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Numerical simulation of fatigue crack growth in AA6156 T6 panels

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Abstract

Fatigue crack growth in a panel with 4 stringers and 3-clips, made of AA6156 T6, was modelled numerically using xFEM. The central crack of the length a=17 mm was propagated in the total of 91 steps (in each step crack length increased by 2 mm) and after 14 steps the first clip began to deform. At the same time, crack continued to grow through the base plate, reaching the right and left stringers after 91 steps and beginning to grow along those stringers. Number of cycles for panel with additional 3-clips was higher than for panel with just 4-stringer, (278476 cycles vs. 2649587) cycles, improving fatigue life for cca 5%.

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1. Introduction

Recent advancements in welding of Al alloys, especially Laser Beam Welding and Friction Stir Welding, enabled wide use of so-called integral skin-stringer structures, Fig. 1, /1-6/. Compared to conventional riveted structures, integral skin-stringer structures are lighter, cheaper to manufacture, easier to inspect and have more favourable stresses distribution, making crack initiation more difficult, /7/. Also, once initiated, crack would grow significantly slower in an integral structure, /8-12/.

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Figure 1. Integral skin-stringer structure of the fuselage.

Although Laser beam welding (LBW) has been successfully applied for manufacturing skin-stringer curved panels for various civilian aircraft in Europe, two types of cracks appeared in a large transport aircraft, longitudinal cracks under hoop stresses (induced by cabin pressurization) and circumferential cracks under stresses from vertical bending of the fuselage, /13/. Therefore, it is of utmost importance to predict the growth rate of fatigue cracks under applied loading. Extensive experimental study has been performed in GKSS /14/, followed by recent numerical simulation using xFEM, /3,6,8,12/. Two different materials were used in this analysis, focused on the effect of stringers on fatigue crack growth in a panel as a standard element of aeronautical structure, Fig. 2. Experimental investigation indicated benefits of stringers, expressed as significant improvement in number of cycles up to the critical crack length, defining the life of a panel. Numerical simulation indicated the same trend and effectiveness of stringers, /3,6,8,12/. In any case, additional experiments on panels with clips have shown relatively small improvement. In this paper, numerical simulation of a panel with 4 stringers and 3 clips is presented, also confirming the experimental results.

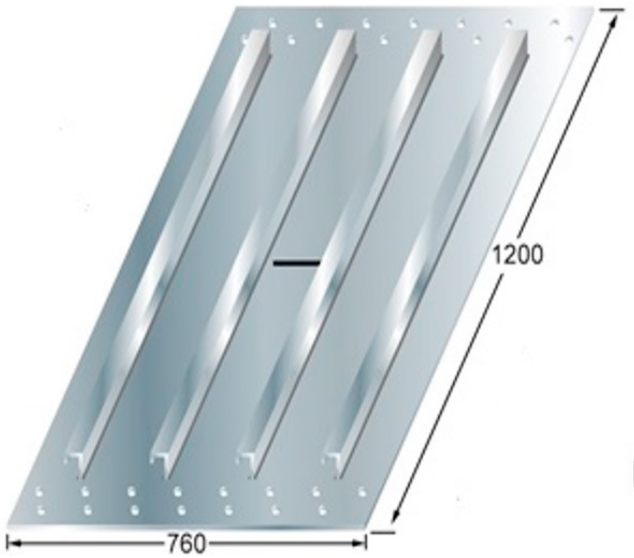

Fig. 2. Panel with 4 stringers

2. Numerical simulation of fatigue crack growth in panel with 4 stringers and 3 clips

Panel with 4 stringers and 3 clips structure, shown in Figure 3, was modelled after numerical simulation of 4 stringer plate with different sizes of meshes (elements 1, 2 and 4 mm), as shown in /12/. Panel with 4 stringers and 3 clips is modeled only with 2 mm size of elements, and refined mesh around the crack. The central crack of the length a=17 mm was made and the load identical to that was used for 4-stringer plate applied, /12/.

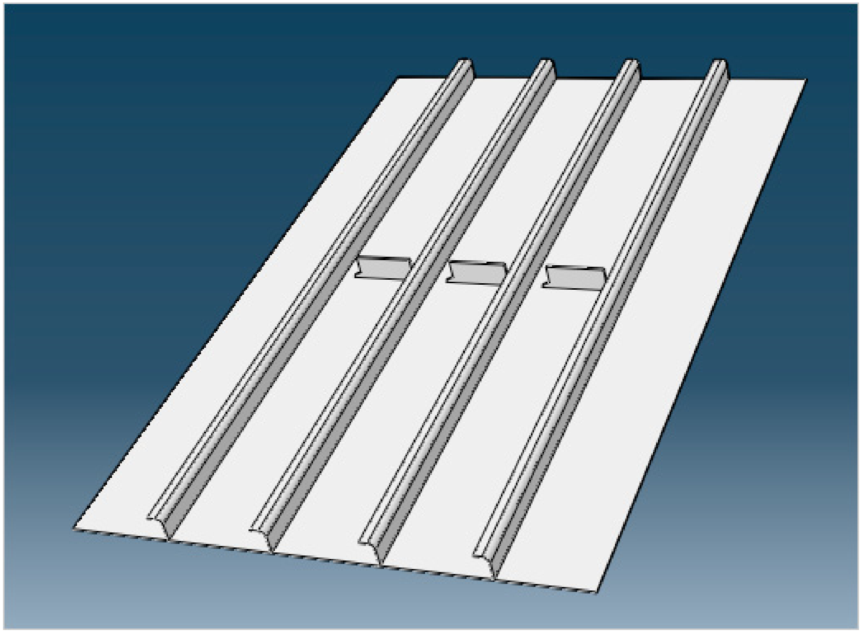

Figure 3. Panel with 4 stringers and 3 clips

In this simulation aluminum alloy AA6156 T6 was used (Young's modulus E = 71000 MPa, Poisson's ratio ν = 0.33). Coefficients for Paris equations were adopted on the basis of the values obtained in tests with base metal plates: m=3.174 and C=1.77195E-012 MPa $mm^{1/2}$. /12/

The loads used in simulation were equal to average values of maximum tensile forces over time measured in experiments. The maximum force was Fmax=112.954 KN, while the load ratio R=0.146 was determined on the basis of average minimum tensile force measured, /12/.

Extended FEM (xFEM) was used here for numerical simulation of crack growth. This method and its modifications, /15-17/ has been used in last few decades as the most suitable for numerical simulation of crack growth. It has been applied successfully in number of applications, as shown in /18/. The main advantage of xFEM is that it does not need re-meshing after every crack growth step.

3. Results

Central crack with initial length 17 mm was propagated in the total of 91 steps. In each step crack length was increased by 2 mm. After 14 steps, as shown in Figure 4, the first clip began to deform along its length. At the same time, crack continued to grow through the base metal plate, reaching the wall of the right and left stringer after 91 steps, as shown in Figure 5, and starting to grow also through these two stringers. One should notice that clip is practically not deformed after crack passes it, contrary to stringers which deform significantly, as shown in /3,6,8/. This difference is very important since it reflects on the number of cycles and life of the panel.

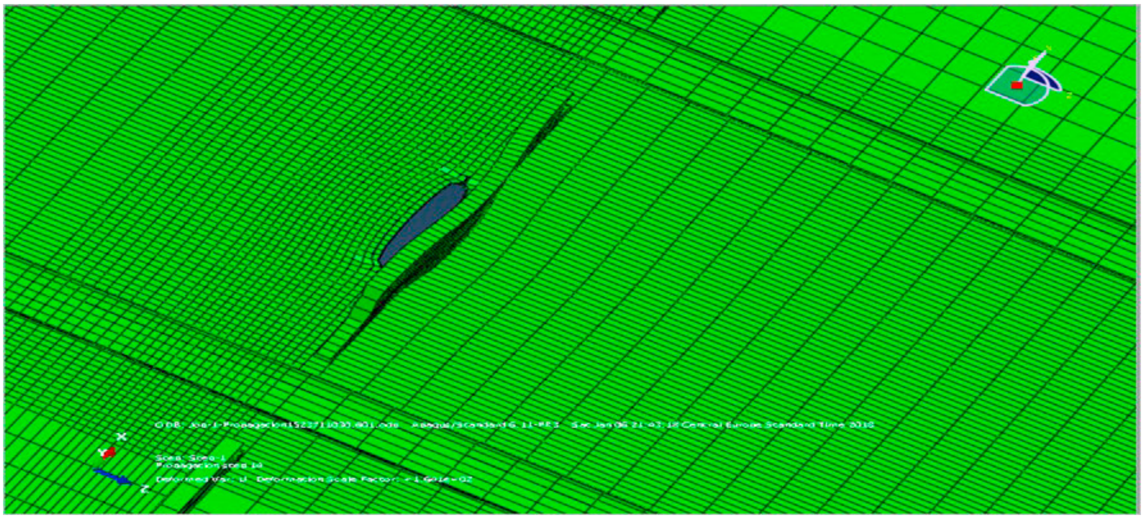

Figure 4. Central crack after 14 steps of growth

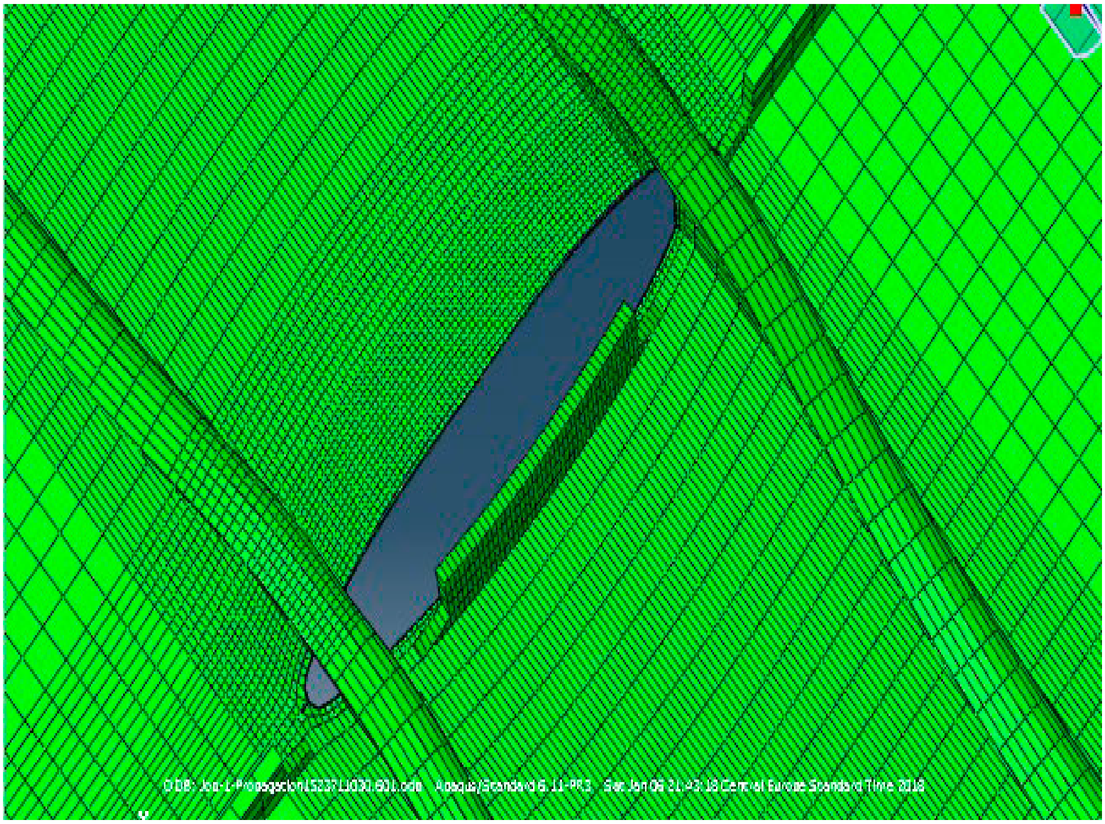

Figure 5. Central crack after 91 steps of growth

Results for crack length vs. number of cycles are shown in Figure 6, as a comparison between panel with 4 stringers and panel with additional 3 clips. One can see that the number of cycles for panel with additional 3-clips is higher than for panel with just 4-stringer, (278476 cycles vs. 2649587) cycles, improving fatigue life for circa 5%.

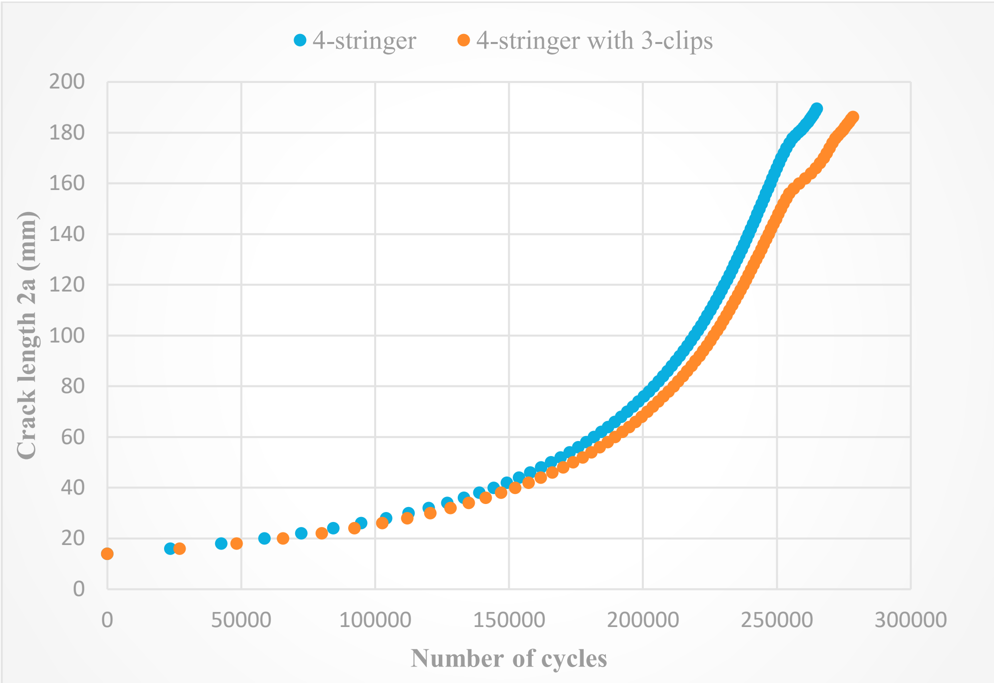

Fig. 6. Crack length .vs. Number of cycles for panels with 4 stringers and with additional 3 clips.

4. Conclusions

Based on the results presented in this paper, one can conclude that additional 3 clips do not contribute significantly to the increase of life of panel with 4 stringers. In other words, it is not justified to increase production costs with additional welding of 3 clips.

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