Characterization of the Viscoelastic Properties of Tires Through Non- Destructive Tests

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Abstract. The design of a vehicle, whatever it is, is strongly influenced by the characteristics of the tire: it is important to understand how this determines the driveability, safety, performance, efficiency and comfort of the vehicle. The tire supports the weight of the vehicle and allows the forces of interaction with the road to be exchanged. It is one of the main examples of viscoelastic material for which the evaluation of the viscoelasticity of tires is a fundamental issue that aims at the development of polymers for innovative compounds, for the optimization of vehicle performance and road safety. The viscoelastic properties of tires are commonly determined by destructive methods among which dynamic mechanical analysis (DMA) is the most widespread. However, this method has several disadvantages, including the need to produce samples to be tested in the laboratory. In the automotive sector, on the other hand, the need to safeguard the entire structure is often dictated by regulations: it is therefore important to study alternative methods of analysis. In this work, a specific innovative and non-destructive device is presented to determine the dynamic characteristics of the compound of a tire. Specifically, the activity is aimed at developing experimental tests, carried out with the device, on different tire compounds to determine their viscoelasticity. The need to develop prototypes, which allow non-destructive analysis of the material, thus benefiting the analysis of a tire from a temporal point of view and from an economic point of view, is spreading in the world panorama of the development of racing and road tires.

Keywords: tire · viscoelasticity · dynamic load · non-destructive analysis

1 Introduction

In the nineteenth century, the physicists James Clerk Maxwell, Ludwig Boltzmann, Woldemar Voigt worked on models of viscoelasticity by studying the phenomena of creep (also called "creep") and recovery of various materials, including: glass, metals and rubber [1]. The phenomenon of viscoelasticity was further elaborated at the end of the twentieth century on the synthesis of the first synthetic polymers, which show viscoelastic behavior. Viscoelasticity is a phenomenon expressed through mathematical models, which describes a material that behaves in an intermediate way between an elastic solid and a fluid [2]. Although some materials follow Newton's law or Hooke's law quite well, all materials show a marked deviation from elastic behavior and purely

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viscous behavior, so from a practical point of view all materials are viscoelastic [1]. Some striking examples of viscoelastic materials include: amorphous polymers, semi-crystalline polymers, biopolymers, high temperature metals, and bituminous materials.

The tire of a vehicle is the contact element between the vehicle and the road and is the most important component in vehicle dynamic. The performance of the vehicle is strongly influenced by the characteristics of the tire: it effects handling and comfort, it supports the weight of the vehicle and, in particular, it allows the forces of interaction with the road to be exchanged [4].

The tire is one of the main examples of viscoelastic material so the evaluation of the viscoelasticity is a fundamental issue for the optimization of vehicle performance and road safety. The viscoelastic properties of tires are commonly determined by destructive methods among which dynamic mechanical analysis (DMA) is the most widespread [3, 5, 6]. However, this method has several disadvantages [3]. In this work, a specific innovative and non-destructive device is presented to determine the dynamic characteristics of the compound of a tire. Specifically, the activity is aimed at developing experimental tests, carried out with the device, on the tire to determine their viscoelasticity. The need to develop prototypes, which allow non-destructive analysis of the material, thus benefiting the analysis of a tire from a temporal point of view and from an economic point of view, is spreading in the world panorama of the development of racing and road tires [7].

2 Methods, Materials and Equipment

In the automotive sector, the need to characterize the tire compound thanks to non-destructive tests, to safeguard the entire structure, means that these tests are progressively developing and spreading. From 2021, among the non-destructive methods of tire compound characterization, the automotive world can also count on VESevo: "Viscoelasticity Evaluation System Evo": a specific innovative and non-destructive device for determining the dynamic characteristics of a tire compound [8–10]. The tests were carried out directly on the tires. The tire used for the experimental tests is a traditional passenger tire compound [3] that represents the contact element between the vehicle and the road and it is the most important component in vehicle dynamic. The performance of the vehicle is strongly influenced by the characteristics of the tire: it effects handling and comfort, it supports the weight of the vehicle and, in particular, it allows the forces of interaction with the road to be exchanged [4].

The activity is aimed at the development of experimental tests, carried out with this device to determine their viscoelasticity.

2.1 Device

The VESevo device was designed [3] taking into consideration a gun-shaped handle; therefore, the ergonomics of the instrument, practical and functional, allows a high number of tests with satisfactory repeatability (Fig. 1).

Fig. 1. VESEVO device [3]

The device is internally characterized by a steel rod with a hemispherical indenter. The rod is free to bounce on the surface of the tire by sliding inside a special guide, thus neglecting the phenomenon of damping during the movement of the rod. The system features a spring to ensure minimum preload and a magnet that ensures that the movement of the rod always starts from the same starting position: this magnet is mounted on a special cursor and can hold the upper plate of the rod. During each test it is necessary to analyze the displacement of the rod starting from the initial position with respect to the surface of the compound. A displacement sensor with a high response frequency is used to acquire the displacement signal. Since the temperature is a parameter that influences the behavior of a material, the temperature of the compound must also be acquired together with the displacement data during a single test. Therefore, an IR pyrometer was chosen and positioned at the end of the device to analyze the signals corresponding to the different viscoelastic behaviors of the sample of interest in the different test conditions [3].

2.2 Test

Pressing the “trigger” positioned on the handle activates the test allowing the indenter, present at the end of the steel rod, to impact the surface of the tire. In a single acquisition that takes place thanks to a National Instruments data logger and a software created in the Lab-View environment, the rebound of the rod has three different phases that are essential for the evaluation of the indices related to the viscoelastic behavior. The first is characterized by the impact of the sensorized rod on the surface of the tire; this first phase coincides with the minimum point of the curve acquired and reported in Fig. 2. During the second phase, the rod bounces up to the maximum point of the curve due to its interaction with the outer rubber layer of the tire; in particular, after the first one, different rebounds could occur depending on the surface temperature and the starting position. The last phase is characterized by a displacement value of the rod corresponding to the damping of the bar at the end of the reciprocal dynamic action.

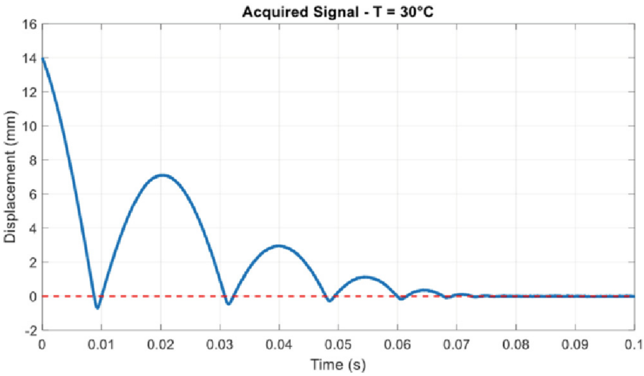

Fig. 2. Signal acquired at 30° [3]

2.2.1 Temperature

During a test session the tread surface is cooled and heated without degrading the material until its temperature stabilizes: the temperature plays a fundamental role in the study of tires. For the complete characterization of a tire it is necessary to study it in a range of temperatures according to the needs suitable for the use. Special devices such as heat guns or coolant sprays are used which modify the thermal conditions of the tire. Considering the typical shape of the signals provided by the VESevo, it is possible to estimate a set of indicators of the viscoelastic behavior of the material for the time-temperature characterization [3].

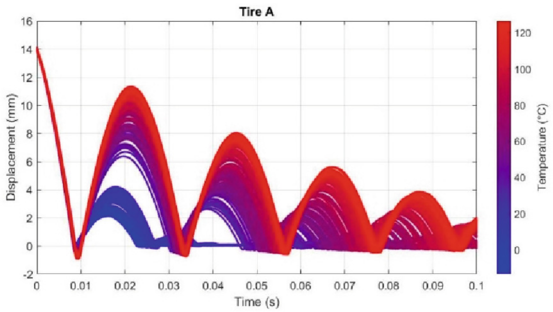

Fig. 3. Time-temperature characterization [3]

It can be seen in Fig. 3, which shows the data acquired on a tire compound, how these data vary as the temperature varies. As the temperature increases, the movement of the rod changes due to the different responses of the material. The signal is characterized by small amplitudes and a reduced number of bounces at low temperatures; on the contrary, at high temperatures there are more rebounds with higher amplitude values. This phenomenon is strictly dependent on the variations in viscoelasticity because of temperature: at lower temperatures, the strain energy loss peak decreases and the bar cannot reach its maximum amplitude during return phase, vice versa at higher temperatures.

3 Comparison and Validation

Beyond the reasons presented at the beginning on the practical aspects of the described non-destructive methods compared to the destructive ones, it is possible to conclude that the results are completely in agreement: the glass transition temperature values, estimated through VESevo acquisitions, are compared with those obtained through D.M.A. shown in the Table. As clear, the results are very similar to demonstrating the goodness of the non-destructive method [4].

Tested Tire	Tg (D.M.A.)	Tg (VESevo)
Tire A	-26.8°C	-27.02°C
Tire B	-45.2°C	-46.42°C
Tire C	-25.5°C	-26.01°C

4 Conclusions

In this paper, the importance of non-destructive tests for determining the dynamic characteristics of a tire compound was highlighted and an interesting device, VESevo, that allows to carry out numerous experimental tests directly on the entire tire in a practical, simple and fast way to determine its viscoelasticity under varying conditions such as temperature, loading speed and composition of the compound, was presented. Given the importance of tires for the safety and efficiency of a vehicle and the need, sometimes dictated by regulations, not to destroy the structure, the prototypes that allow non-destructive analysis of the material, with consequent advantages both from a point of both temporal and economic, are the basis of research in recent years and will be the subject of future ones.

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