








# Tire Viscoelasticity Characterization for Adhesion Phenomena Analysis by Using the VESevo Innovative Technology

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**Abstract.** In vehicle dynamics, the study of the viscoelastic characterization of tires is crucial for a better understanding of the adhesion phenomenon during tire-road interaction, with the ultimate goal of enhancing vehicle performance and safety. The viscoelastic characterization of polymeric specimens traditionally involves costly and destructive practices. However, the development of the VESevo device has allowed to overcome these limitations for tire viscoelasticity characterization. This paper presents an analysis on tire adhesion by considering three different compounds tested with the VESevo device, to compare the acquired curves with and without the use of talc on the compound. Additionally, since the adhesion phenomenon is dependent on temperature, the various specimens were heated to explore the thermal effect. The paper investigates the adhesion variances among soft, medium, and hard compounds under changing temperature and compound conditions, commencing with rebound curve comparisons with and without talc.

**Keywords:** Tire Adhesion · Viscoelasticity · Rebound Curves · VESevo Device

## 1 Introduction

In the world of vehicle dynamics, identifying and maximizing the tires performance is a crucial topic as there are several factors that affect it, starting from tire thermodynamic [1–3] and the phenomena involved in tire road interaction [4–6], to the various quantities related to the vehicle itself whose estimation can be made by developing reliable models [7–9].

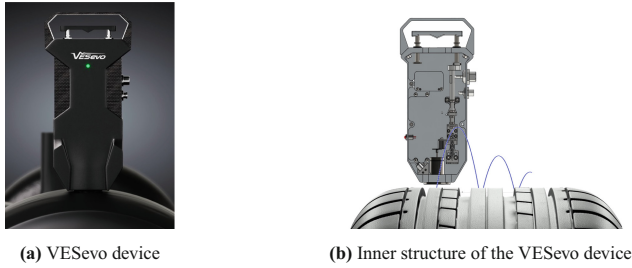
In addition, the characterization of tire tread viscoelasticity is a fundamental topic in the optimization of vehicle performance [10–12]. A viscoelastic material is a deformable material with a behavior that lies between a viscous liquid and an elastic solid [13]. This kind of solid does not show a linear relationship

between stress and applied strain and the typical response of viscoelastic materials is characterized by a strong dependence on the rate of straining: the faster the stretching, the larger the stress required [14, 15]. The viscoelastic properties of the tire are influenced by two main parameters: the frequency of the applied force and the temperature, which produce opposite effects on the rubber [16, 17]. Specifically, when the stress frequency increases at a fixed temperature, the polymer transitions into a glassy state. Conversely, when the material is heated at a given stress frequency, it becomes softer, exhibiting rubbery behavior [18, 19]. The viscoelastic characterization of polymeric specimens traditionally involves costly and destructive practices such as the Dynamic Mechanical Analysis (DMA), which is a widely employed destructive test used to define the hysteretic behavior of compounds following the Time-Temperature Superposition Principle [20]. In this work three different compounds (a hard, a medium and a soft one) were tested with an innovative device named Vesevo (Viscoelasticity Evaluation System Evolved), developed by the Vehicle Dynamics research group of the University of Naples Federico II, useful for the characterization of tire viscoelastic properties in a non destructive way, starting from the rebound curves of a rod which interact with the tire specimens [21].

In particular, this paper presents an innovative approach to better understand the adhesion phenomenon since the various compounds were tested with and without the use of talc on the tested area. In this way, it was possible to compare the different rebound curves acquired with and without the use of talc, which has a damper effect during the indentation. Moreover, since the dependence of the adhesion phenomenon to the temperature, the tests were performed in a wide temperature range and nine thermal windows have been chosen to carry out the various analysis in order to analyze the temperature effect too. In this way, it was possible to observe the compound effect and the temperature one too, by analyzing not only the differences as the compound vary but also the ones related to the temperature variation.

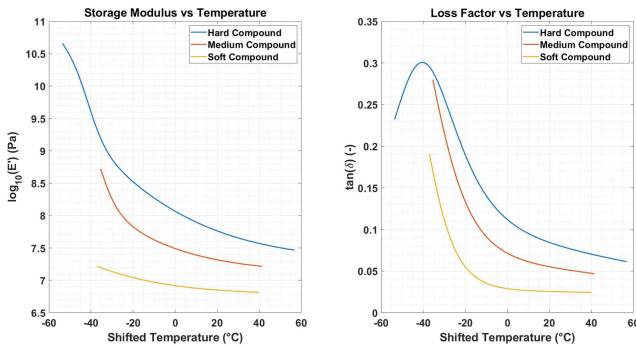
## 2 VESevo Device and Testing Campaign

The VESevo is an innovative and portable device (Fig. 1a) developed by the Vehicle Dynamics research group of the University of Naples Federico II which allows users to characterize the tire tread viscoelastic properties in a non destructive way [22, 23]. The inner structure of the device consist of a steel rod with a semi-spherical indenter which is free to bounce on the surface of the tire tread sliding inside a suitable guide (Fig. 1b). The rod starting position is always the same for each testing condition and its displacement signal is acquired through a compact optical sensor with very high frequency response. The design of the device allows a high number of tests with an optimal repeatability.



**Fig. 1.** Viscoelasticity evaluation system evolved

The aim of the tests performed for this research activity was to acquire the rebound curves of the VESevo rod on the rubber specimen while varying the testing conditions in terms of temperature and compound. In addition, the tests were performed with and without the use of talc on the rubber specimen, that is obtained by sprinkling a thin layer of talc on the tested area. In particular, three different compounds were tested at different thermal conditions, starting from ambient temperature ( $\approx 20^\circ\text{C}$ ) to  $100^\circ\text{C}$ . The viscoelastic properties characterizing the different compounds were evaluated through the VESevo device itself. The analysis were performed on three different compounds: a hard, a medium and a soft one, whose viscoelastic master curves are depicted in Fig. 2 versus the temperature shifted at 1 Hz frequency.



**Fig. 2.** Viscoelastic properties acquired from VESevo device

### 3 Data Processing and Analysis Procedure

The adhesion component of friction influences the rebound curves acquired through the VESevo device, hence an analysis has been performed on those to understand the effect by comparing results with and without the presence of talc. VESevo tests were performed in the [ $\approx 20^\circ\text{C}$ ,  $100^\circ\text{C}$ ] temperature range

and the different response for each compound with and without talc can be depicted in Fig. 3a. It is observable that the temperature has a high influence on such curves, hence nine thermal windows have been properly chosen to carry out the analysis and they are reported in Fig. 3b, on one compound as example to present the approach. In this figure, the differences among the curves obtained with and without the use of talc on the tested area are also observable.

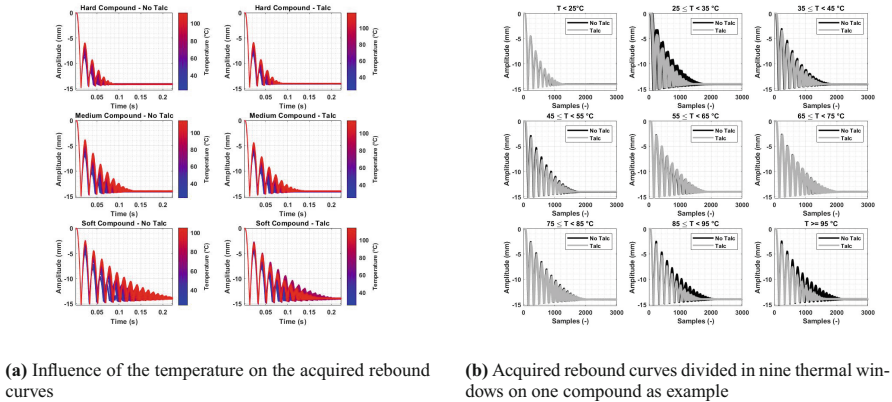
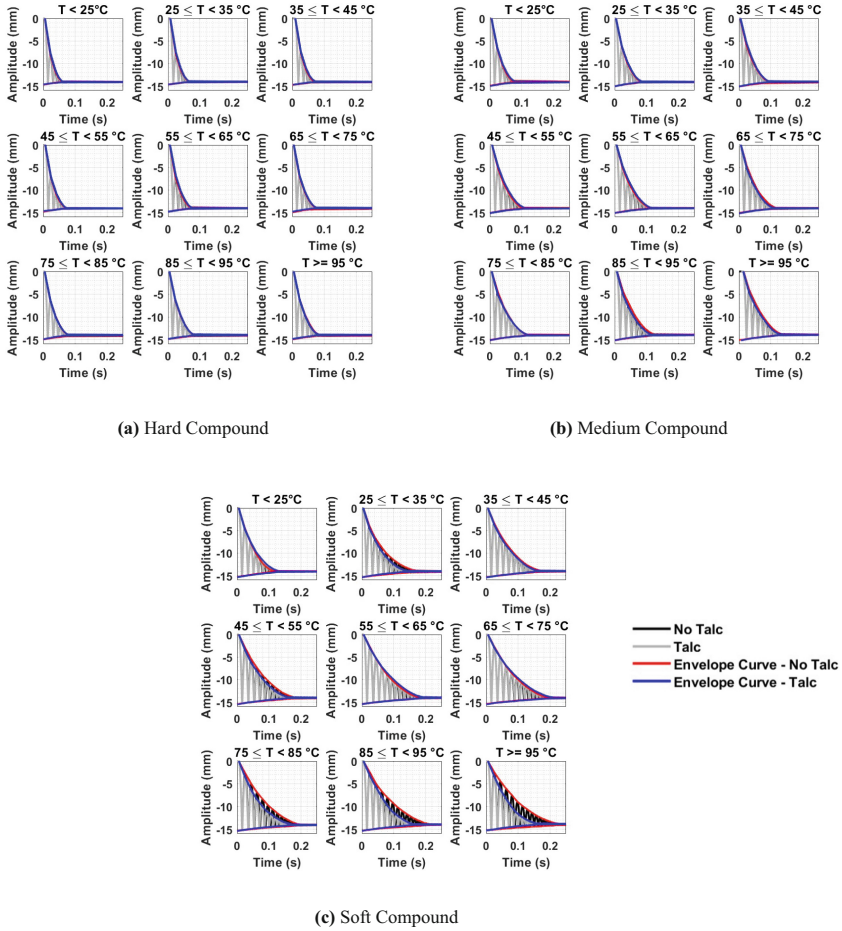


Fig. 3. Acquired rebound curves

## 4 Results and Discussion

For each thermal window, the peaks and the valleys of the acquired curves with and without talc were detected. In each testing condition and for all the compounds and thermal windows, an average rebound curve was identified. On that average curve, the envelope curves, i.e. a spline interpolating its peaks and valley, were recognized and are shown in Fig. 4 for each compound tested with and without the talc in every thermal window. By performing the presented approach, it was possible to observe the differences among the curves with and without talc to analyze the adhesion phenomenon. It can be stated that for lower temperatures, the difference between the curves in the talc and no talc conditions is small, while it increases at higher temperatures, and the average curve in the no talc condition presents higher values than the other one. This points to the fact that the talc has a damping effect on the rebounds of the rod within the VESevo device and this is connected with the variation of the adhesive behavior passing from the no talc testing condition to the talc one. Similar considerations can be performed for the medium and hard compound as well, but with lower intensity. Indeed, for all the three compounds a trend appears: the curves obtained from the no talc testing condition are above the other ones until a specific thermal range depending on the compound is reached, in which there is an inversion in terms of behavior. In particular this inversion

appears at very high thermal range for the hard compound, at a medium one for the medium compound and at low range for the soft one.



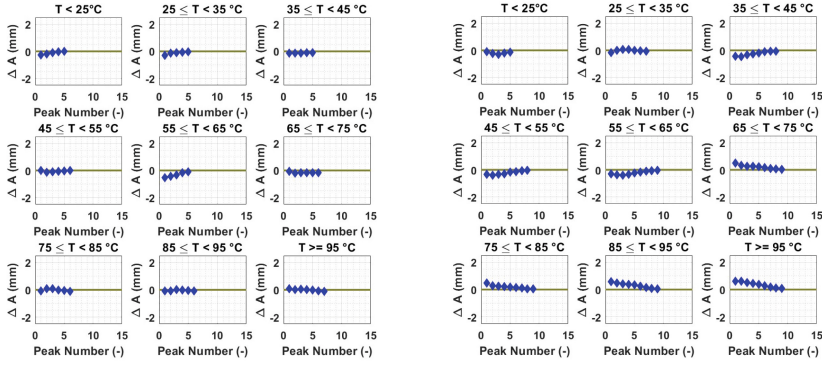
**Fig. 4.** Envelope curves for each thermal window

Another analysis performed to better understand the differences was based on the evaluation of the vertical distance between the no talc and talc peaks for each compound and in each thermal window. Such distance is indicated with  $\Delta A$  and is computed as

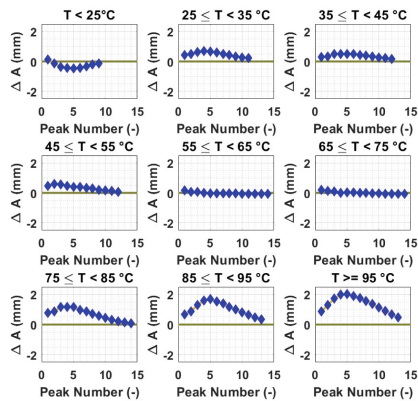
$$\Delta A = A_{NT} - A_T \tag{1}$$

where  $A_T$  and  $A_{NT}$  correspond to the value of each peak related to the average rebound curves with and without the talc respectively. Hence, a positive  $\Delta A$  points to the fact that the no talc curve is above the talc curve and vice versa.

The mentioned quantity is depicted in Fig. 5 for all the compounds and thermal windows, from which the mentioned difference among the rebound curves appears clearly.



(a) Hard Compound (b) Medium Compound



(c) Soft Compound

Fig. 5. Vertical distance among the peaks for each thermal window

## 5 Conclusions

A novel approach to understanding the adhesion phenomenon has been introduced, starting from a non-destructive testing campaign. The outcomes of this research involve comprehending the adhesive behavior by analyzing the rebound curves obtained from the VESevo device. The tests were conducted at various temperatures using different compounds, with and without talc on the tested

area, to highlight the adhesive behavior of the rubber specimens. This approach not only allowed for understanding the thermal effects by comparing results at different temperature ranges but also revealed the compound effect, passing from hard to medium, and finally to soft compounds.

Starting from the results obtained and reported here, further developments are related with the investigation on various key performance indicators correlated with the material's viscoelastic properties while considering the adhesion effect. Furthermore, analyzing the damping effect related to talc for different compounds and temperatures could provide valuable insights. Finally, extending the procedure to other compounds would enhance the statistical significance of the global database.

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