LS-DYNA Features for Hot Stamping

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Abstract

LS-971 has several new features to model the hot stamping process. A thick thermal shell formulation allows modeling a temperature gradient through the thickness of the shell. The new keyword, *MAT_ADD_THERMAL_EXPANSION, allows calculating thermal strains for all the mechanical material models. A new feature has been added to thermal contact which turns off thermal boundary conditions when surfaces come in contact. A new thermal one-way contact algorithm has been added which more accurately models heat transfer between a blank and die. New features have been added to thermal-mechanical contact which allows modeling the coefficients of friction as a function of temperature and thermal contact resistance as a function of interface pressure.

Units

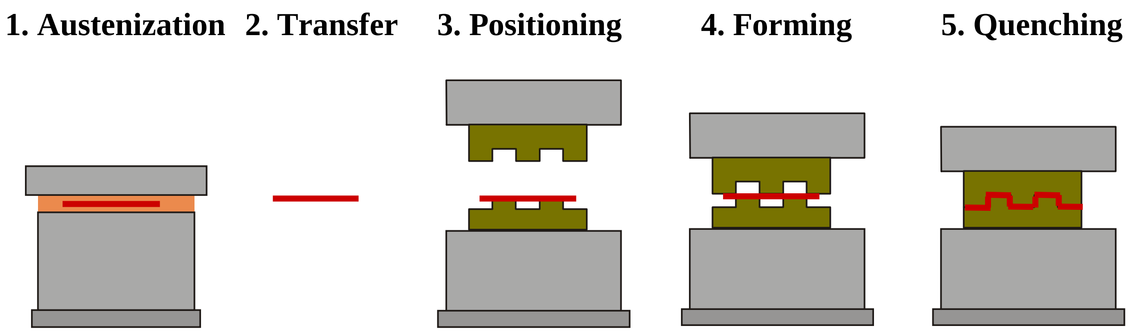
A consistent set of units must be used in performing a coupled thermal-mechanical analysis. Problems arise due to a mismatch between the mechanical unit for work and the thermal unit for energy. SI presents a consistent set of units to perform a coupled thermal mechanical analysis. However, units are typically chosen based on historical practice in the industry. Table 1 presents typical units used for metal stamping. There are 2 approaches that can be taken to satisfy the requirement of a consistent set of units.

1. Convert the thermal units into the base units being used for the mechanical problem. This is done for unit sets 1 and 2 in Table 1. The mechanical units for Unit Set 1 are defined in a way that the thermal units are in joules and watts. This is not the case for Unit Set 2. Although Unit Set 2 is consistent, the thermal units are not familiar.
2. Use the SI unit for thermal energy, the joule, and define the mechanical equivalent of heat to convert the mechanical work unit into joules. This is done for Unit Set 3. The mechanical equivalent of heat is entered in the *CONTROL_THERMAL_SOLVER keyword.

Hot Forming Process

The hot forming process has 5 steps [1]:

1. Austenization → The blank is heated and held at the austenization temperature of 950C.
2. Transfer → The blank cools by convection and radiation during transfer from the oven to the forming press.
3. Positioning → The blank is placed on the lower die and begins to cool due to contact with the colder die.
4. Forming → The blank is formed.
5. Quenching → The blank is held in the press and cooled to induce a solid-solid phase transition from austenite to martensite.

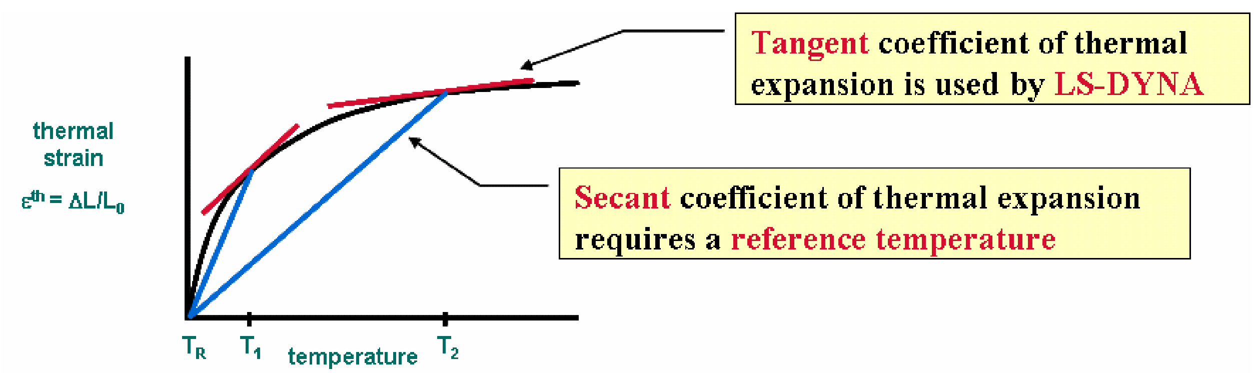


Thick Thermal Shell

The blank is modeled by a thin mechanical shell and flagged to be treated as a thick thermal shell by the parameter TSHELL on the *CONTROL_SHELL keyword. The thick thermal shell is a 12 node element – 4 nodes in the plane of the shell and 3 nodes through the thickness. The 3 nodes through the thickness allow the use of quadratic shape functions to more accurately calculate the through thickness temperature gradient. LS-PrePost can display temperatures on the mid-plane, bottom surface, and top surface of the shell.

*MAT_ADD_THERMAL_EXPANSION

The coefficient of thermal expansion as a function of temperature can be defined using the *MAT_ADD_THERMAL_EXPANSION keyword. This allows the calculation of thermal strains for any of the mechanical material models in LS-DYNA. LS-DYNA requires the tangent value of the coefficient of expansion as defined in the following figure.



Thermal Mechanical Contact

Two new features have been added to the *CONTACT_option_THERMAL keyword.

1. bc_flag → During the transfer operation from the oven to the press both surfaces of the blank lose heat to the environment. However, once the blank is positioned on the lower die, only the top surface of the blank transfers heat to the environment. Setting bc_flag=1 turns off thermal boundary conditions for those surfaces that are in contact.
2. 1_way → In the mechanical definition of the problem, the dies are typically modeled using a rigid material. Therefore, the dies do not deform. Analogously for the thermal definition of the problem, the dies do not change temperature because their mass is much

greater than that of the blank. The parameter 1_way invokes this modeling assumption – only the blank can change temperature due to contact.

The suffix FRICTION added to the keyword *CONTACT_option_THERMAL_FRICTION adds the capability to model the mechanical coefficients of friction as a function of temperature and the thermal contact resistance as a function of interface pressure. There are currently 4 formulas to calculate the contact resistance, h, as a function of interface pressure, P:

1. load curve h(P) is defined by a load curve
2. polynomial $h(p) = a + bP + cP^2 + dP^3$
3. Shvets formula [2] $h(P) = \frac{\pi k_{gas}}{4\lambda}\left[1. + 85\left(\frac{P}{\sigma}\right)^{0.8}\right]$
4. Sellers formula [3] $h(P) = a\left[1. - \exp\left(-b\frac{P}{c}\right)\right]^d$

Other formulas will be added in the future.

MAT_113 [4] and Thermal User Subroutine

Material type 113 applies to shell elements only. It features a special hardening law aimed at modeling the temperature dependent hardening behavior of TRIP-steels. TRIP stands for Transformation Induced Plasticity. The material gains ultra high strength through the hot forming process. In this material, a phase transformation from austenite to martensite occurs during forming, an effect which is sensitive not only to the stain level, but also to strain rate and temperature. The material model is composed of 2 basic equations:

1. TRIP kinetics rate equation $\frac{\partial V_m}{\partial \varepsilon} = \frac{B}{A}\exp\left(\frac{Q}{T}\right)\left(\frac{1-V_m}{V_m}\right)^{(1+B)/B} V_m^P \frac{1}{2}\left(1 - \tanh(C + DT)\right)$
2. yield stress equation $\sigma_y = \{B_{HS} - (B_{HS} - A_{HS})\exp(-m\varepsilon^n)\}(K_1 + K_2 T) + \Delta H_{\gamma\to\alpha} V_m$

The user subroutine allows the creation of more sophisticated material models with the interchange of material history variables between the mechanical material user subroutine and the thermal material user subroutine.

References

1. Figure courtesy of David Lorenz, DaimlerChryler, Mercedes Car Group, Germany.
2. I.T. Shvets, “Contact Heat Transfer Between Plane Metal Surfaces”, Int. Chem. Eng., Vol. 4, No. 4, p621, 1964.
3. Li & Sellers, Proc. Of 2nd Int. Conf. Modeling of Metals Rolling Processes, The Institute of Materials, London, 1996.
4. D. Hilding & E. Schedin, “Experience from Using a New Material Model for Stainless Steels with TRIP-effect”, 5th European LS_DYNA Users Conference, Birmingham, UK, 2005.

Table 1: Shown are typical unit sets used for metal stamping. Properties are for 1020 cold rolled steel.

Mass	Length	Time	Force	Pressure	Work or Energy	Mechanical Equivalent of Heat	Density	Elastic Modulus	Thermal Conductivity	Heat Capacity	Flux
SI											
kg	m	s	N	Pa	N m = J	J / N m	kg/m^3	Pa	W/m K	J/kg K	W/m^2
						1.	7.87e+03	2.05e+11	5.19e+01	4.86e+02	1.
Unit Set 1											
kg	mm	ms	kN	Gpa	N m = J	J/kN mm	kg/mm^3	GPa	kW/mm K	J/kg K	kW/mm^2
						1.	7.87e-06	2.05e+02	5.19e-05	4.86e+02	1.e-09
Unit Set 2											
ton	mm	s	N	MPa	N mm	Not Applicable	ton/mm^3	MPa	$ton\ mm/s^3\ K$	mm^2/s^2K	ton/s^3
						1.	7.87e-09	2.05e+05	5.19e+01	4.86e+08	1.e-03
Unit Set 3											
ton	mm	s	N	MPa	N mm	$10^{-3}J/N\ mm$	ton/mm^3	MPa	W/mm K	J/ton K	W/mm^2
						1.e-03	7.87e-09	2.05e+05	5.19e-02	4.86e+05	1.e-06