Comparison of Standard AMS Reference Notches to Equivalent Tight Cracks in Aerospace Structures

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Abstract:
Ultrasonic Non Destructive Testing is an important tool in evaluating the structural integrity of various aerospace structures. This method is a very promising quality control tool for evaluating wide range of materials. The ground stage of launch vehicles are designed with ultra high strength maraging steel which is highly prone to fracture failure. Hence sizing of critical defects and controlling them during manufacturing process is an important step in achieving structural integrity. Currently the defects occurring in such maraging steel pressure vessels are sized using standard AMS reference notches viz. E-Notch, F-Notch and G-Notch. Many times it is seen that the linear dimensions of critical defects arrived from fracture mechanics approach exceed the specification. In the current study EDM notches of various standard configurations are examined using angle beam ultrasonic testing and compared it with equivalent known fabricated defects. Simultaneously maraging steel tensile specimens with standard notches are tested to estimate fracture load and thereby tight crack equivalence is estimated. The equivalent tight crack sizes arrived from both ultrasonic examination and tensile testing are compared with reference to their failure loads. From these results, it is arrived that, a critical defect (i.e. tight crack) of 4 x 1.5 mm is comparable to that of an AMS F-notch (1.26 x 0.76 x 0.25 mm). The critical defect sizing pertaining to various type of aerospace pressure vessels are also discussed.

Keywords: Ultrasonic testing, EDM notches, Pressure vessel, tight crack.

Introduction:
The structural integrity of materials, components and structures has to be assessed for quality control, safety regulations and product specifications. Numerous testing techniques have been developed for maintenance and condition monitoring. These techniques can be categorized into two main classes: destructive testing based on fracture mechanics, and non-destructive testing which leaves the inspected component undamaged. Non-destructive testing (NDT) is particularly relevant to the inspection of large and expensive components. The aerospace, food, nuclear and offshore industries are only a few examples of industries which employ a wide range of NDT techniques. Aerospace Products call in for Stringent Quality screening both in raw material and finished product stage. During raw material production, especially in Rolling, Forging and Extrusion processes, there is a high probability of occurrence of discontinuities like laminations, tight cracks and piping as well as the case of welding of these high strength steel alloys, probability of tight crack occurrence in weldments is common. Process optimization, qualified procedures, good welding practices minimize occurrence of defect during material processing and fabrication stage. Inspite of exhibiting excellent machining/ manufacturing properties, maraging stee material is prone to fracture. Hence fracture based design is to be followed.
NDT tools are used to identify & characterise such defects. The acceptable defects are arrived during the Design process. The defects are idealised to be thumbnail defects and LEFM technique is used to arrive at critical defect size. Griffith \cite{1} introduced the relation between crack size and stress intensity factor as below.

\[ K_{IC} = \sigma \sqrt{\frac{\pi a}{Q}} \]  

Where \( K_{IC} \) = stress intensity factor,
\( Q \) = correction factor,
\( \sigma \) = Ultimate tensile strength.
2a, 2b are sizes of crack.

\[ \sigma_{max} = \sigma(1+2a/b)-\frac{2}{\pi} \sqrt{\frac{a}{\rho}} \]  

Fig. 1: Griffith’s theory\cite{1} crack parameters

Aerospace quality of material shall confirm to AMS standards reference notches are classified for testing and quality classes are also defined with reference to these notches The Notches are made on Maraging steel with Electrode Discharge Machine (EDM) which provides accuracy in sizing and location as per requirement.

EDM notches can be machined as small as few hundred micron wide on a plate. Transverse (circumferential) notches are normally made with electrodes precisely ground to the respective radius of the workpiece. This ensures uniform notch depth along the notch length. Notches can also be made to match an irregular surface, or have a thumbnail (semi-elliptical) profile.

Maraging steel \cite{3,4} strength and malleability in the pre-aged stage allows it to be formed into thinner rocket and missile skins than other steels, reducing weight for a given strength. Maraging steels have very stable properties and even after over-aging due to excessive temperature, only soften slightly. These alloys retain their properties at mildly elevated operating temperatures and have maximum service temperatures of over 400 °C (752 °F). Using TIG (Tungsten Inert Gas) Welding, equivalent size of tight cracks were fabricated in Maraging steel plates and Ultrasonic data compared with notch reference data.
Experimental work:

Maraging steel welded Test plate 300 x 300 x 3.6mm with the above said notches is prepared. Based on series of trials, the probe & parameters are optimized. 70°, 4 MHz & 80°, 4 MHz probes are used to draw DAC (Fig. 3) with reference to standard reference to F Notch. Distance Amplitude Correction Curve is drawn at 64 dB of Amplitude (80%, 60% and 20% of Full Screen Height). Ultrasonic A-Scan was performed on the sample plate with E, F & G notches at the same gain. The G Notch has almost raised upto 100% of the screen at the 1st skip. On the other hand, at the same gain, F notch raised to 45% and E-Notch to 25%. The same is given in Fig.3

Tensile testing of notched specimens:

The tensile test has been carried out on notched specimens, based on the fracture load and using LEFM approach. The tensile test setup and specimens used are shown in Fig.4 & 5. The equivalent tight crack that causes failure is calculated using LEFM approach and tabulated in Table 2. The actual failure values are tabulated in Table 3.
It can be seen that a specimen with 4x1.5 defect is predicted to fail at approximately 69 KN. Simultaneously, it can be seen that during actual tensile testing, the failure happened at 70.25 KN. Similar equivalence has been exhibited by other notches as well.

<table>
<thead>
<tr>
<th>Specimen Specification</th>
<th>Tight Crack Dimension [mm]</th>
<th>K Ic [MPa√m]</th>
<th>Load [KN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notch Free</td>
<td>-</td>
<td>-</td>
<td>80.46</td>
</tr>
<tr>
<td>Specimen 1</td>
<td>3 X 1</td>
<td>80</td>
<td>75.94</td>
</tr>
<tr>
<td>Specimen 2</td>
<td>4 X 1.5</td>
<td>80</td>
<td>69.33</td>
</tr>
<tr>
<td>Specimen 3</td>
<td>7 X 3</td>
<td>80</td>
<td>64.28</td>
</tr>
</tbody>
</table>

Table 1: Calculated Ultimate Tensile Strength of Tensile Specimens

<table>
<thead>
<tr>
<th>class</th>
<th>Specimen Specification</th>
<th>Tight Crack Dimension [mm]</th>
<th>K Ic [MPa√m]</th>
<th>Load [KN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA</td>
<td>E Notch</td>
<td>1.02 X 0.52 X 0.25</td>
<td>80</td>
<td>80.15</td>
</tr>
<tr>
<td>A1</td>
<td>F Notch</td>
<td>1.26 X 0.76 X 0.25</td>
<td>80</td>
<td>70.25</td>
</tr>
<tr>
<td>A</td>
<td>G Notch</td>
<td>2.52 X 1.26 X 0.25</td>
<td>80</td>
<td>67.96</td>
</tr>
</tbody>
</table>

Table 2: Experimental UTS of SAE AMS 2632 Notched Tensile Specimens
Conclusion:

Tight cracks are identified and compared with equivalent SAE AMS 2632 notches experimentally. Notched specimens are prepared and tested on UTM. Failure load identified and the same is compared to predicted failure load by fracture mechanics approach of a tight cracked weldment. Failure load of cracked specimen (4 X1.5 mm) and F-Notched specimen are comparable.

References: