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Review

State of the art of tribological tests for bituminous binders

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HIGHLIGHTS

- Some WMA additives are supposed to improve the lubricating properties of bitumen.
- An overview on tribology and tribological tests is presented.
- Current tests adopted for bitumen and the main outcomes in literature are discussed.
- Suggestions for further development of tribological tests on bitumen are proposed.

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ABSTRACT

Kinetic friction is a physical phenomenon which originates when two or more bodies are in contact and in relative motion, and causes energy consumption and wear. Lubricants are widely used in many fields to reduce kinetic friction and their behaviour is usually characterized through appropriate tribological tests. In fact, the science of tribology (from the Greek word "tribo" that means to rub and the Latin word "logia" that means study) investigates interactions between surfaces in relative motion. In the field of road materials, during asphalt mixing and compaction, bitumen acts similarly to lubricants, reducing friction between aggregates, and its lubricating properties significantly affect the energy required. According to recent studies, some Warm Mix Asphalt additives are able to reduce production and compaction temperatures (and therefore energy consumption) of asphalt mixtures by potentially improving the lubricating behaviour of the binder. Thus, tribological tests have recently been introduced in the investigation of bituminous binders to characterize their lubricating properties. This paper aims at providing the state of the art of tribological tests currently employed for the study of bituminous binders, as well as useful suggestions for improving these procedures. Since the introduction of such tests in the field of road materials is quite recent, an overview on tribology and tribological tests on common lubricants is presented, with the aim to highlight the main aspects to take into account when applying the tribological characterization of bituminous binders.

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1. Introduction

Tribology is the science that studies friction, lubrication and wear of surfaces in contact and in relative motion. Because of the kinematic nature of machines [1], tribology has many applications in mechanical engineering. Indeed tribological characterization is always the basis for the selection of materials [2–4] and coatings [5,6] to be used in machining processes in which friction causes significant energy consumption.

Another widespread application concerns the field of lubricants, as the main task of these materials is to reduce friction and wear of mechanical parts in relative motion. Recently, given the increasing importance of environmental issues, together with traditional lubricant materials, interest has focused on biodegradable greases [7] and on biofuels, such as vegetable oils [8–18], biodiesels [19,20] and biomass fuels [21]. Moreover, tribological tests are often employed for studying the effects of nanoparticles as lubrication improvers [22–24].

More recent fields of application are food industry [25–27], biomedical engineering [28] and cosmetics industry [29,30], areas in which the study of friction plays an increasingly important role.

For bituminous materials, tribological tests are rather recent and aimed mainly at understanding the benefits provided by Warm Mix Asphalt (WMA) additives. WMA technology refers to asphalt mixtures that are produced and placed at temperatures 20–55 °C lower than typical hot mix asphalt (HMA) [31], leading to several environmental and technical benefits [31–34]. Although WMA technologies work effectively in the field [35,36], the mechanisms that allow this temperature reduction are not completely understood yet. Recent researches [37–45] have demonstrated that viscosity reduction is not the only mechanism responsible for reduced production and compaction temperature; the reduction of the internal friction (which means improvement of lubricating properties) in the bituminous binder has been proposed as a possible further mechanism involved. The latter idea has prompted research on tribological characterization of bituminous binders, even if it is still doubtful whether tribological tests can really detect the effect of WMA additives. Moreover, the most appropriate test geometry, test conditions and test procedures for bituminous binders should be optimized.

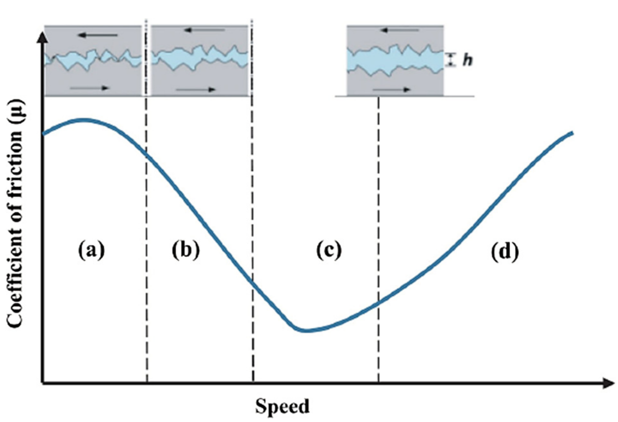

Fig. 1. Stribeck curve: coefficient of friction as a function of speed [46].

This paper provides the main fundamental concepts of tribology, highlights the most important aspects to take into account when performing tribological tests, presents the most common test geometries and analyzes in detail the current tribological tests proposed for bituminous binders. Future developments in the field of tribological characterization of bituminous binders are also suggested.

2. Fundamentals of tribology

2.1. General aspects

Friction originates from the contact between two solids and it is defined as "static" when neither of the two bodies is moving and "kinetic" (or "dynamic" or "sliding") when the objects are moving relative to each other.

The friction force F_F can be expressed by the following equation:

$$F_F = \mu \cdot F_N \tag{1}$$

where μ is the coefficient of friction and F_N is the "normal" reaction between the objects that are involved. The coefficient of friction is a property of the system, which means that it depends on the material of the bodies in contact. Its value is usually between zero and one, but can be greater than one. A value equal to zero means that there is no friction at all between the objects, but this is only theoretically possible, as all objects in the real world display some friction when they touch each other. A value equal to one means that the friction force is identical to the normal force. A coefficient of friction greater than one means that the friction force is higher than the normal force.

The friction behaviour between two solids in relative motion and separated by a lubricating film is usually studied through the Stribeck curve which describes the evolution of the coefficient of friction (linked with the changes in the lubricating film) as a function of the sliding speed. A typical Stribeck curve is shown in Fig. 1 [46] and can be divided into four lubrication behaviour regions [37,38,46,47]:

- in the boundary regime (a), at low sliding speeds, the friction mainly originates from the interaction of the asperities of the two surfaces.
- in the mixed regime (b), with increasing speed, the lubricant starts to build up a hydrodynamic pressure that reduces the direct contact between the two surfaces, reducing also friction.
- in the elasto-hydrodynamic regime (c), the minimum friction is reached when the surfaces do not touch anymore.
- in the hydrodynamic regime (d), at high sliding speed, friction mainly depends on the viscous drag of the lubricant. Specifically, as the internal friction of the lubricant increases, the friction of the entire system increases again.

However, when the Stribeck curve is considered in the speed domain (as shown in Fig. 1), changing the dynamic viscosity of the material or the normal contact load, the value of the coefficient of friction changes and the lubricating regime may also change. This does not allow a unique frictional behaviour to be defined.

In order to overcome this drawback, when the behaviour of Newtonian lubricants is studied, a more complete representation