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):

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

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):

$$\left(\frac{|f_n|}{S_n(T)}\right)^n + \left(\frac{|f_s|}{S_s(T)}\right)^m \geq 1 \tag{2}$$

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.

Card 1	1	2	3	4	5	6	7	8
Variable	N1	N2	SN	SS	N	M	TF	EP
Type	I	I	F	F	F	F	F	F
Default	none	none	optional	optional	none	none	1.E+20	1.E+20
Remarks	1.		2.				3	4

Figure 1 Snapshot of Card 1 for keyword *CONSTRAINED_SPOTWELD

Table 1 Updated input rules for SN and SS in card 1 of *CONSTRAINED_SPOTWELD

Variable	Description
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 1^{st} 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.

1st tier: 3-D table

```
*DEFINE_TABLE_3D
$     T3BID       SFA      OFFA
     10000
$       TEMPERATURE  TABLE_ID
             273.15     10100
             773.15     10200
             823.15     10300
             873.15     10400
             923.15     10500
             973.15     10600
            1023.15     10700
            1073.15     10800
            1123.15     10900
            1173.15     11000
```

2nd tier: 2-D table

```
*DEFINE_TABLE_2D_TITLE
T=273.15
$     TBID        SFA      OFFA
     10100
$        STRAIN_RATE  CURVE_ID
             0.01000     10101
             0.05000     10102
             0.10000     10103
             0.50000     10104
             1.00000     10105
             5.00000     10106
            10.00000     10107
```

3rd tier: stress-strain curves

```
*DEFINE_CURVE_TITLE
T=273.15 strain_rate=0.010
$     LCID      SDIR       SFA       SFO      OFFA      OFFO
     10101                          1.20
$ EFF_PLASTIC_STRAIN       YIELD_STRESS
             0.0000            131.570
             0.0025            157.967
             0.0050            166.473
             0.0075            172.669
             0.0100            177.721
             0.0150            185.913
             0.0200            192.593
             0.0250            198.335
             0.0300            203.425
             0.0350            208.031
             0.0400            212.258
             0.0500            219.850
             0.0600            226.581
             0.0700            232.671
             0.0800            238.260
             0.0900            243.447
             0.1000            248.299
             0.2000            285.916
             0.3000            313.314
             0.4000            335.654
             0.5000            354.858
             0.6000            371.882
             0.7000            387.284
             0.8000            401.422
             0.9000            414.539
             1.0000            426.813
```

Figure 2 Example of 3-D Table characterizing rate-and-temperature-dependent hardening

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.

Card 1	1	2	3	4	5	6	7	8
Variable	MID	RO	E	PR	HR	P1	P2	ITER
Type	A8	F	F	F	***3.0***	F	F	F

Card 2	1	2	3	4	5	6	7	8
Variable	A	C11	C22	C33	LCID	E0	K	P3
Type	F	F	F	F	***3d table ID***	F	F	F

Figure 3 Example input of 3-Table characterizing rate-and-temperature-dependent hardening