The European Materials Modelling Council

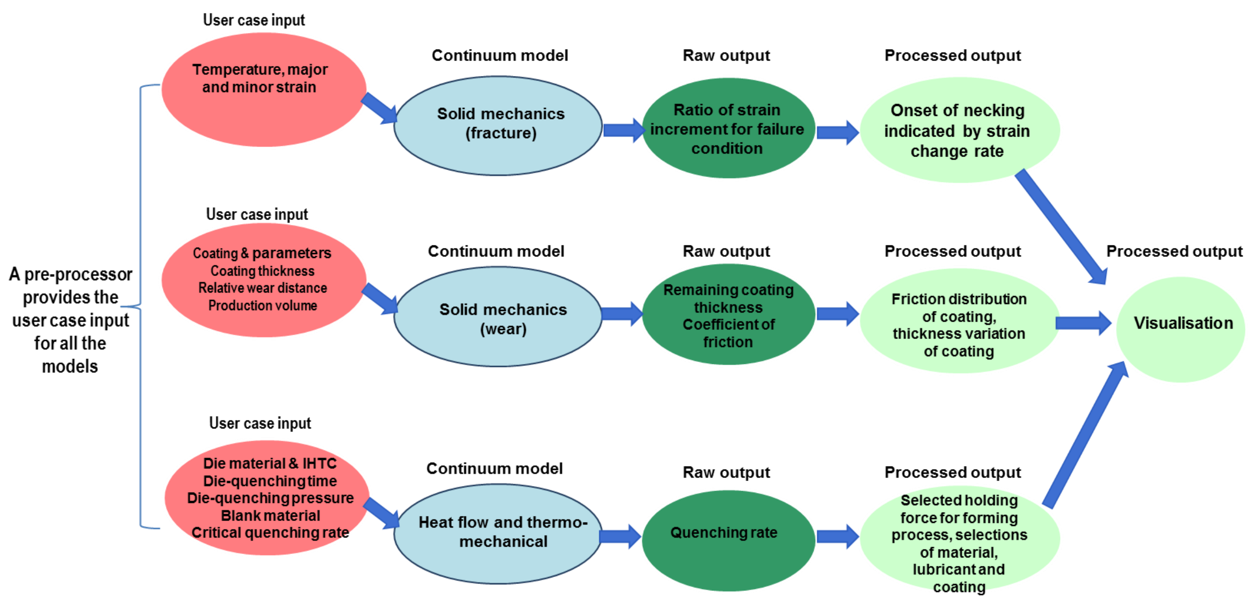
LoCoMaTech: Low Cost Materials Processing Technologies for Mass Production of Lightweight Vehicles

Purpose of this document:
Definition of a data organisation that is applicable to ALL materials modelling simulations. The fiche should contain all elements that are needed to describe one simulation. This information spans from the end-user (manufacturer) information to the computational modelling details.

OVERVIEW of the simulation			
1	**USER CASE**	The automotive industry users want to optimize the design of structure, subsystem, components and manufacturing processes for complex shaped, lightweight panel components by optimizing the material selection, structural properties/performance.	
2	**CHAIN OF MODELS**	**MODEL 1**	The structural mechanics model for forming which describes the onset of failure/necking is part of Chapter 4 Continuum modelling of materials in the Review of Materials Modelling V.
		MODEL 2	The structural mechanics model for tool life which describes wear and the life time is part of Chapter 4 Continuum modelling of materials in the Review of Materials Modelling V.
		MODEL 3	The structural mechanics model for tool maker which describes interfacial heat transfer in the forming process is part of Chapter 4 Continuum modelling of materials in the Review of Materials Modelling V.
3	**PUBLICATION ON THE SIMULATION**	N/A	
4	**ACCESS CONDITIONS**	The Forming Limit model, Tool Life model and Tool Maker model are developed by the researchers at Imperial College London. The published model and data for the LoCoMaTech project are open to share. The software can be found on http://smartforming.com/ .	

Workflow

Materials models: Knowledge Based Cloud FEA



Elements in the simulation of Model 1: Forming Limit model

1	ASPECT OF THE USER CASE/SYSTEM TO BE SIMULATED
1.1	ASPECT OF THE USER CASE TO BE SIMULATED AND HOW IT FORMS A PART OF THE TOTAL USER CASE	The prediction of the necking/failure conditions in a sheet forming process in which temperature, strain path and strain rate changes occur.
1.2	MATERIAL	Aluminium alloys (mainly consists of Al, Mg, Si, Zn, etc.)
1.3	GEOMETRY	The geometry of vehicle components such as the door inner with approximation of dimension of 1.5 m by 1 m by 0.02 m.
1.4	TIME LAPSE	The Forming Limit model runs from minutes to hours.
1.5	MANUFACTURING PROCESS OR IN-SERVICE CONDITIONS	The manufacturing condition is an anisothermal process with high forming speed which can influence the strain change rate. For hot forming and quenching (HFQ) process, the temperature of sheet metal material is up to 500 degree Celsius and that of forming tool is approximately 50 degree Celsius. The forming speed is up to 400 mm/s.
1.6	PUBLICATION ON THIS ONE SIMULATION	N/A

2	GENERIC PHYSICS OF THE MODEL EQUATION		
2.0	MODEL TYPE AND NAME	Continuum solid mechanics model (fracture)	
2.1	MODEL ENTITY	Finite elements	
2.2	MODEL PHYSICS/ CHEMISTRY EQUATION PE'S	Equations	Conservation equation of mass and energy $E_{kinetic} + E_{potential} = E_{total}$
		Physical quantities for each equation	Kinetic energy within a system, $E_{kinetic}$ Pontential energy within a system, $E_{potential}$ Total energy within a system, E_{total}
2.3 MATERIALS RELATIONS		MR Equations	The unified viscoplastic-Hosford-MK constitutive equations are established by data mining on experimental data for high temperature forming limit diagram prediction. It is assumed that there exists an initial imperfection in the material, denoted zone B, where the thickness is slightly lower than the rest of the material, denoted zone A. 1. $\dot{\bar{\varepsilon}}_{P(A,B)} = \left(\frac{\bar{\sigma}_{(A,B)} - R_{(A,B)} - k}{K}\right)^{n_1}$ 2. $R_{(A,B)} = B\bar{\rho}_{(A,B)}^{0.5}$ 3. $\dot{\bar{\rho}}_{(A,B)} = A\left(1 - \bar{\rho}_{(A,B)}\right)\dot{\bar{\varepsilon}}_{P(A,B)} - C\bar{\rho}_{(A,B)}^{n_2}$ 4. $\bar{\sigma}_{(A,B)} = E\left(\bar{\varepsilon}_{(A,B)} - \bar{\varepsilon}_{P(A,B)}\right)$ 5. $R_2{\sigma_1}^a + R_1{\sigma_2}^a + R_1R_2(\sigma_1 - \sigma_2)^a = R_2(R_1 + 1)\bar{\sigma}^a$ 6. $f = f_0 \exp(\varepsilon_{3B} - \varepsilon_{3A})$

			7. $\frac{d\varepsilon_{1B}}{d\varepsilon_{1A}} \geq 10, or\ \frac{d\varepsilon_{3B}}{d\varepsilon_{3A}} \geq 10$, condition for the onset of necking
		Physical quantities/ descriptors for each MR	1. Temperature-dependent material constants, $k, K, n_1, B, A, C\ and\ E$ 2. Constants, a, n_2 3. Dislocation density, $\bar{\rho}_{(A,B)}$ 4. Longitudinal or transvers r-values, R_1, R_2 5. Isotropic hardening, $R_{(A,B)}$ 6. Imperfect factor, f 7. Initial imperfect factor, f_0, 8. Strain, $\varepsilon_{n(A,B)}, n = 1{,}2\ or\ 3$ (orientation in x, y and z axis) 9. Stress, $\sigma_{n(A,B)}$,, $n = 1{,}2\ or\ 3$ (orientation in x, y and z axis) 10. Plastic strain, $\bar{\varepsilon}_{P(A,B)}$, the subscript 'P' stands for plastic
2.4	SIMULATED INPUT	N/A	

3	SPECIFIC COMPUTATIONAL MODELLING METADATA		
3.1	NUMERICAL SOLVER	Solver developed at Imperial College London	
3.2	SOFTWARE TOOL	The functional modules are shared on http://smartforming.com/	
3.3	TIME STEP	The typical time step is 1e-4 seconds for providing sufficient accuracy and good computation speed.	
3.4	COMPUTATIONAL REPRESENTATION	PHYSICS EQUATION, MATERIAL RELATIONS, MATERIAL	The explicit Euler solver for differential equations is used. At each time step, the strain is incremented and the corresponding variables are updated to calculate the stress and also used to check the failure condition. The computation is completed when either the forming process is finished or the onset of necking occurs beforehand based on the condition being met: $\frac{d\varepsilon_{1B}}{d\varepsilon_{1A}} \geq 10, or\ \frac{d\varepsilon_{3B}}{d\varepsilon_{3A}} \geq 10$.
		BOUNDARY CONDITIONS	N/A
		ADDITIONAL SOLVER PARAMETERS	N/A

Post processing

4	POST PROCESSING	
4.1	THE PROCESSED OUTPUT IS CALCULATED FOR	The calculated results from the Forming Limit model are imported for visualising the onset of necking (part of the same software as the solver).
4.2	METHODOLOGIES	The failure condition values at each computed element are sampled using a self-developed data format, and then the distribution map of onset of necking for a component is plotted.
4.3	MARGIN OF ERROR	Based on the data obtained from the forming of a door inner of a vehicle, the error of calculation is controlled at about 5-10%.

Elements in the simulation of Model 2: Tool Life model

1	ASPECT OF THE USER CASE/SYSTEM TO BE SIMULATED	
1.1	ASPECT OF THE USER CASE TO BE SIMULATED AND HOW IT FORMS A PART OF THE TOTAL USER CASE	The prediction of service life of tools, such as punch, blank holder and die in industrial environment. Reduction of coating in operation cycles due to stamping/pressure. The improvement of tool design will enhance the operation life of the manufacturing facility.
1.2	MATERIAL	TiN coating on a component of a forming tool.
1.3	GEOMETRY	A typical lab forming test component, such as a dome with diameter of 0.2 m.
1.4	TIME LAPSE	The tool life model operates within 2 minutes.
1.5	MANUFACTURING PROCESS OR IN-SERVICE CONDITIONS	The manufacturing process to be simulated includes stamping speed, initial friction coefficient, high temperature and external pressure that can influence the coating thickness and relative wear distance in the industrial operation, such as the hot stamping process.
1.6	PUBLICATION ON THIS ONE SIMULATION	N/A

2	GENERIC PHYSICS OF THE MODEL EQUATION		
2.0	MODEL TYPE AND NAME	Continuum model – Solid Mechanics	
2.1	MODEL ENTITY	Finite elements	
2.2	MODEL PHYSICS/ CHEMISTRY EQUATION PE'S	Equations	Conservation equation of energy $E_{kinetic} + E_{potential} = E_{total}$
		Physical quantities for each equation	Kinetic energy within a system, $E_{kinetic}$ Pontential energy within a system, $E_{potential}$ Total energy within a system, E_{total}
2.3 MATERIALS RELATIONS		MR Equations	Friction model 1. $\mu = \mu_{\alpha} + \mu_{P_c}$, friction 2. $\mu_{P_c} = \mu_{P_s} exp[-(\lambda_1 h)^{\lambda_2}]$ 3. $h = h_0 - \dot{h}dt$ 4. $\dot{h} = \frac{KPv}{H_c}$ 5. $H_c = H_s(\frac{\alpha^2+h\beta^2}{\alpha+h\beta^2})$ 6. $\lambda_1 = k_{\lambda_1} P^{N_{\lambda_1}}$ 7. $K = k_K P^{N_K}$ Archard equation:

		8. $Q = \frac{KWL}{H}$
	Physical quantities/ descriptors for each MR	1. Load independent parameters, $\mu_{(Ps)}$ and λ_1 2. Hardness ratio between coating and substrate, α 3. Coefficient of thickness, β 4. Constants, k_{λ_1}, k_K, N_K and N_{λ_1} 5. Volume of wear, Q 6. Constant, K 7. Load, W 8. Sliding distance, L 9. Hardness, H
2.4	**Simulated input**	N/A

3	**Specific Computational Modelling Metadata**		
3.1	**Numerical Solver**	Solver (code) developed at Imperial College London	
3.2	**Software Tool**	The FE model can be shared on http://smartforming.com/	
3.3	**Time Step**	Unclear	
3.4	**Computational Representation**	**Physics Equation, Material Relations, Material**	The explicit Euler solver for differential equations is used. At given time step, the thickness of coating is reduced and the corresponding variables are updated to calculate the remaining thickness and are used to quantify the coating failure condition. The computation stops when either the coating failure occurs or a certain number of operation cycles for the coated component is achieved.
		Boundary Conditions	N/A
		Additional Solver Parameters	N/A

Post processing

4	**POST PROCESSING**	
4.1	**The processed output is calculated for**	The calculated results from the Tool Life model are imported for visualising the friction distribution of coating and the profile of thickness variation of coating (part of the same software as the solver).
4.2	**Methodologies**	The coefficient of friction and remaining coating thickness for each computed element are collected using a self-developed data format, and then a single distribution map of friction of coating is plotted.
4.3	**Margin Of Error**	N/A

Elements in the simulation of Model 3: Tool Maker model

1	ASPECT OF THE USER CASE/SYSTEM TO BE SIMULATED
1.1	ASPECT OF THE USER CASE TO BE SIMULATED AND HOW IT FORMS A PART OF THE TOTAL USER CASE	The prediction of temperature evolution and hence quenching rate of blank material in the forming process.
1.2	MATERIAL	Aluminium alloys (mainly consists of Al, Mg, Si, Zn, etc.)
1.3	GEOMETRY	A typical lab forming testing sample, e.g. a dome with diameter of 0.2 m.
1.4	TIME LAPSE	The forming process is completed within half an hour.
1.5	MANUFACTURING PROCESS OR IN-SERVICE CONDITIONS	The manufacturing condition to be simulated includes die quenching pressure, lubricant thickness, die material, surface roughness, cooling rate and forming speed etc. For example, a blank material is quenched to room temperature during the forming process.
1.6	PUBLICATION ON THIS ONE SIMULATION	N/A

2	GENERIC PHYSICS OF THE MODEL EQUATION		
2.0	MODEL TYPE AND NAME	Continuum model – Heat flow and thermal-mechanical	
2.1	MODEL ENTITY	Finite elements	
2.2	MODEL PHYSICS/ CHEMISTRY EQUATION PE'S	Equations	The conservation equation of energy $$E_{in} + E_{conversion} - E_{out} = \Delta E_{store}$$
		Physical quantities for each equation	Thermal energy transferred into a system, E_{in} Thermal energy transferred out of a system, E_{out} Thermal energy generated due to another energy source, $E_{conversion}$ Stored energy in the system, ΔE_{store}
2.3 MATERIALS RELATIONS		MR Equations	Interfacial heat transfer coefficient (IHTC) $h = a(1 - \exp(-b\,P))$
		Physical quantities/ descriptors for each MR	1. IHTC, h 2. Contact pressure, P 3. Constants, a and b
2.4	SIMULATED INPUT	N/A	

3	SPECIFIC COMPUTATIONAL MODELLING METADATA	
3.1	NUMERICAL SOLVER	FE

3.2	SOFTWARE TOOL	The FE model can be shared on http://smartforming.com/	
3.3	TIME STEP	Unclear	
3.4	COMPUTATIONAL REPRESENTATION	PHYSICS EQUATION, MATERIAL RELATIONS, MATERIAL	The explicit Euler solver for differential equations is used. At each time step, the time value is incremented and the temperature field is updated. The computation is completed when the target time is reached.
		BOUNDARY CONDITIONS	N/A
		ADDITIONAL SOLVER PARAMETERS	N/A

Post processing

4	POST PROCESSING	
4.1	THE PROCESSED OUTPUT IS CALCULATED FOR	The calculated results from the Tool Maker model are imported for visualisation which helps the user to select blank holding force, material, lubricant and coating for forming process (part of the same software as the solver).
4.2	METHODOLOGIES	The calculated quenching rate is compared with the pre-defined critical quenching rate until the agreement is achieving by varying the holding force, lubricant thickness and surface roughness in the calculation.
4.3	MARGIN OF ERROR	N/A