Advanced numerical model for viscous friction between rough rubber and smooth ice

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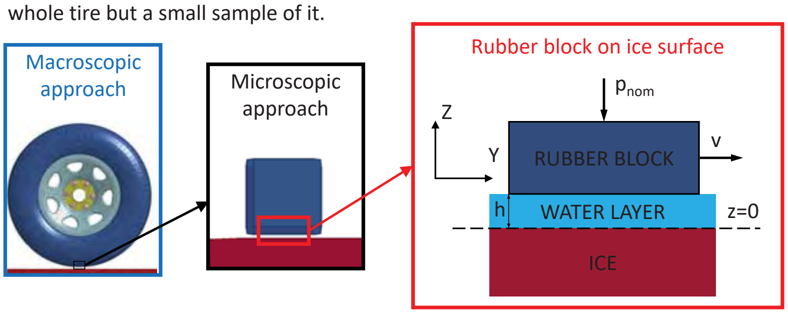
Introduction

Safety driving on icy road conditions is one of the most important challenges in the tire industry. A detailed understanding of the contact phenomena in the rubber-ice interface, could be very helpful in the design of the winter tire. To achieve this aim, an advanced FE model for viscous friction between rubber and ice was implemented. The main problems affecting the numerical simulation of the rubber-ice interaction are the phase changing of the ice and the dimensions of the tread. A customized subroutine for the LS-DYNA software was developed to simulate the effects of the melting of the ice and the related hydrodynamic behaviours during the sliding of a rubber block on a ice surface.

Analytical model

The formula implemented in the subroutine derives from a viscous formulation, using a microscopic approach. For this reason, the subject of this study is not the whole tire but a small sample of it.



Considering a rubber block sliding on an ice surface, the whole thermodynamic process can be represented by 3 terms:

viscous shear stress | melting energy | heat flow into ice

$$\eta_{water}\frac{v^2}{h(t)} = \rho\, L\frac{dh(t)}{dt} + \lambda\frac{T_m - T_0}{(\pi\,\alpha\, t)^{0.5}} \quad (1)$$

$$\frac{dh(t)}{dt} = \frac{1}{\rho\, L}\left(\eta_w\frac{v^2}{h(t)} - \lambda\frac{T_m - T_0}{(\pi\,\alpha\, t)^{0.5}}\right) \quad (2)$$

$$\mu(t) = \frac{\eta_w\, v}{h(t)\, p_{nom}} \quad (3)$$

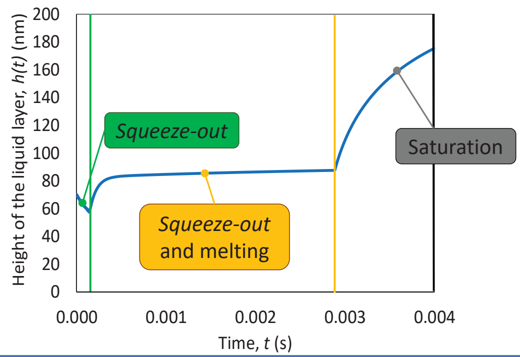
Considering the roughness (modelled as a series of small cylinders) of the rubber block and the related hydrodynamic effects, the equation (2) becomes:

$$\frac{dh(t)}{dt} = \frac{1}{\rho\, L}\left(\eta_w k\frac{v^2}{h(t)} - \lambda\frac{T_m - T_0}{(\pi\,\alpha\, t)^{0.5}}\right) - \frac{8}{3\eta_w}\frac{p_{nom}}{D_{asp}^2}\, h(t)^3\chi_{(H_{s(t)}<H_v)} \quad (4)$$

The hydrodynamic effects are:

- The *Squeeze-out*: the water is squeezed-out by the pressure and the sliding motion of the asperities of the rubber
- The *Saturation*: the free surface of the rubber is completely filled by the water

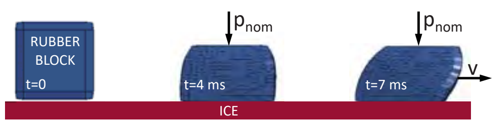
There are 3 phases during the sliding motion



Numerical model

The subroutine was developed in Fortran language. It works in parallel with a standard contact algorithm. Starting from the value, at the current time-step, of the thermo-mechanical parameters (e.g. the interface pressure, the nodal temperature and the sliding velocity), the subroutine gives as output, step by step, the value of the friction coefficient (Equation 3-4). The thermo-mechanical simulation was made in 2 steps:

1. Pre-load step (via dynamic relaxation): the rubber block is loaded by a nominal pressure. The velocity is applied to the rubber block when the equilibrium due to the load is reached. The ice surface is constrained in the space.



2. Transient step: the rubber block slides on the ice surface, the thermo-mechanical simulation and the user defined subroutine work in parallel.

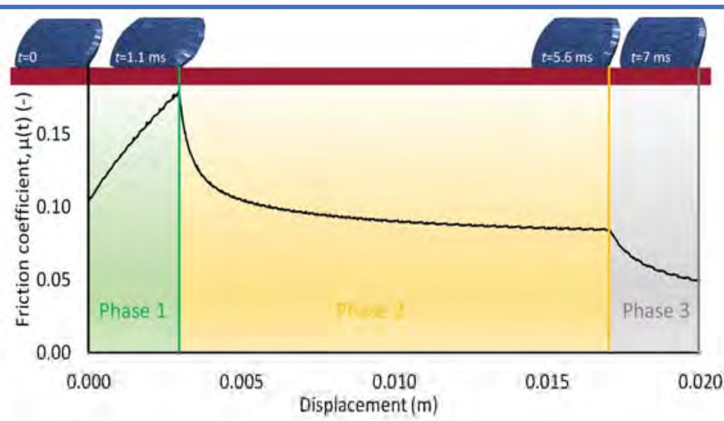
Results and discussions

The values of the friction coefficient affect the deformation of the rubber block.

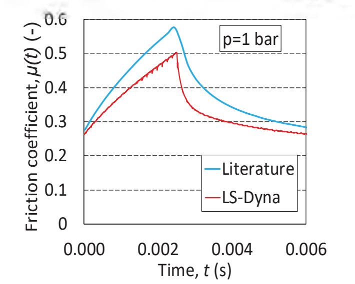
The higher the friction coefficient, the higher the bending of the rubber block.

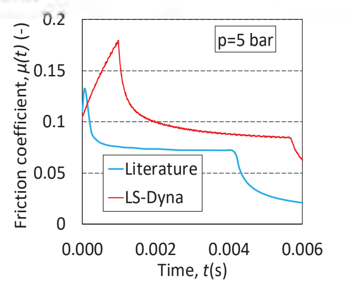
The trend of the friction coefficient put in evidence three different phases:

- Phase 1: it is mainly governed by the squeeze-out effect
- Phase 2: it starts with a singularity point where the melting temperature is reached. The increase of temperature produce additional water leading to an increasing value of the height of the liquid layer *h(t)*
- Phase 3: it is governed by the saturation effect



The duration of the described occurrence is few milliseconds, which corresponds to the first transient phase of the full phenomenon. This implies that it does not exits any test facility able to measure the friction coefficient in such a time range.
Due to this, the numerical results obtained with the FE approach were compared to the numerical solution of the equation (4) proposed in literature.





The comparison between the numerical results obtained with LS-DYNA and the results proposed in literature shows that:

- a good level of agreement is obtained in particular when the pressure applied on the rubber block is low
- the differences related to the melting-time, in particular when the pressure is high, are due to the uncertainness about the thermal parameters of the rubber material

Conclusions

The proposed methodology is the first step of a mature approach to support the design of winter tyre; indeed, in the ongoing project with an important tyre manufacturer, the planned developments are the introduction of macroscopic physical effects such as water wiping, in order to model the frictional behaviour of real tread on ice.

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