Propagation of a Crack in a Composite Plate

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In this paper, a model of a composite plate with a central elliptical cut-out and with an initial fissure was subjected to a tension load in the finite element method (FEM) software Abaqus to observe the propagation of that crack during a certain amount of time that elapsed in the FEM analysis. Due to symmetry, only half of the plate was modeled, as a shell, and the extended finite element method (XFEM) was used for the crack. The material properties that were assigned to the plate were taken from the database of the Ansys Mechanical software. In the vicinity of the crack a finer mesh was applied to be able to better observe the evolution of the fissure and the changes of the Von Misses stress graphs for each time step of the analysis.

Keywords: Crack Propagation, Abaqus, XFEM, Composite Plate

For designing and fabricating a strong, resistant composite material, that doesn't break very easily, an important factor that is necessary to be analyzed is how cracks form and propagate in different combinations of materials, based on their purpose. The propagation of the cracks can be influenced by some fabrication flaws, for example there can be flaws related to the fibers, matrix porosity, interfacial porosity, etc. The existence of these flaws can reduce the durability of the material, the cracks propagating faster and easier [1].

Because cracks are one of the possible defects that can appear in composite materials, there is an interest in simulating the propagation of these cracks, to be able to predict the initiation of a crack, in which direction it will propagate, how much time it takes until a structure made from a certain composite breaks due to cracking, etc. [2].

There have been multiple studies that have analyzed different aspects of crack propagation, under different types of loading cases.

Some researchers [3-5] studied the fracture behavior of composites under static loading conditions, this being a simplification of what happens in reality, when there are more complex, dynamic loading cases [2].

There are also numerous studies on the behavior of cracks in composite materials subjected to dynamic loadings [6- 8] and fatigue loading cases [9, 10].

In 1999, Ted Belytschko created the extended finite element method (XFEM) [11]. Multiple crack propagation studies [2, 12, 13] have used this method, since then, for some of its advantages when it comes to meshing models with fractures. In the last decade the various meshing methods have been used for the modelling of multilayered polymeric composites, like in [14, 15], where so static and dynamic analysis is studied.

Experimental part

Model description

In this paper an epoxy-glass composite plate with a central cut-out was analyzed using the Abaqus software. The dimensions of the plate (fig. 1) were 3000 mm length, 2000 mm width and the central elliptical cut-out had 1500 mm total length with a radius of 500 mm at each end. An initial crack of 150 mm was also modeled for the extended finite element method. Only half of the plate was modeled, with symmetry conditions.

The following boundary conditions have been applied to the model (fig. 2):

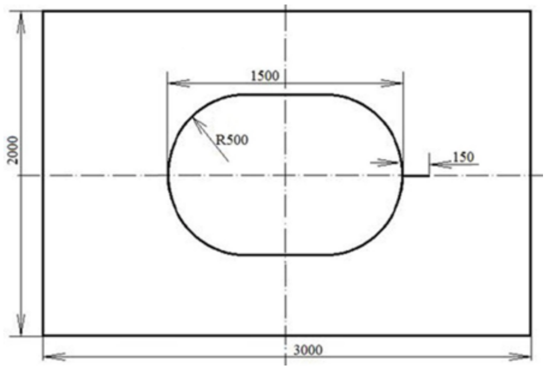

Fig. 1. The geometry of the plate with a central elliptical cut-out and a crack (dimensions in mm)

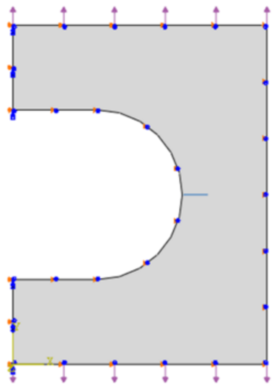
Fig. 2. The boundary conditions and the tension pressures applied to the analyzed model

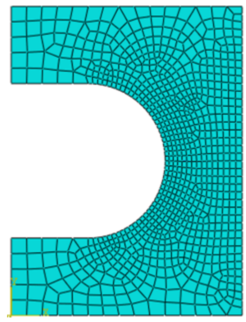
Fig. 3. The mesh used for the analysis

-the translation on the x axis and the rotation around the z axis were blocked on the contour of the model

-symmetry conditions for the other half of the plate

On the top and bottom contour lines of the shell model tension pressures of 100 - 500 MPa were applied.

A quadrilateral mesh was used (fig. 3), with an approximate global size of 100 millimeters. Around the crack and also on the right contour line, more elements were applied. This was done so that the difference in size of the elements wasn't very big in the vicinity of the crack and to improve the accuracy of the results.

Results and discussions

FEM analysis

After the maximum number of increments (1000) and the increment size (initial 0.02; minimum 1e-007; maximum 1) have been set, a static analysis was run. The

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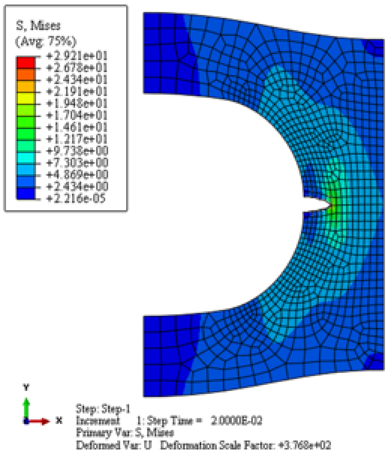

Fig. 4. The Von Misses stresses [MPa] for the first increment of the analysis for an applied tension pressure of 100 MPa

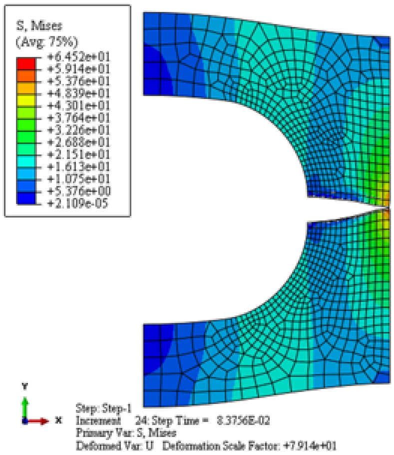

Fig. 5. The Von Misses stresses [MPa] for the increment of the analysis when the plate model breaks, for an applied tension pressure of 100 MPa

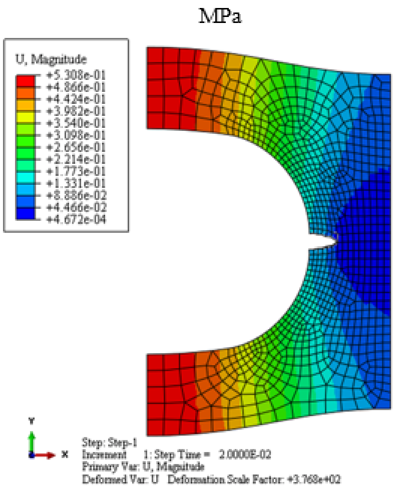

Fig 6. The displacement values [mm] for the first increment of the analysis for an applied tension pressure of 100 MPa

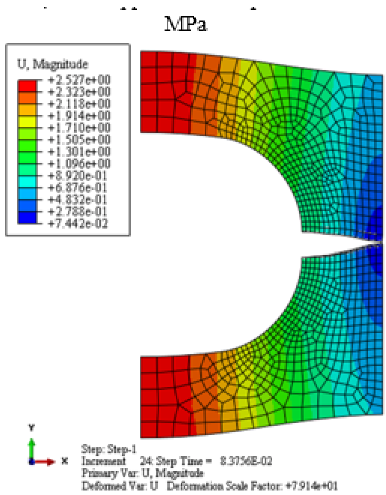

Fig. 7. The displacement values [mm] for the increment of the analysis when the plate model breaks, for an applied tension pressure of 100 MPa

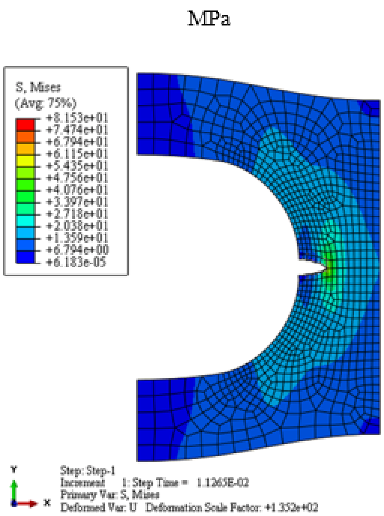

Fig. 8.The Von Misses stresses [MPa] for the first increment of the analysis for an applied tension pressure of 500 MPa

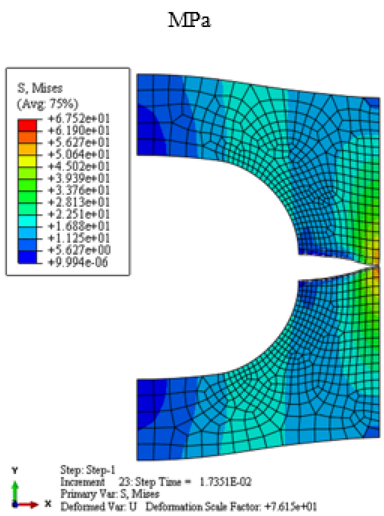

Fig. 9. The Von Misses stresses [MPa] for the increment of the analysis when the plate model breaks, for an applied tension pressure of 500 MPa

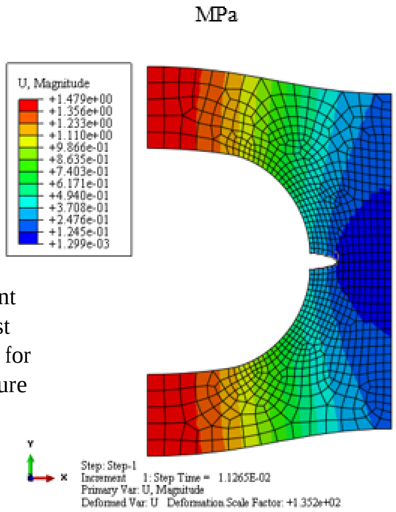

Fig. 10. The displacement values [mm] for the first increment of the analysis for an applied tension pressure of 500 MPa

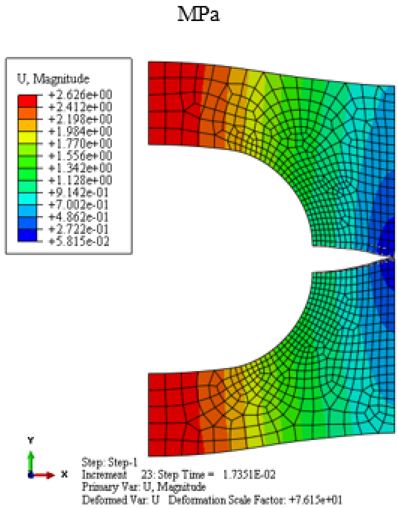

Fig. 11. The displacement values [mm] for the increment of the analysis when the plate model breaks, for an applied tension pressure of 500 MPa

Table 1
THE VON MISSES STRESSES FOR THE ANALYZED PRESSURE CASES

Increment	The Von Misses stresses for the 100MPa pressure case [MPa]	The Von Misses stresses for the 200MPa pressure case [MPa]	The Von Misses stresses for the 300MPa pressure case [MPa]	The Von Misses stresses for the 400MPa pressure case [MPa]	The Von Misses stresses for the 500MPa pressure case [MPa]
0	0	0	0	0	0
1	29.21	58.43	82.21	81.87	81.53
2	58.86	75.63	86.37	86.15	85.93
3	74.3	84.49	62.34	62.09	61.86
4	82.87	70.32	73.92	73.86	73.8
5	68.55	72.88	65.69	65.67	65.66
6	71.12	56.54	67.43	67.44	67.46
7	55.39	58.19	71.14	70.59	70.13
8	57.51	65.9	66.43	66.01	65.64
9	65.45	64.79	58.81	58.08	57.57
10	70.87	67.86	63.37	63.73	61.52
11	67.61	58.32	57.87	62.18	63.02
12	65.85	62.83	62.66	55.36	63.2
13	57.82	63.86	63.54	62.11	58.72
14	64.66	62.89	57.5	64.07	59.97
15	56.17	59.05	59.3	59.06	62.14
16	61.46	59.99	54.67	60.24	57.12
17	55.21	54.66	56.37	55.18	58.65
18	59.61	57.61	58.47	58.7	58.88
19	61.88	58.53	60.3	59.2	55.07
20	57.08	60.37	55.5	55.02	56.82
21	60.07	56.87	55.57	55.68	58.61
22	56.82	57.74	57.74	56.8	66.2
23	59.99	60.96	58.12	57.59	67.52
24	64.52	66.78	58.84	60.79	-
25	-	68.72	64.17	65.82	-
26	-	71.06	65.45	67.66	-
27	-	-	67.37	70.26	-
28	-	-	68.52	71.26	-

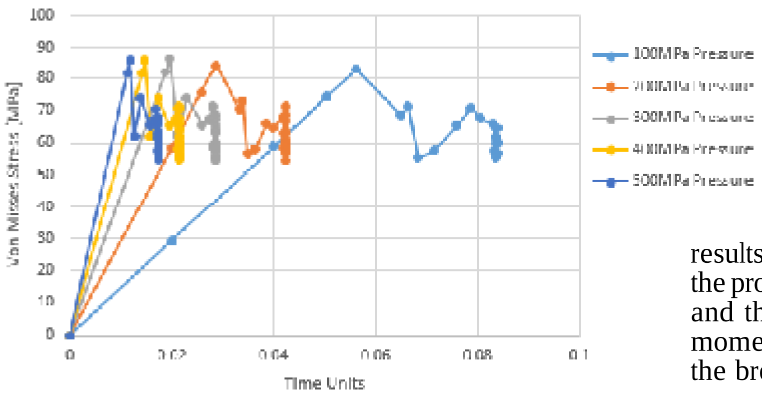

Fig. 12. The variation of the maximum Von Misses stress values in time for the analyzed tension pressures cases that were applied

results that were observed were, mainly, the effects that the propagation of the crack had on the Von Misses stresses and the displacements of the plate, until the breaking moment occurs. In the following figures, the starting and the breaking increments for the 100 MPa pressure cases are presented. The rest of the results are presented in the tables 1, 2 and the diagrams 12, 13.

Increment	Displacement values for the 100MPa pressure case [mm]	Displacement values for the 200MPa pressure case [mm]	Displacement values for the 300MPa pressure case [mm]	Displacement values for the 400MPa pressure case [mm]	Displacement values for the 500MPa pressure case [mm]
0	0	0	0	0	0
1	0.5308	1.062	1.494	1.486	1.479
2	1.072	1.378	1.574	1.572	1.569
3	1.352	1.539	1.718	1.716	1.714
4	1.508	1.825	1.891	1.891	1.89
5	1.786	1.864	2.17	2.17	2.17
6	1.825	1.931	2.296	2.297	2.298
7	1.895	2.021	2.405	2.403	2.402
8	1.988	2.154	2.422	2.421	2.42
9	2.125	2.236	2.468	2.462	2.458
10	2.21	2.409	2.497	2.491	2.487
11	2.261	2.437	2.512	2.497	2.506
12	2.387	2.46	2.524	2.508	2.553
13	2.415	2.475	2.533	2.528	2.579
14	2.462	2.512	2.549	2.541	2.583
15	2.468	2.532	2.56	2.569	2.59
16	2.483	2.536	2.568	2.573	2.602
17	2.492	2.542	2.574	2.58	2.61
18	2.499	2.551	2.578	2.592	2.612
19	2.504	2.553	2.581	2.594	2.615
20	2.512	2.556	2.582	2.598	2.619
21	2.517	2.56	2.584	2.6	2.622
22	2.521	2.562	2.587	2.602	2.624
23	2.524	2.564	2.587	2.603	2.626
24	2.527	2.565	2.588	2.604	-
25	-	2.566	2.588	2.605	-
26	-	2.567	2.589	2.605	-
27	-	-	2.59	2.607	-
28	-	-	2.591	2.607	-

Table 2
THE DISPLACEMENT VALUES FOR THE ANALYZED PRESSURE CASES

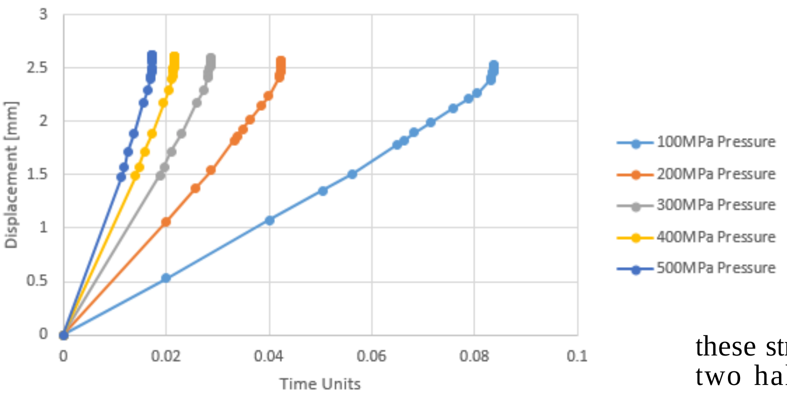

Fig. 13. The variation of the maximum displacement values in time for the analyzed tension pressures cases that were applied

The results obtained from Abaqus are gathered in the tables 1 and 2 and the diagrams from figures 12 and 13.

Conclusions

The analysis using the FEM software Abaqus of an epoxy-glass composite plate with a central elliptical cut-out and an initial crack was presented in this paper. Only half of the plate was modeled, due to symmetry, with contour constraints and five tension pressure cases were applied to two of the plate's edges. The main results that were observed were the variation of the Von Misses stress and the evolution of the displacement values in a certain amount of time that was needed for the initial crack to propagate until the break of the plate.

By analyzing the tables and the graphs it can be observed that the Von Misses stresses, for all pressure cases, have an initial linear increase until the initial crack visibly opens more than the length it had until then, due to the tension pressures, then there is a decrease, until the crack starts opening more, when another stress increase can be seen; these stress variations continue until the plate breaks in two halves. After a certain point, when the crack approaches the breaking point, there are multiple rapid stress increases and decreases, meaning that the fissure propagates faster. By observing the displacement values it can be seen that there is an almost linear increase until near the breaking point, when there is a much faster increase.

As it can be expected and also according to the results from Abaqus, the higher the applied tension pressure is, the faster the fissure will propagate until the plate breaks.

Some of the future research directions may include changing the composite materials used, replacing the constant pressures with fatigue loadings and comparisons between software results and experimental results.

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