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Review of “Non-local fatigue criterion based on standard deviation for notches and defects in Ti-6Al-4V”

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Review of version 1

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Reviewer 1 (Anonymous)

Reviewer The paper proposes an original non local fatigue criterion to take into account stress heterogeneity using standard deviation in the integration domain. The application of the criterion to notches and defects in a TA6V alloy is convincing. In my opinion, the paper is worth publishing in JTCAM with minor revisions that consist mainly in more details and a few corrections. Please find my main comments below. In the annotated pdf document, you could also find a few typos and comments.

Please note that the fatigue data on artificial and natural defects in TA6V could be made available in an open access repository.

Reviewer p3, last paragraph: please introduce the material of the Lanning database as compared to the one of the study

Authors Done, added to the text: “We have chosen to use this single base to guarantee the same state of preparation - machining and polishing of the notches - indeed, the Ti-6Al-4V is sensitive to these last parameters.”

Reviewer Table 1: Could you please add a column with Kt value? I guess it is in the specimen name but it is not obvious. By the way, what is the use of specimen name? Does it refer to an existing database? There are no specimens names in Lanning paper.

Authors This is a judicious remark taken into account in revised table 1. Actually these names don't appear in Lanning's work, it is a name specific to our study.

Reviewer p9, last paragraph: “For the $\sigma_{\text{grad nl}}$ criterion, the parameters obtained are $\sigma_{\text{grad}} = 44.43$ mm and $n = 0.18$.” I guess the authors wanted to write “ $a_{\text{grad}} = 44.43$ mm”?

Authors Modified.

Reviewer p10, section “application to defects”: A description of the authors fatigue tests is lacking. Could you please present the fatigue tests: specimen geometry (not only the defect geometry), fatigue

machine, stress ratio, frequency...

- Authors** Done, added to the text: “In this study the tests are carried out with a resonance machine with a frequency of 80 Hz for a load ratio $R = 0.1$. We used flat 5 mm thick specimens.”
- Reviewer** p10, last sentence: A heat treatment was performed to remove the residual stresses induced by manufacturing process on artificial milled and drilled defects. What about the residual stresses due to welding? Are they assumed negligible so that the heat treatment is limited to artificial defects? The influence of residual stresses is evoked p21 so that it seems necessary to make clear in which cases, residual stresses may still be present in the specimens.
- Authors** Heat treatments were carried out to ‘approximate’ a natural defect. Residual stresses linked to welding are assumed to be minimal but no quantification of residual stresses was carried out in this study because it is a very complex measurement to carry out for titanium.
- Reviewer** p13: “The 60 MPa difference between mill/drill defects can be explained only by the type of defects (surface finish, residual stresses, microstructure).” Does it mean that the heat treatment 680 °C/2h (p10) was not enough to relieve the residual stresses? Please explain.
- Authors** We cannot conclude categorically, we cannot identify the driving element between the residual stresses, the microstructure and the surface state. Residual stresses were not measured due to technical constraints.
- Reviewer** Figure 5: What is the reason for the increase of fatigue limit amplitude for natural porosities larger than 150 μm in Fig. 5a? Could the authors discuss this point?
- Authors** For natural porosities larger than 150 μm Murakami’s parameter is not suitable. Indeed, larger defects are further away from the surface and have very varied morphologies making the application of this parameter unsuitable. This parameter doesn’t seem suitable for titanium as we show later in the paper.
- Reviewer** Figure 6: Please give precision on the type of artificial defect (drilled or milled defects?) either in the legend or in the text or both.
- Authors** Milled defects. We have corrected the legend.
- Reviewer** p18, last paragraph, first sentence: “Nine isolated defects, with diameters between 200 μm and 2000 μm , were studied”. Does it corresponds to the milled defects with square root area from 150 to 1050 μm ? Only 8 points are visible. Please give precision in the text.
- Authors** The text has been corrected.
- Reviewer** p18, last paragraph, third sentence: Fig. 8a does not show what is stated in the text as it does not contain any information on the defect’s diameter for isolated defects. Maybe the authors could add this information in the figure.
- Authors** We have chosen not to include the figure corresponding to the text so as not to make the publication heavier. We therefore correct the reference to Fig. 8a which is unsuitable.
- Authors** Others spelling or grammar comments has been corrected.
- Reviewer 2 (David NOWELL)**
- Reviewer** Accept with Minor Revisions
- Reviewer** Why choose the average fatigue limit from the database of test results? How much does it typically vary? Surely if there is significant variation one either needs to predict the lowest value of the fatigue limit or both the mean and standard deviation of the quantity.
- Authors** There are 4 points per type of test in the database, for these points the amplitude of the stress value is between ± 10 MPa. This variation is due to the specimen preparation and the materials intrinsic variability. We use the average of the test results to simplify the comparison of the different fatigue criteria.
- Reviewer** The authors state that a mesh size of 50 μm was used. Why was this value chosen? Given that

the smallest notch root radius was 127 μm , this does not seem sufficiently small to capture the variation in the stress beneath the notch. What convergence studies were undertaken?

Authors Indeed, the choice of this size does not allow the mesh to have completely converged. This is a compromise between calculation time and constraint precision. Added to the text: “This value is not the result of mesh convergence analysis but a compromise between quality of the result and computing time.”

Reviewer A further concern is that the approach seems to assume that the material is an isotropic continuum at the length scales being discussed (which are of the order of microns). What is the grain size of the material and why is a continuum approach thought to be applicable?

Authors The microstructure is complex (ex beta grains of variable sizes and lamellae inside) and therefore includes several scales. The study carried out by Airbus aims at an industrial application: it appears inappropriate to consider the materials intragranular heterogeneity.

Reviewer Presumably the photographs in Fig 4 are cross-sections through the defects in the y - z plane where the surface of the specimen is $x - y$. Are the cross-sections in the $x - z$ plane the same (i.e., are the defects circular in cross-section in the $x - y$ plane)? Presumably this has to be the case for the drilled holes, but it is not entirely clear what the milling operation was and what geometry it produced.

Authors Sorry, we don't understand the question. All defects are observed on the fracture surface perpendicular to the loading axis.

Reviewer Why is $\sqrt{\text{area}}$ thought to be the appropriate parameter to capture the size effect of the defects introduced, when the notch root radius was used earlier?

Authors The $\sqrt{\text{area}}$ was chosen for small defects because the Murakami approach is the most commonly used in the literature to quantify the effect of a defect on fatigue. It seemed important to compare our criterion to this approach. Most of the time $\sqrt{\text{area}}$ gives good results for material defects when the local radius is used for notches.

Reviewer Could we please be told the precise grade of Ti-6Al-4V used and what was its hardness?

Authors The Ti-6Al-4V used was grade 6. We tried to measure its hardness but only got a result with a lot of variation because the indentation size was too small compared to the grain size.

Reviewer Are the properties of the weld material (microstructure, hardness etc) identical to the parent metal? If they are not, might this cause the natural defects to behave differently from the artificial ones, which I think are introduced into the parent metal rather than the weld.

Authors The natural defects are present in the melted area, the artificial defects were placed in this same zone to obtain the most homogeneous properties between the two types of defects. Welding is done without filler metal, so the metal remains the same but the microstructure is different. See highlighted sentence: “All artificial defects are machined exactly in the same location in the welded junction (Fig. 4a) in order to have the same microstructure surrounding the defect.”

Reviewer Finite element analysis was carried out on the defects, but we are not shown any of the results. It would be interesting to have some sample figures showing a stress component and how quickly this falls away.

Authors Figure 10 presents a representation of the stress mapping.

Reviewer Is the finite element analysis purely elastic? If it is, do any of the predicted values exceed the yield stress?

Authors For the notch part, the finite element analysis is purely elastic, without exceeding the elastic threshold. For the defects part: the analysis is done in elastoplasticity because the elastic threshold is exceeded. This appears in the text on pages 8 and 17.

Reviewer The discussion section is difficult to follow. Please re-write trying to simplify the arguments and language.

Authors We added connecting elements to structure the discussion.

Editor’s assessments (Julien RÉTHORÉ)

The main theme of this paper is the fatigue of metallic materials. It focuses on the development of a new criterion for predicting the fatigue life limit at points where the stress states are heterogeneous and multiaxial. It is a difficult subject that is in line with the scope of the journal. The paper received two positive reviews recommending only minor revisions. These argued revisions were approved by the reviewers and the paper was accepted in this first revision.

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