Two material model updates relating to temperature-dependent behaviors

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Abstract

Two material model updates are presented in this paper: (1) temperature-dependent failure criteria for spot-welds; (2) rate-and-temperature-dependent hardening rule in material type 233 (MAT_CAZACU_BARLAT). Procedures of how to enable these features are given in detail in this paper.

I. Introduction

Temperature-dependent material models are becoming increasingly important in numerical simulations to incorporate the effects of thermal softening in various application scenarios. This paper introduces two newly implemented features related to material temperature dependence in LS-DYNA®: (1) temperature-dependent failure criteria for spot-welds; (2) rate-and-temperature-dependent hardening rule in material type 233 (MAT_CAZACU_BARLAT).

II. Temperature-dependent failure criteria for spot-welds

The spot-weld failure criteria in LS-DYNA® is defined as shown in equation (1):

\[
\left( \frac{|f_n|}{S_n} \right)^n + \left( \frac{|f_s|}{S_s} \right)^m \geq 1
\]  

(1)

where \(S_n\) and \(S_m\) are normal and shear forces at spot-weld failure, respectively. \(n\) and \(m\) are exponents for normal and shear spot-weld forces, respectively. In the newly-implemented feature, temperature dependence is introduced into this criteria as shown in equation (2):

\[
\left( \frac{|f_{n(T)}|}{S_{n(T)}} \right)^n + \left( \frac{|f_{s(T)}|}{S_{s(T)}} \right)^m \geq 1
\]  

(2)

where \(S_n\) and \(S_m\) can be input as functions of the spot-weld temperature \(T\). The keyword input for spot-weld constraints (*CONSTRAINED_SPOTWELD) is shown in Figure 1, where SN and SS correspond to \(S_n\) and \(S_m\) in equations (1) and (2). The rules as shown in Table 1 are applied to SN and SS to enable the temperature-dependent feature while keeping the program compatible with older forms of inputs. To define a temperature-dependent failure in a spot-weld constraint, first define curves which characterize the normal and/or shear forces at failure as functions of temperature, then input the negative curve IDs as SN and/or SS in the *CONSTRAINED_SPOTWELD keyword. The failure criteria will then be updated with the local temperature of the spot-weld according to the SN and/or SS curves. Note that if the analysis itself has no temperature solutions, this temperature-dependent criteria will be disabled.
Table 1 Updated input rules for SN and SS in card 1 of *CONSTRAINED_SPOTWELD

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
</table>
| SN       | EQ. 0.0: the failure criteria is disabled.  
          | GT. 0.0: Normal force at spot-weld failure.  
          | LT. 0.0: Curve ID which specifies the normal force at spot-weld failure as a function of local temperature. |
| SS       | EQ. 0.0: the failure criteria is disabled.  
          | GT. 0.0: Shear force at spot-weld failure.  
          | LT. 0.0: Curve ID which specifies the shear force at spot-weld failure as a function of the local temperature. |

III. Rate-and-temperature-dependent hardening for material type 233

To characterize the strain hardening behavior at raised temperatures, the material type 233 is updated to allow the input of a rate-and-temperature-dependent hardening rule. To enable this option, the user first needs to define a three dimensional (3-D) table, which characterizes the hardening behavior as a function of both the strain rate and temperature. An example of a 3-D table input is shown in Figure 2 where the first tier defined by keyword *DEFINE_TABLE_3D has two columns: (1) temperatures; (2) 2-D table IDs corresponding to each temperature. The second tier defined by keyword *DEFINE_TABLE_2D_TITLE includes two columns: (1) strain rates; (2) curve IDs corresponding to each strain rate. Note that a total of ten 2-D tables need to be defined in this example because the 1st tier 3-D table has 10 temperature inputs. The third tier defined by keyword *DEFINE_CURVE_TITLE gives the effective stress as a function of effective plastic strain. For this example where 10 temperatures and 7 strain rates are given, a total of 70 stress-strain curves need to be defined to characterize the material’s hardening behavior.
Figure 3 shows how to activate the rate-temperature-dependent hardening in the material keyword *MAT_CAZACU_BARLAT. First of all, HR in the 1st card needs to be set to 3. In the meantime, the 3-D table ID that defines the hardening rule should be input as LCID in the 2nd card. Note that the analysis should have temperature solutions in order to utilize this feature. Otherwise, 2-D table for the 1st temperature input in the 3-D table definition will be used to model the hardening behavior. To further include the thermal strain/stress effects in the analysis, consider using *MAT_ADD_THERMAL_EXPANSION to characterize the material’s thermal expansion. Note that currently this option is only available for shell elements.

4. Summary

To characterize material behaviors at raised temperatures, two new temperature-dependence features are introduced into LS-DYNA®: (1) temperature-dependent failure criteria for spot-welds; (2) rate- and temperature-dependent hardening rule in material type 233 (MAT_CAZACU_BARLAT). In the 1st feature, the normal and/or shear forces at failure can be defined as functions of local temperatures at the spot-weld. In the 2nd feature, the material hardening law can be defined with a 3-D table which allows the strain hardening curves varies at both temperatures and strain rates.
Figure 3 Example input of 3-Table characterizing rate-and-temperature-dependent hardening

<table>
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<tr>
<th>Card 1</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<td>E</td>
<td>PR</td>
<td>HR</td>
<td>P1</td>
<td>P2</td>
<td>ITER</td>
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<table>
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<tbody>
<tr>
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<td>C22</td>
<td>C33</td>
<td>LCID</td>
<td>E0</td>
<td>K</td>
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<tr>
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<td>F</td>
<td>F</td>
<td>F</td>
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