A modeling approach for the fatigue behavior of laser drilled micro perforated structural panels

Dort Daandels [1], Stefan Riekehr [2], Nikolai Kashaev [2], Jon Mardaras [3], Sammy Zein El Dine [1], Christian Heck [1],
[1]*Airbus Operations GmbH, Bremen, Germany*
[2]*Institute of Materials Research, Materials Mechanics, Helmholtz-Zentrum Geesthacht, Geesthacht, Germany*
[3]*Airbus S.A.S., Toulouse, France*

Hybrid laminar flow control (HLFC) is a technology approach to reduce the drag of civil jet transport aircrafts. The aim of HLFC is to create a longer laminar flow along the airfoil on an aircraft. This is done by boundary layer suction through small holes in the skin panels. The holes are small (<100µm) and there are millions of them per square meter. The impact of these holes on the structural capability of the aircraft design is significant. The objective of this paper is to describe the best way how to model the influence of these micro drilled holes on the properties of the sheet material as an input for fatigue life calculations.

The main application of HLFC is on leading edges, e.g. wing or empennage. The extension over the chord of the micro drilling depends on the available design space for this feature and the aerodynamically efficiency of the solution. Underneath the micro drilled panels there is a controlled pressure level in order to get the desired suction of the external boundary layer. Via a smart design of this pressure chamber the structural function of the outer skin can be reduced from a primary structural element to a secondary level. Therefore, in this abstract the focus is on the fatigue properties and crack initiation of the design and not on the fracture mechanics of macro cracks.

The production process of micro drilled panels consists of several steps. An example of a description of the process can be found in [1]. To start a material sheet of desired thickness is selected, together with a hole diameter and pitch. For the laser drilling itself many parameters can be set, for example pulse energy level and amount of pulses per hole. With these parameters the geometry and quality of the hole will be defined, influencing: The entrance hole diameter, the exit hole diameter, the shape of the cone, the inner hole surface, the hole edges, the burrs. After the drilling process burrs will remain on the hole edges and some drops might have hit or stuck on the outer surface of the plate. To remove these burrs de-burring is necessary. De-burring can be done chemically or mechanically depending on the material used. This step in the production will alter the surface of the sheet.

Whereas the impact on static properties for the sheet is mainly determined by the remaining net section, the impact on fatigue properties will be much more complicated. The fatigue properties depend on the stress concentrations caused by the hole geometry. Moreover as fatigue is a material surface driven phenomenon [3] many of the production parameters influence the surface finish and thus the fatigue behavior of the material. Typically there are: the inner-hole surface quality, localized altered heat-treatment around the holes, polishing or etching of the sheet surface. Therefore it is important to determine their influence on the fatigue life of the created parts.

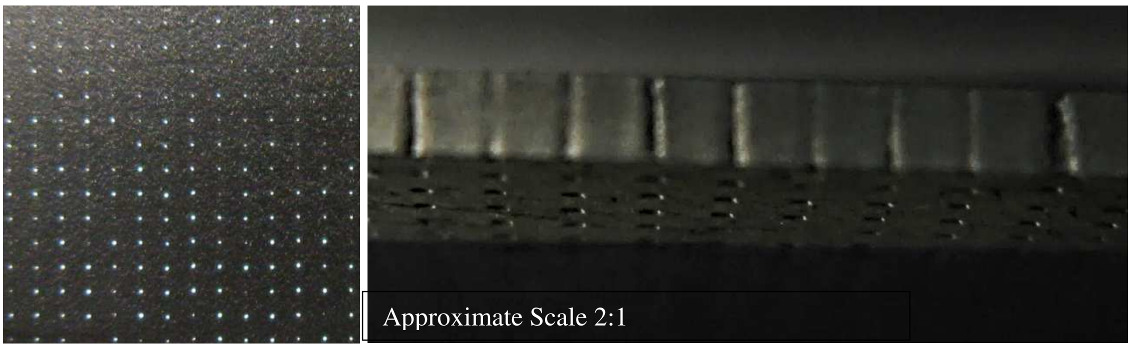

Figure 1. Top view and cross section of a laser micro drilled plate [Pictures by Airbus].

The durability of the design is another important factor. As the HLFC is on the leading edge, impacts damage and erosion might occur. Impact resistance can be determined by the overall design; on the other hand the erosion resistance is a material property of the micro drilled sheet. This is essential as the holes need to remain open, so protective paints or coatings are not an option. The micro holes should not change significantly in size, otherwise the efficiency of the HLFC system will reduce. For designs with undrilled sheets, typically metals are better against erosion than composites. For micro drilled panels a comparison study was done [2]. In this study Titanium, Aluminium and CFRP were compared via a flight test performed with a SAAB 2000 aircraft. Several laser drilled panels were fitted on the wing leading edge. Over the time of 20 months of routine service these panels were monitored with regards to contamination and durability and the following results were obtained. Titanium is the most durable material with no evidence of degradation, the mean hole size appeared to be unchanged. The Aluminium panels displayed evidence of corrosion and micro-cracking. The hole size was significantly increased on the outer surface. The composite material, flown only two months, had significant damages. Noticeable amounts of fibre were removed on the surface between holes. Based on the outcome of this study it was decided to perform the fatigue tests on titanium micro drilled sheets.

For the fatigue tests, within the frame of the EU Clean Sky2 Project DELASTI [5], a test matrix, was setup to create a few full data sets to create SN curves for titanium CP (grade 2). Four SN curves were generated: two drilling patterns were selected (0°/-90° and -45°/+45°) and tested in the two major material directions L and LT. The pitch and diameter was the same for all drilled specimens.

The specimens have all been tested and the assessment of the test results is in progress. A comparison of the initial test results is shown in figure 2. The slope of the four SN curves is similar for all for test variants. A first observation showed no significant difference between the 0° and 45° micro drilling pattern. This indicates that the distance between the holes is so big that there is no significant interaction between the separate holes for the fatigue initiation. This is supported by literature studies comparing pitch vs. diameter [4]. The rolling direction of the material resulted in a significant gap in the SN curves. With the loading in the LT direction giving somewhat better results. This offset is also seen in the undrilled sheets and not expected to be caused by the micro drilling. In a next step the test results are compared to SN curves of the base material to see if a stress concentration factor is sufficient to model these micro drilled holes. Also a factor to account for the high amount of holes is introduced. With this baseline some historical test results will be compared with the newly obtained data. Some further testing is requested and if available will be added to comparison.

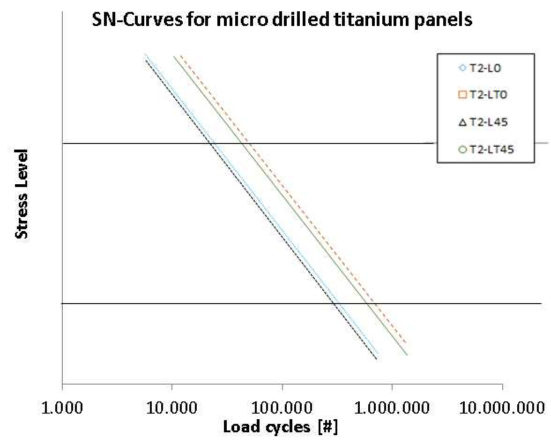

Figure 2. Initial test results from the test matrix.

Keywords: Hybrid laminar flow, micro drilling, de-burring, fatigue, durability, erosion, SN curve, laser

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Ref 4: Peterson's Stress concentration Factors, W. Pilkey and D. Pilkey, issue 3 (2008)
Ref 5 EU Clean Sky 2 Project "Development of advanced laser based technologies for the manufacturing of titanium HLFC structures/DELASTI" (grant agreement no: 687088).