VESevo: an Innovative Device for Non-Destructive Viscoelasticity Characterization

The evaluation of the viscoelastic properties is a key topic for the analysis of the dynamic mechanical behaviour of polymers. In vehicle dynamics, the knowledge of the viscoelasticity of tread compounds is fundamental for tire-road contact mechanics modelling and for friction coefficient prediction aimed to the improvement of vehicle performance and safety. The availability of such information would define new scenarios in vehicle dynamics field, as the chance to provide physical inputs to grip models or the study of the suspension setup able to make tires work inside their optimal thermal working range.

Particularly, motorsport racing teams use to face with the restrictions linked to the employment of confidential tires, provided by tiremakers and not available to invasive testing. The development of procedures for the acquisition of data concerning the tire thermal working conditions represents an innovation able to make the difference in the evaluation of the optimal vehicle setup and the development of strategic vehicle simulation tools, getting the quantitative differences among the various available tread specs.

A viscoelastic material, such as the tread compound, behaves between a purely elastic (Hookean Solid) and a purely viscous one (Newtonian Liquid) exhibiting mechanical properties depending on frequency and temperature. Thus, the σ-ε relationship is defined by a complex dynamic modulus as the amount of the overall resistance to deformation of the compound:

$$\frac{\sigma}{\varepsilon} = E^* = E' + iE''$$

where the real part is defined *Storage Modulus* as a measure of the elasticity of material, linked to the ability to store energy during the solicitation, whereas the imaginary part is called *Loss Modulus* linked to the aptitude of the compound to dissipate energy as heat. The ratio of these magnitudes is defined *Loss Factor* and its knowledge is fundamental for vehicle dynamics applications, as well as grip or tread wear prediction (for further details some references are suggested at the end of the page).

These viscoelastic properties are usually determined by the Dynamic Mechanical Analysis (D.M.A.), a technique requiring expensive rheometers with different geometries testing compound samples of specific dimensions. Through this procedure, the viscoelastic master curves as function of temperature or frequency can be determined (Fig. 1). Unfortunately, the standard D.M.A. cannot be employed for the analysis on tires that cannot be destroyed, or, obviously, on tires equipped on running vehicles, due to the need to cut the tread and test the compound sample.

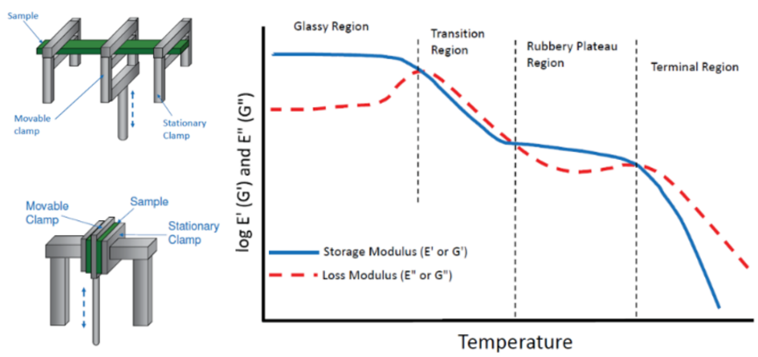

Fig. 1 D.M.A. master curves

In this scenario, the non-destructive procedures are an advantageous solution for the analysis of the tread viscoelasticity, without affecting the tire integrity, allowing a great number of tests in the shortest possible time. The Vehicle Dynamics Research Group of the Department of Industrial Engineering of the University of Naples Federico II, powered by its spin-off company MegaRide, has designed and developed an innovative and portable device, defined as *Viscoelasticity Evaluation System Evolved* (VESevo, as the ancient name of the iconic Vesuvius volcano, located in Naples), which allows users to characterize the tire tread viscoelasticity and its variations due to cooling or heating, due to wear phenomena, aging or different compounding, depending on vehicle applications. Thus, engineers, especially Motorsport ones, are capable to get useful information about their tires, improving the reliability of the data processed by their physical models, and consequently the vehicle performances.

In its first release, the device VESevo has been designed with a sort of gun-shape handle (Fig. 2). Thus, the ergonomics of the instrument allows a high number of tests with a satisfying repeatability. The inner structure of the device is characterised by a steel rod with a semi-spherical indenter. This rod is free to bounce on the surface of the compound of interest sliding inside a suitable guide so that the damping phenomenon during the rod motion inside the case can be neglected. A spring is arranged in the system in order to guarantee a minimum preload. The motion of the rod always starts from the same initial position thanks to an innovative system based on a proper leverages layout: a mechanical hold/release system is capable of "grabbing" the upper plate of the rod and lifting it up to the maximum ascent point. The described system and device are object of an international patent, held by the Vehicle Dynamics research group of the University of Naples Federico II. To acquire properly the displacement signal, an optical sensor has been chosen for its compact dimensions and very high frequency response (necessary for the physical application of the WLF law in the data processing algorithms). The temperature of the compound during a single test can be acquired together with the displacement data. Therefore, a compact IR pyrometer has been chosen and set up in the suitable sensor housing in order to analyse the signals at different viscoelastic behaviour.

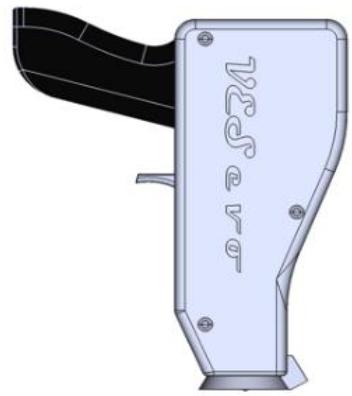

Fig. 2 Vesevo Design

A self-made customized software for raw data acquisition has been developed in LabVIEW environment to find out any acquisition anomalies and check the reliability of each "micro-hammering" test. During the test session, the tread surface is progressively cooled and heated by the user, by means of thermal devices. During the temperature evolution, each test consists of three consecutives acquisitions at the same temperature, stored in order to have a suitable amount of data for statistical processing.

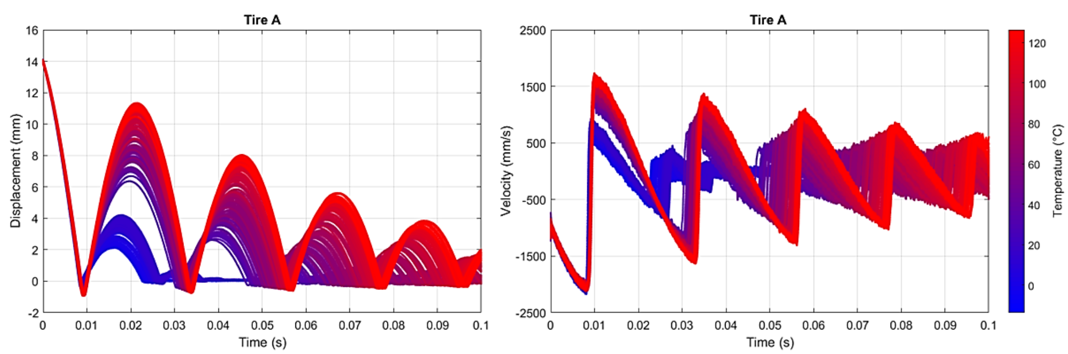

Fig. 3 VESevo output signals

In Fig.3, the data acquired by the VESevo on a high-performance tire at different temperatures are shown. Increasing the temperature, the motion of the rod changes due to different compound responses. The signal is characterised by small amplitudes and reduced number of bounces within a low temperature range; whereas, more bounces with substantial amplitudes values occur at high temperatures. This phenomenon is crearly depending on the viscoelasticity changes due to temperature effect. A further analysis on the viscoelastic behaviour of the tested tire compound can be carried out considering the velocity signals of the rod motion (right figure): the slope of the displacement curve before and after the maximum indentation depth changes due to the rebound on a viscoelastic surface.

Thus, a preliminary index of viscoelastic behaviour can be defined as the variation of kinetic energy of the rod pre- and post-the first indentation, within the temperature range for each tested tire. Such index has been chosen for this preliminary analysis because of its physical coherence with the intrinsic concept of dissipation due to viscoelasticity and for the good fitting with the available loss factor master curves.

The viscoelastic index of three reference tire compounds (A, B and C) as function of the temperature together their fit curves are plotted (Fig. 4). The trends show good correlation to loss factor ones, which are normalised due to industrial confidentiality, exhibiting a peak matching with the glassy transition temperature at which occurs the maximum energy loss: on one hand, the tire C seems to be characterised by a higher loss factor peak rather than the others; on the other hand, the tire B seems to exhibit the lowest glassy transition temperature.

Of course, this represents just an example analysis considering a simple physical-based viscoelastic index, resulted able to provide suitable information concerning the viscoelastic behaviour among the tested tread compounds. The effective viscoelastic properties can be determined starting from the results shown, and specific modelling and data processing activities are currently under development in the R&D group.

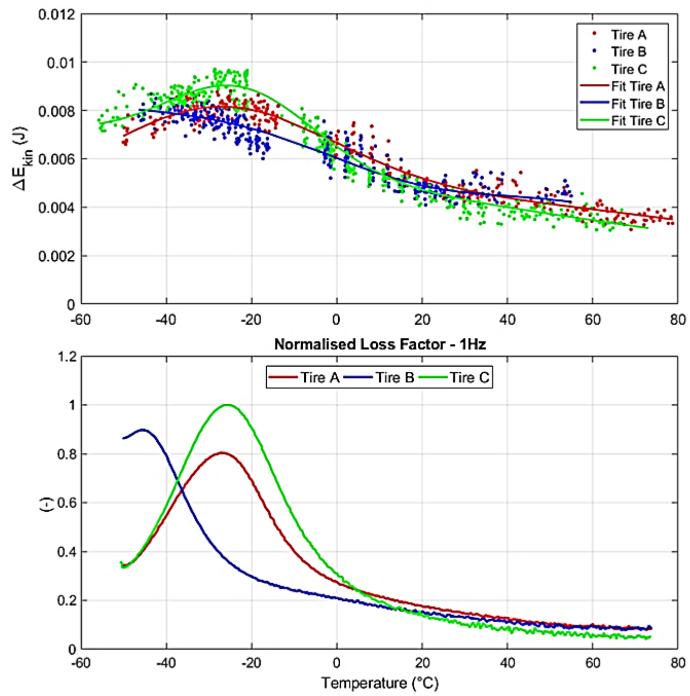

Fig. 4 VESevo viscoelastic index trend

To sum up, the recently developed VESevo shows an interesting potential in polymers characterizations, both in “online” tire production quality process monitoring and in Vehicle Dynamics field, where the knowledge of viscoelastic properties of the tire tread compounds could provide essential information concerning their applications in motorsport, truck or passenger vehicles (monitoring the tread status in running vehicles, analysis in multi-spec motorsport categories, post-vulcanization and post-manufacturing tread quality assessment).

For further info, feel free to contact me and the whole UniNa Vehicle Dynamics Research Group or MegaRide team, and to refer to the following bibliography:

1. Farroni F., Russo M., Russo R., Timpone F. - A physical analytical model for local grip estimation of tyre rubber in sliding contact with road asperities - “Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering" - Vol. 228, n. 8, pp. 958 - 972, 2014
2. F. Farroni, R. Russo, and F. Timpone, “Experimental Investigations on Rubber Friction Coefficient Dependence on Visco-Elastic Characteristics, Track Roughness, Contact Force, and Slide Velocity,” Tire Sci. Technol., vol. 45, no. 1, pp. 3–24, Jan. 2017.
3. F. Farroni, M. Russo, A. Sakhnevych, and F. Timpone, “TRT EVO: Advances in real-time thermodynamic tire modeling for vehicle dynamics simulations,” Proc. Inst. Mech. Eng. Part D J. Automob. Eng., vol. 233, no. 1, pp. 121–135, 2019.
4. F. Farroni, A. Sakhnevych, and F. Timpone, “Physical modelling of tire wear for the analysis of the influence of thermal and frictional effects on vehicle performance,” in Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 2017.
5. A. Genovese, F. Farroni, A. Papangelo, and M. Ciavarella, “A Discussion on Present Theories of Rubber Friction, with Particular Reference to Different Possible Choices of Arbitrary Roughness Cutoff Parameters,” Lubricants, vol. 7, no. 10, p. 85, Sep. 2019.
6. K. P. Menard and N. Menard, “Dynamic Mechanical Analysis,” in Encyclopedia of Analytical Chemistry, Chichester, UK: John Wiley & Sons, Ltd, 2017, pp. 1–25.