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Evaluation of graphene grease compound as lubricant for spline couplings

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ABSTRACT

Improving machine efficiency and reliability is an endless challenge that is even more important considering environmental issues related to fuel consumption and the related emissions. One way to reduce machine losses is to reduce components friction. In this paper, the effect graphene added to standard grease to create a high performance lubricant has been investigated. Experimental tests have been performed on a mechanical component (a spline coupling) commonly used in many industrial applications. In particular, the friction force has been measured lubricating the parts with different compositions of grease-graphene compounds. Tests have been performed by means of a dedicated test rig. Results show that graphene added to grease reduces the coefficient of friction.

1. Introduction

Graphene attracted much interest in a wide field of applications because of its exceptional mechanical, electric and thermal properties. Discovered in 2004 by Geim and Novoselov [1], graphene is an allotropic form of carbon, comprising a monoatomic layer of carbon atoms arranged in a two dimensional plane according to a honeycomb pattern, in which the distance between the carbon atoms equals to 0.142 nm [2]. The outstanding characteristics of graphene make it suitable for various technical applications, like high frequency electronics, solar cells, sensors, and flexible composite materials [3–5].

Moreover, the unusual properties of graphene make it an attractive material for tribological applications. Studies on both nanoscale and microscale demonstrated that applying graphene as lubricant, either solid or lubricant additive, allows to reduce considerably friction of steel, and then to drop wear by 3–4 orders of magnitude [6]. The early studies on graphene as solid lubricant were performed by Filleter et al. [7], they demonstrated that a reduction of the thickness of the most common solid lubricant graphite to few layers allow a reduction of the friction coefficient.

In the other hand, few researches on graphene like lubricant additive have been made. Huang et al. [8] conducted an investigation on tribological properties of graphite as lubricant additive proving that the development of a physical deposition film of graphite on the rubbing surface allows the reduction of friction and wear. In 2011, Lin et al. studied the effectiveness of modified graphene platelets (MGP) like a lubricant oil additive [9]. In particular, their results show that the MGP improves the oil performances reducing wear resistance adding only 0.075 wt% of MGP. Senatore et al. [10] investigated the reduction of friction and wear obtained using mineral oils formulated with graphene oxide (GO) nanosheets; the development of a protective deposited films permits to avoid the direct contact between the rubbing surfaces determining an important reduction of coefficient of friction (between 16% and 20%). In 2015 Dou et al. [11] investigated the use of crumpled graphene balls as a high-performance additive in polyalphaolefin base oil. Also in this case the addiction of graphene results in superior friction and wear performance; the tribological properties of crumpled graphene balls are consistently good at different concentrations thanks to its aggregation-resistant property, in contrast to other carbon additives such as graphite, reduced graphene oxide and carbon black.

Fan et al. [12] and Bahaa et al. [13] investigated the effect of multilayer graphene nanosheets used as additive into respectively bentone grease and calcium grease, finding a reduction of the friction coefficient due to the additive.

Wei et al. [14] exploited the excellent thermal properties of graphene and evaluated the effect of graphene nanoplatelets on heat transfer properties of silicone grease showing that it is possible to enhance the thermal conductivity up to more than 600%.

Zhi-Lin et al. [15] investigated the friction performance by means of a standard friction testing machine of graphene-based semi solid grease obtaining reduction of both friction coefficient and wear of about 50%.

Liu et al. [16], Song et al. [17] and Fan et al. [18] investigated the behavior of graphene oxide as lubricant additive obtaining lubricants with enhanced tribological performance.

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More recently, Fan et al. [19] investigated the tribological properties and the friction mechanism of different solid nanoparticles, including graphene quantum dots finding out that spherical nanoparticles have better tribological performance respect to lamellar ones.

High friction between surfaces in contact causes low efficiency, noisiness, malfunction and low durability, therefore reducing the confident of friction would increase the machine performances and reliability. This issue can be addressed also by enhancing the performance of standard lubricants.

Despite the big potential of graphene in this field, its use as a lubricant or a lubricant additive on macro/mesoscale remains relatively unexplored [20]. In particular, the literature is lacking about specific applications of graphene added lubricants on mechanical systems.

In this paper, a practical application of graphene used as grease additive is presented. In particular, grease added with graphene nanoplatelets has been evaluated as enhanced performance lubricant for spline couplings. Spline couplings are mechanical components used to connect two rotating shafts [21]. The torque is transmitted between the shafts by means of a certain number of engaging teeth. These components are critical especially in certain applications such as in aerospace field [22]. One of the most common failure in spline couplings is due to teeth wear, this phenomenon is due to reciprocating sliding between engaging teeth. One of the main parameters influencing wear damage is the lubrication therefore CoF between matching surfaces [23,24].

As an example, Fig. 1 shows the difference between a spline coupling tested without lubricant (Fig. 1A) and with oil lubrication (Fig. 1B), the two tests were performed with the same working conditions [25]. It is clear how the lubricant can reduce wear damage: in Fig. 1A the teeth result very damaged, on the other hand, in the test with lubricant (Fig. 1B) the wear damage is reduced more than 60% [25].

Considering these data, it is clear that enhancing the performance of lubricants and therefore reducing the CoF would allow a reduction of wear damage.

Another problem of these component is the misalignment loads that overload the transmissions system and in particular the bearings, reducing system efficiency [26,27]. In particular, the friction moment is due to the friction between engaging teeth [28,29], a reduction of the CoF will allow to lower friction moments.

It is clear that the CoF plays a very important role in the reliability and efficiency of spline couplings, and improving the performance of lubricants would be a step on in enhancing the behavior of these components and consequently of the machines where they are mounted.

The aim of this work is to evaluate the coefficient of friction (CoF) in spline couplings lubricated with grease added with graphene. In particular, the effect of different graphene quantities in grease lubricant has been investigated. Tests have been performed by means of a dedicated test rig, which allowed to evaluate the CoF with different working parameters.

2. Experimental set up

Spline couplings transmit torque by means of a certain number of engaging teeth. Referring to a generic spline coupling represented in Fig. 2, given a torque T to be transmitted from the hub to the shaft (or vice-versa) each tooth pair is loaded by a tangential force F_{Ti}. This force is the resultant of the contact pressure [30] and it is applied on the average contact radius r_a, such as:

$$T = \sum_{1}^{N} F_{Ti} \cdot r_a \tag{1}$$

where N is the number of engaging teeth.

Each tangential force may generate a friction force F_{Fi} on tooth surface. This friction force is generated by the coefficient of friction μ as:

$$F_{Fi} = F_{Ti} \cdot \mu \tag{2}$$

The sum of all the friction forces F_{Fi} acting on all the spline coupling teeth gives the total friction force F_F that represents the force needed to move the shaft in axial direction (Fig. 2).

If the F_F is known (by measurements), then it is possible to calculate the coefficient of friction as:

$$F_{Fi} = \sum_{1}^{N} F_{Ti} \cdot \mu \tag{3}$$

2.1. Test bench description

In this work, a dedicated test rig to measure the force F_F has been developed. The test rig, represented in Figs. 3 and 4, is composed of rotating flange, connected to the fixed part of the test rig, where one part of the spline coupling (the hub) is fixed to. The other part of the spline coupling (the shaft) is connected to a skid that can translate in axial direction by means of linear motion guides. The rotating shaft is connected to a bar where weights can be placed, generating the force W in Fig. 3. This force generates the torque T that loads the spline coupling. Varying the weight it is possible to change the load applied on the spline coupling. The test rig is designed to hold a load up to 40 Kg, corresponding to a torque on the spline coupling of 63 Nm.

The skid is connected through a load cell to a screw jack actuated by a gearmotor. The screw jack pulls and pushes the spline coupling shaft respect to the fixed hub and the load cell measures the force needed to perform this operation. This force is the F_F force, knowing its value it is possible to obtain the coefficient of friction from equation (3).

The gearmotor used for the test rig is 24 V DC with 4Nm nominal torque and 40 Nm maximum torque, the nominal speed at the out shaft is 35 rpm.

The load cell used is a Miniature Burster 8435 characterized by a measuring range of 1000 N. Data are acquired by a data acquisition board (NI USB-6210 National Instruments) with a sampling frequency of 50 Hz and collected by a dedicated software developed in LabVIEW environment.

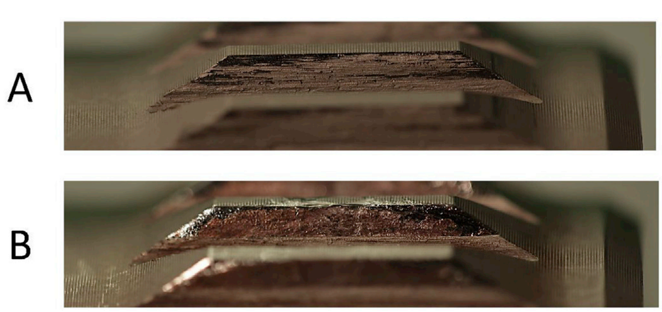

Fig. 1. Spline coupling after wear test with lubricant (A) and without lubricant (B) [25].

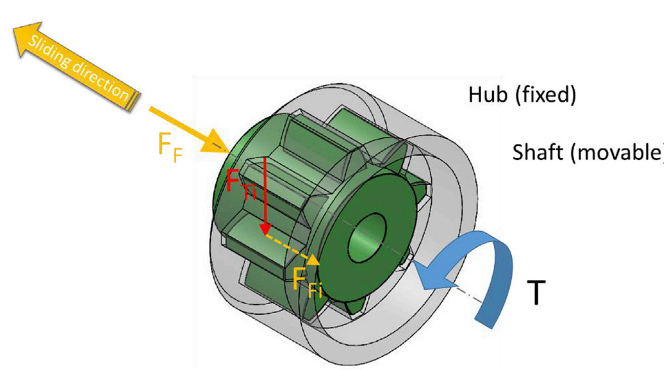

Fig. 2. Spline coupling loading.