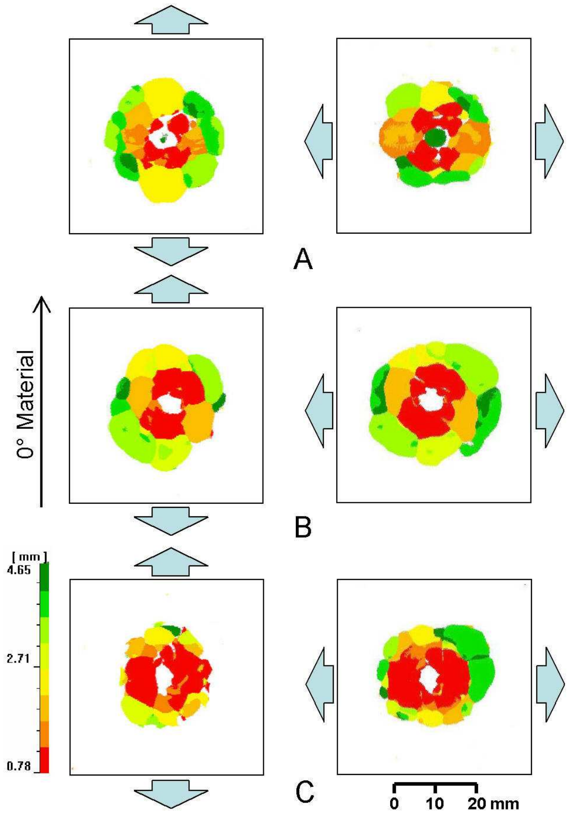

Figure 7: Delamination versus tensile direction

4.2 Influence of bending properties

Of the three stacking sequences tested it is interesting to note that the extent of impact damage is restrained up to a tensile load of 30kN in the 0° degree material direction rather than the "step" behaviour noted for sequences A and B. In fact sequence C has a pronounced anisotropy in bending with a 25% difference between the 2 directions tested in the study; direction 0° coincides with the lowest bending stiffness and confirms previous observations that high flexural stiffness leads to more extensive impact damage.

4.3 Influence of stacking sequence

Sequences A and B are identical in bending isotropy, see Table 3 and, as could be expected, impact damage is very similar, indirectly confirming the role of the bending stiffness in the propagation of impact damage. However, there is a systematic difference in the results obtained for the directions designated 0° and 90°. In fact these are quite arbitrary directions and should have little meaning for isotropic material. The quite marked differences in impact damage zones as a function of applied load direction for the 15kn load level are not clear. The narrowing gap as load level increases suggests that some internal mechanism of crack propagation is able to facilitate the growth in all directions; Figures 4 and 5.

5 Conclusions

Results obtained in this study show a direct link between impact damage propagation and the presence of some existing applied stress.

For the stacking sequences studied there seems to be some critical stress level that must exist before damage moves into another mode and thereafter can be seen to increase with increased applied stress.

The extent of any impact damage is dependant on the respective bending stiffness of the materials.

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