CRACKED SAMPLES FOR AIRFRAME COMPONENTS

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Abstract. Evaluation of NDT performance and reliability is an important part of any NDT system. Traditionally, the challenge has been limited supply of representative cracked samples, that would allow accurate evaluation of the achieved performance.

This paper describes production of cracked samples in airframe component representative of typical rivet hole configuration. The flaws were produced using local thermal fatigue loading and are representative of in-service fatigue cracks.

The manufactured flaws were inspected using typical eddy current inspection. The flaws gave inspection indication comparable to those expected from service-induced cracks.

Introduction

Demonstration of NDE reliability is an important part of any inspection system. Capability is commonly assessed in terms of probability of detection (POD) as function of crack size.

The largest flaw, that could be missed during inspection is of particular importance. In the case of airframe rivet holes, it is sometimes assumed, that cracks with size below the detection capability of the NDE system may exist in the component even after clean inspection result. The possible existence of such cracks can be dealt with by boring rivet holes to larger size and thus removing possibly existing cracks. However, this procedure is limited by the amount of material that can be removed without other adverse effects. Consequently, it is particularly important to have accurate information on the detection capability of the NDE system to avoid leaving cracks in the component on the one hand and to avoid removing unnecessary material on the other.

To demonstrate performance and to find out the detection capabilities of an NDE system, inspection is performed on a set of cracked test samples. These inspections should replicate the actual inspection as closely as possible. In particular, the cracks should be representative of service induced cracks. The determination of POD curve is codified in ASTM standards [1] and handbooks [2]. In general, crack sizes ranging from undetectable to highly detectable should be included to get meaningful POD curve.

Traditionally, it's been challenging to manufacture the necessary cracked samples for performance demonstration. Various techniques including mechanical fatigue of plate samples with crack initiators or stress concentrators have been used. As the detection targets for the NDE systems decrease, the production of controlled cracks has become increasingly difficult.

For number of years, Trueflaw has manufactured cracks for NDE purposes using thermal fatigue loading. These have been used extensively in the nuclear industry performance demonstrations for over a decade. The cracks have also been used in aero-engine components for method development [3] and POD determination.

Trueflaw uses in-situ thermal fatigue loading to grow cracks for NDE purposes. This approach has number of advantages: the flaws are natural (thermal)fatigue cracks and as such highly representative of service-induced cracks. The location and size is highly controllable and range of cracks with different sizes can be produced, as is needed for a POD determination. No artificial initiators or stress concentrators are needed and cracks can be produced to actual components and geometries. This enables far greater representativeness for the POD inspections than would be possible for more traditional small samples.

So far, the use of Trueflaw cracks in the aerospace industry has been limited to engine components. The reason is, that the most interesting materials for airframe components, i.e. aluminum, has been very difficult for thermal fatigue crack manufacturing due to the very high thermal conductivity of the material.

Recently, the crack manufacturing technology was developed to allow crack production also in aluminum thus enabling the use of these cracks also for airframe components.

Materials and methods

In present study, cracked evaluation samples representing a typical airframe component, i.e. a rivet hole was manufactured. Similar samples were manufactured in titanium and aluminum. Titanium is used both in the aero engines and in airframe and its thermal properties are closer to the previously cracked aero-engine materials. Thus, it was used as a reference material. Aluminum, on the other hand, is more interesting material for airframe components and more directly shows the potential for these cracks on the airframe components. Due to the different thermal conductivity and other material properties, the cracks produced in aluminum show somewhat different properties. The used sample geometries are shown in Figure 1.

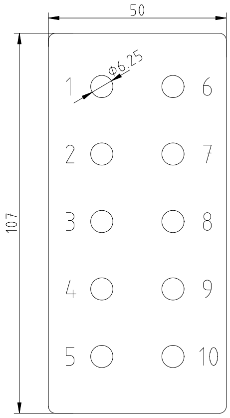

Figure 1. Sample geometry.

Crack manufacturing by thermal fatigue

During crack manufacturing, the sample is locally heated and cooled repeatedly. The heating is done by high frequency induction and cooling by water spray. Rapid heating and cooling cause uneven temperature distribution which induces compressive and tensile surface stresses onto the sample, respectively. The alternating thermal stresses result in gradually accumulating fatigue damage, crack initiation and crack growth. The loading is stopped periodically and the sample inspected in order to follow the crack growth. The process is highly repeatable and thus crack properties that are not directly observable (e.g. crack depth) can be reliably assessed using a separate validation sample that is destructively examined.

Results

Table 1 shows the generated cracked samples and associated crack sizes. Figures 2 and 3 show typical microscopic images of generated cracks in titanium and aluminum, respectively.

Table 1. Generated cracks and crack sizes.

#	Flaw ID	Material	Length (mm)
1	187BFB2859	Titanium	0.2
2	189BFB2862	Titanium	1.4
3	190BFB2865	Titanium	1.1
4	191BFB2869	Titanium	0.3
5	194BFB2871	Titanium	1.4
6	195BFB2872	Titanium	0.3
7	196BFB2873	Titanium	0.6
8	210BFB2891	Aluminum	0.4
9	212BFB2901	Aluminum	2.2
10	218BFB2907	Aluminum	1.3
11	221BFB2908	Aluminum	2.1
12	222BFB2910	Aluminum	0.1

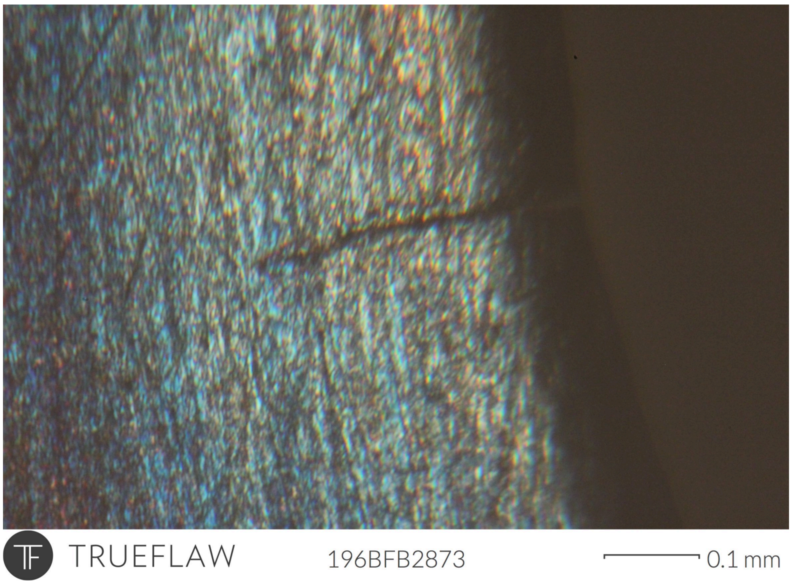

Figure 2. Microscopic image of typical crack in titanium.

Figure 3. Microscopic image of typical crack in aluminum.

The manufactured cracks were first inspected using fluorescent dye penetrant (FPI) at Trueflaw. The samples were subsequently sent to Patria for representative eddy current inspection and further evaluation. At Patria, inspection more closely representing the actual inspection for airframe components were conducted. Figures 4 and 5 show typical FPI-images for titanium and aluminum samples, respectively. Figures 6 and 7 show corresponding EC-images.

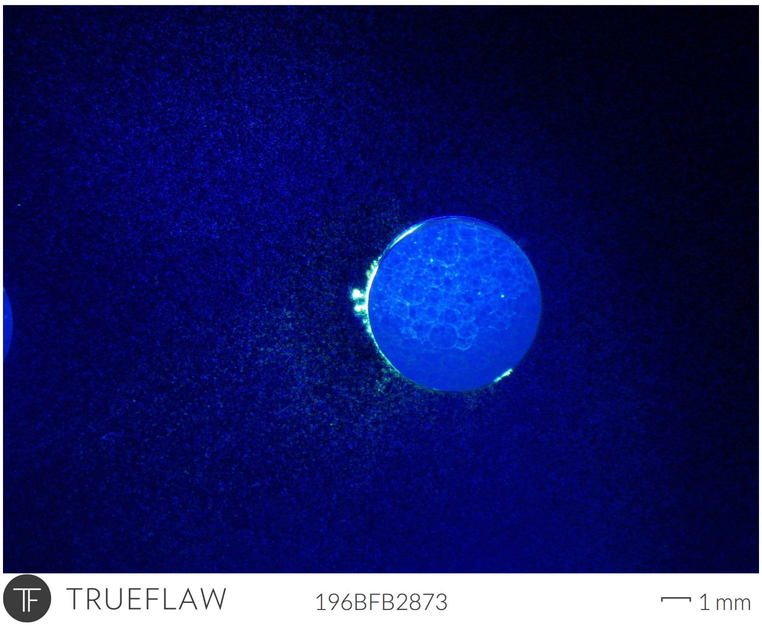

Figure 4. FPI image of typical crack in titanium. The crack is the same as that depicted in Figure 2 (Trueflaw crack number 196BFB2873).

Figure 5. FPI image of typical crack in aluminum. The crack is the same as that depicted in Figure 3 (Trueflaw crack number 218BFB2907).

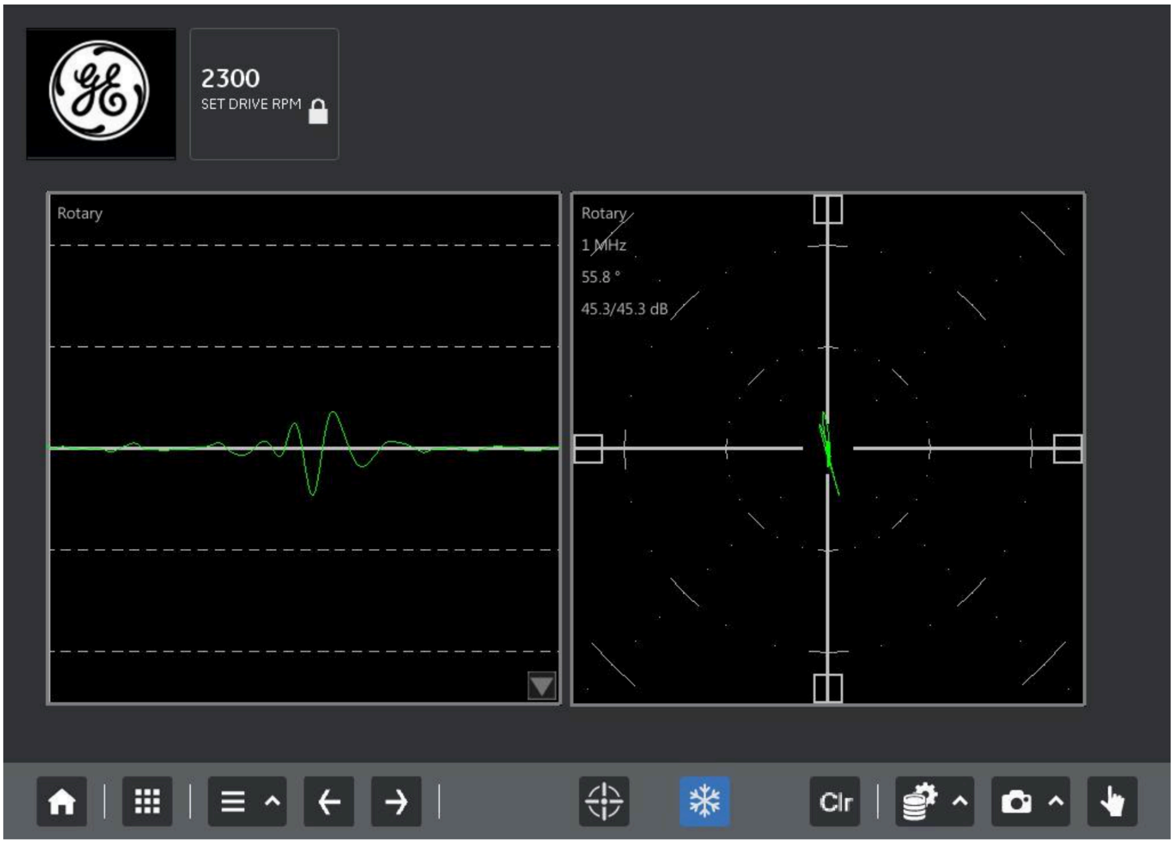

Figure 6. EC image of typical crack in titanium. The crack is the same as that depicted in Figures 2 and 4 (Trueflaw crack number 196BFB2873).

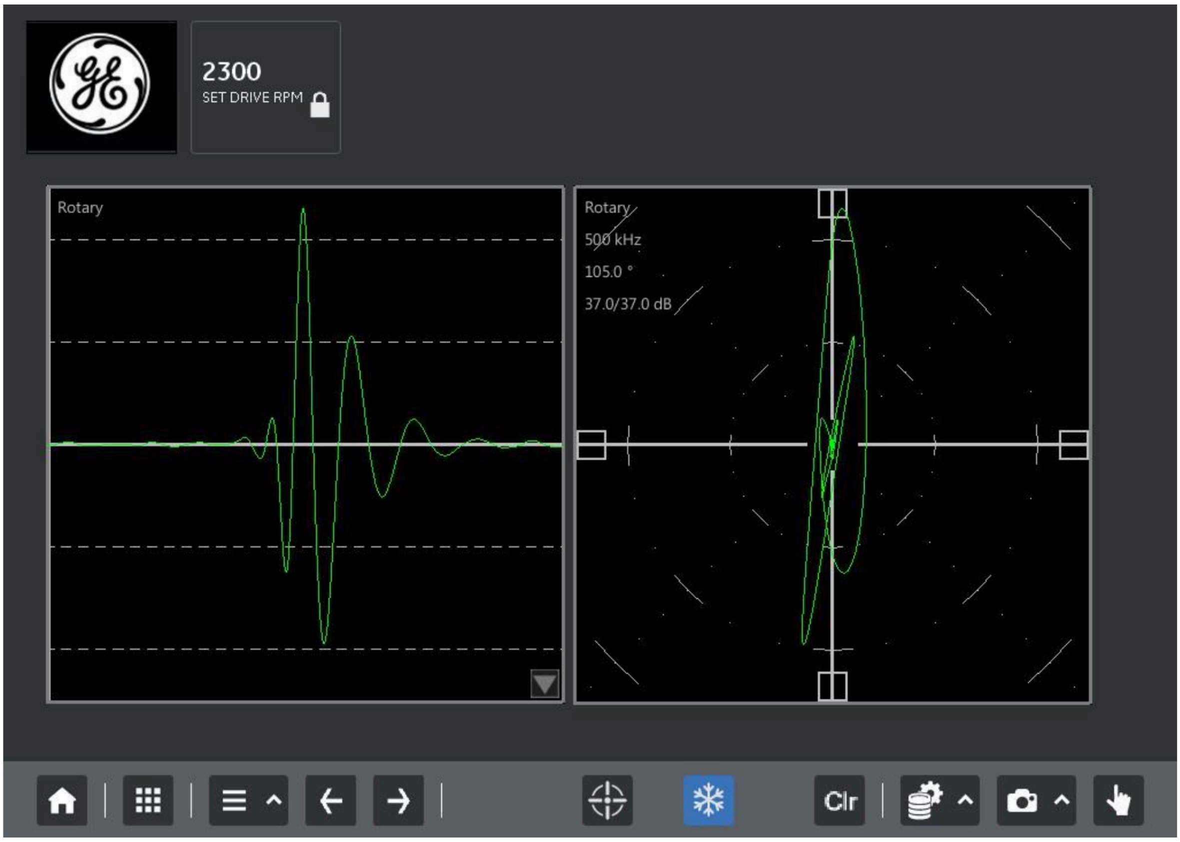

Figure 7. EC image of typical crack in aluminum. The crack is the same as that depicted in Figure 3 (Trueflaw crack number 218BFB2907).

The inspection results on various used EC techniques is collected in Table 2 and depicted graphically in Figure 8. The number of cracks generated for this preliminary study is insufficient for full ASTM-E2862 POD analysis. However, the results demonstrate, that an array of cracks ranging from undetectable to clearly detectable can now be produced in materials and components representative of typical airframe components.

Table 2. Summary of inspection results.

#	ID	Crack length (mm)	Inspector #1	#2	#3	#4	Hit rate
Titanium							
1	187BFB2859	0.2	miss	miss	miss	miss	0 %
2	195BFB2872	0.3	miss	miss	miss	hit	25 %
3	191BFB2869	0.3	hit	miss	hit	miss	50 %
4	196BFB2873	0.6	hit	hit	hit	hit	100 %
5	190BFB2865	1.1	hit	hit	hit	hit	100 %
6	194BFB2871	1.4	hit	hit	hit	hit	100 %
7	189BFB2862	1.4	hit	hit	hit	hit	100 %
Aluminium							
8	222BFB2910	0.1	miss	miss	miss		0 %
9	210BFB2891	0.4	hit	hit	hit		100 %
10	218BFB2907	1.3	hit	hit	hit		100 %
11	221BFB2908	2.1	hit	hit	hit		100 %
12	212BFB2901	2.2	hit	hit	hit		100 %

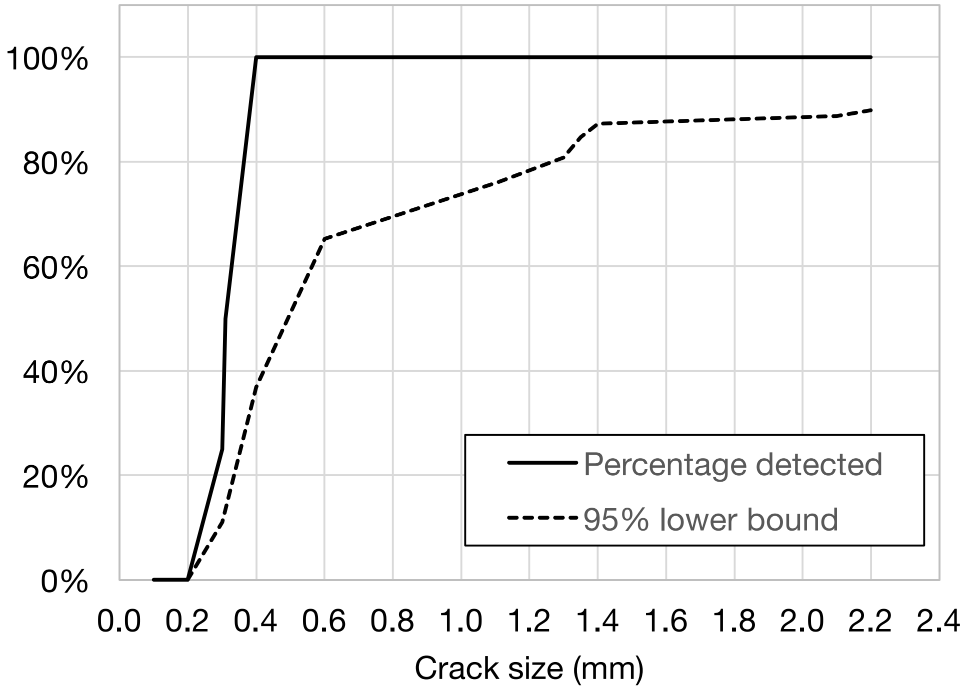

Figure 8. Summary of inspection results.The solid line shows the detection as percentage from trials in Table 2. The dashed line shows rough estimate 95% confidence bound based on the binomial model (true POD above this line would show the better-than-given results at 95% confidence, assuming POD increases with increasing crack size). The data is insufficient for true POD analysis and thus this is likely to seriously underestimate the true POD.

Discussion

Cracked sample plates representing typical airframe rivet hole configuration were manufactured from titanium and aluminum materials. The samples had thermal fatigue cracks with different sizes manufactured to them. The cracks were characterized with optical microscopy and subjected to inspections representative of actual in-service inspections of comparable components.

The microscopic characterization shows that cracks initiate from the hole surface and grow following the local microstructure as expected for natural fatigue cracks. The cracks initiate at the hole corner and extend to both directions. The cracks in titanium show, in general, smaller crack opening than those in aluminum. This can be caused by both different material properties and different loading conditions. The smaller yield strength of the aluminum increases crack tip plastic zone size and increases crack tip blunting and crack opening for similar stresses. In the future, this could be alleviated to some extent by decreasing the loading (with corresponding increase in the crack production time). The aluminum samples also showed some increased oxidation during the loading. This can be attributed to both the increased temperature and the interaction between the deformation and oxidation (i.e. the oxide film may break during tensile loading and expose new material to the environment). The oxidation also caused conductivity changes, which caused phase angle change in eddy current inspection. This tendency was reduced using corrosion inhibits in the cooling medium. Nevertheless, mechanical removal of affected oxide layer was necessary after production. Although these issues were reduced by the use of inhibit, some additional development is necessary to fully remove oxidation effects.

The eddy current inspection showed detectable indications for all but the smallest cracks. The signals were comparable to those expected of a service-induced cracks in titanium. In some of the aluminum cracks, the eddy current signals differed slightly in phase angle and in form from service-induced cracks. The cracks were still detectable, as shown in Table 2. Consequently, the cracks were evaluated positively for further use in airframe NDE performance demonstration use. The current sample set was too small for proper POD analysis. Nevertheless, the results already give better indication on the capabilities of the NDE techniques used and can be used to focus further effort on POD determination to interesting range of crack sizes.

Conclusions

Cracks were successfully manufactured to titanium and aluminum samples representative of typical airframe rivet hole configuration. This represents the first application of thermal fatigue cracks for NDE performance demonstration in airframe components and first evaluation of developed technique in typical aerospace aluminum materials.

The manufactured cracks showed characteristics representative of service-induced cracks and were positively evaluated for use in airframe NDE performance demonstration.

Acknowledgements

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