Fatigue resistance optimization of armored vehicle structures using weld master S-N curve

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**Motivation**

“The Army Chief of Staff set his priority as Readiness. Readiness for ground combat is – and will remain – the US Army’s #1 priority... Readiness is #1, and there is no other #1.” TARDEC 30-Year Strategy, V. 2.0, January 2016.

Cracks in welds of Army vehicle structures are encountered due to fatigue, resulting in reduced availability of vehicles for warfighting.

**Fundamental Research Questions**

- What are the unique fatigue behaviors associated with thick plate joints used in armored vehicle structures?
- How can the unique fatigue behavior associated with armor plate weldments be predicted through a systematic new computational and experimental investigation?
- How modeling and optimization can improve the fatigue life of Army vehicles?

**Objectives**

- Develop a fundamental understanding of unique fatigue behaviors associated with thick plate joints used in armored vehicle structures through computational modeling and selected laboratory testing.
- Establish a theoretical framework for data transferability of fatigue test data from different joint types, loading modes, thicknesses, and material combinations relevant to applications in armored vehicles, i.e., establish a Master S-N curve for joints of armored vehicles.
- Develop computational algorithms for incorporating the Master S-N curve for fatigue evaluation and optimization of armored vehicle structures.

**Approach**

- Development of a fatigue test plan.
- Experimental study for investigating unique issues of armor plate weldments.
- Mesh-insensitive method for modeling armored vehicle structures for structural life evaluations and for establishing a Master S-N curve for joints of armored vehicles.
- Optimization algorithm that integrates mesh-insensitive stress simulations and the Master S-N curve fatigue life prediction with manufacturing considerations for Army vehicle structures.

**Results**

**Testing Campaign**

- The previously developed test plan was executed for the ½" strip specimens for the material combinations below (47 different tests).
- Joint misalignment & mesh insensitive modeling used for processing the testing results and for generating data points in the Master S-N curve.

<table>
<thead>
<tr>
<th>Test ID</th>
<th>Base-Filler Combination</th>
<th>Mismatch Ratio</th>
<th>Point of Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>AISI with E6010LS</td>
<td></td>
<td>High deform, stainless</td>
</tr>
<tr>
<td>B</td>
<td>4600 with E6010LS</td>
<td>0.264</td>
<td>Lowest mismatch ratio</td>
</tr>
<tr>
<td>C</td>
<td>12560 with E100C-G H4</td>
<td>0.095</td>
<td>Highest mismatch ratio</td>
</tr>
<tr>
<td>D</td>
<td>12560 with E6010S6</td>
<td>0.405</td>
<td>Most common combo</td>
</tr>
<tr>
<td>E</td>
<td>A514 with E6010S6</td>
<td>0.715</td>
<td>High deform, non-stainless</td>
</tr>
<tr>
<td>F</td>
<td>4600 with E6010S6</td>
<td>0.332</td>
<td>High strength base and filler</td>
</tr>
</tbody>
</table>

**Global Fatigue Life and Cost Optimization Analysis**

- Maximize fatigue life (experimental results are used in fatigue life computations) & minimize cost (Navy’s cost model for welding is used).
- Design variables: location and orientation of welds, weld type, weld filler material.
- Constraints on size of available plates.
- Specialized multidisciplinary algorithm & new developments for automated computations of fatigue life and cost.

**Future Work**

- Complete the experimental campaign with 2.5" wide strip specimens.
- Statistical methods for further analysis of the experimental data.
- Fatigue life optimizer for “building block” manufacturing – practical solution of weld planning considering typical availability of alternative standard sizes of parts.
- Topographic optimization for vehicle components through nested optimization processes comprised of an outer and an inner optimization.