



ELSEVIER

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Frictional heating calculation based on tailored experimental measurements



M. Conte*, B. Pinedo, A. Igartua

IK4-Tekniker, Calle Iñaki Goenaga 5, 20600 Eibar, Spain

ARTICLE INFO

Article history:

Received 23 October 2013

Received in revised form

7 January 2014

Accepted 28 January 2014

Available online 11 February 2014

Keywords:

Frictional heating

Sliding wear

Polymers

PTFE

ABSTRACT

New composites and nano-composites polymers are continuously developed satisfying more and more exigent demands in terms of mechanical and tribological properties. Nevertheless a wide working velocity range has been achieved; one of the main bottlenecks of these materials is related to their thermal resistance. Semi-crystalline materials have a wide range of temperature; however, their operative life decreases exponentially with increasing temperature. For several applications, knowing the contact temperature can give a considerable help in choosing the right polymer to be used. An adequate frictional heating calculation based on Block and Jaeger equations is herein proposed matching experimental tests configuration at laboratory scale and theory to overtake restrictive assumptions.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Frictional heating calculation in metal to metal contact has been deeply investigated and accordingly many reviews have shown it is still not well defined and the contact conditions vary in time and location [1,2]. In [3] a comparison of some calculation model was presented showing high disagreement between the results, due to two important concepts: the right way to calculate the contact area and the variation of the materials properties with temperature, both to be included in the equations. In polymer to metal contact, the first assumption does not affect calculations otherwise temperature reached at the asperities contact would overtake the melting point of the materials. Nevertheless the coefficient of friction, which enters calculation to the first power, is still of great importance. In metal to metal contact, flash temperature was estimated determining the phase transformations and microstructural changes in materials and relating them with the temperature needed for these transformations [4,5]. In polymer to metal contact, the authors [6] have used a Differential Scanning Calorimetry (DSC) technique [7–10] to evaluate the effects of fillers on the crystallinity ratio of some PTFE (Polytetrafluoroethylene) composites, and observed relevant structural changes at the polymers contact surfaces. It was also observed in [11] how the crystallinity of transfer film was higher than the bulk material. According to Persson's investigation [12], due to

the strong temperature dependence of viscoelastic properties of rubber-like material, local temperature calculation should be considered in order to explain the frictional behavior of the tribo-pair, so an estimation of flash temperature at the polymer to metal contact surface is herein proposed for a better understanding of the tribochemical and tribophysical phenomena occurring at the contact. Direct experimental measurement of contact temperature is not viable due to different reasons [13,14]. Taking into account the low diffusivity of this kind of materials, a high velocity thermo camera has been seen to be a good but expensive tool [15]. A frictional heating calculation method for polymers based on tailored experimental tests is herein presented. Aim of this work is to propose a reliable and cheap method for estimating at laboratory scale the frictional heating of polymer to metal contact. First of all, the assumptions limiting one of the most suitable methods have been overtaken by means of an opportune experimental configuration. Particular attention has been then given to the variation of the thermal characteristics of the polymer and to the evolution of the friction force.

A first validation of the method is proposed for PTFE material. In particular, it was chosen due to four reasons: 1) because of its high resistance to high temperature with a melting point of about 330 °C; 2) because of its particular case to have two phase transitions in the range 19–31 °C; 3) because the fluorine chains are not cross linked like in the elastomers, so the mechanical work done for overtaking the friction force can be considered quasi-entirely transformed in frictional heating [16]; and 4) to have a correspondence with experimental tests found in the literature [15].

This method can have not only a practical use in the selection of the most appropriate materials for industrial applications like

* Corresponding author.

E-mail addresses: marcello.conte@tekniker.es, conte.marcello@gmail.com (M. Conte).

seals, bearings and slides, but it can also play an important role in choosing the most opportune operative parameters (velocity, break time, maintenance, etc.).

2. Contact temperature calculation method

The temperature at the interface between rubbing bodies is known as “surface conjunction temperature” [17]; the calculation of this temperature is possible by applying the laws of energy conservation and heat transfer. In fact, most of the energy dissipated during the process of friction is converted into heat [17] resulting in local temperature increment called “flash temperature” that could be divided into transient and steady state flash temperature rise. As reported by Bowden and Tabor [18] in dry contacts the transient flash temperature may become larger than the steady state component. The flash temperature calculation method was formulated firstly by Block [19] and then improved by Jaeger [20] and Archard [5]. It provides a set of formulas for various velocity ranges and contact geometries and it is based on the following assumptions: 1) a planar source of heat is considered; 2) a steady state condition is attained; 3) the thermal properties of the bodies do not change with temperature; and 4) the coefficient of friction is known and reaches a steady value.

The following hypotheses are considered for the calculations:

- the heat source considered corresponds to the final contact area and it is friction dependent;
- the component of energy lost in deformation of the bodies can be considered negligible due to the high mobility of the polymeric chains, and an appropriate test configuration (like high velocity reciprocating movement on a short stroke) avoids the calculation of the Peclet number [17];
- the thermal properties of the bodies change with temperature;
- the experimental curve of the coefficient of friction can be used in the calculation, having as result a direct correlation with the work done by the friction force as shown in the following equation:

$$Q(t) = \mu(t)Wv \quad (1)$$

where μ is the coefficient of friction, W is the normal load and v is the sliding velocity. The contact temperature can be then described also as a function of time as follows:

$$T_{f \max}(t) = \frac{2Q(t)}{KA} \sqrt{\frac{2\chi b}{\pi v}} \quad (2)$$

where K is the thermal conductivity, χ is the thermal diffusivity, A is the contact surface and $2b$ is the contact width. Both K and χ are temperature dependent, so the maximum flash temperature is also a function of temperature itself, $T_{f \max} = T_{f \max}(t, T)$, and they should be evaluated experimentally. The contact area considered for calculations in Eq. (2) is the cylindrical sector of the contact zone at the end of the test, being not reliable to measure or to hypothesize its evolution over time: it means that the calculated temperature was under-estimated.

Eqs. (1) and (2), thus, describe the progressive evolution of the work done by the friction force and the temperature evolution at the contact. Maximum surface contact temperature T_{contact} is calculated considering the following equation:

$$T_{\text{contact}} = T_{\text{bulk}} + T_{f \max} \quad (3)$$

where T_{bulk} is the bulk temperature of the sample before entering the contact.

The energy that is transformed as a consequence of frictional contact can be dissipated (conversion to heat, vibration, material deformation, new surface creation) or stored into the tribosystem.

Specific wear energy (E_w) is a criterion which takes coefficient of friction and wear rate into account: it is the ratio of the friction work spent in the interface along the test (between the initial time t_i and the time at the end of the test t_f) divided by the mass loss (Δm) due to the wear as shown in the following equation:

$$E_w = \frac{Q}{\Delta m} = \frac{vW \int_{t_i}^{t_f} \mu(t) dt}{\Delta m} \quad (4)$$

The amount of material removed from the surface is a function of the energy expended on it by the friction force.

3. Experimental setup and specimens

3.1. Specimens

Polytetrafluoroethylene (PTFE) is a well known semicrystalline polymer having relevant tribological characteristics, in particular low friction and quasi-absence of sticking effect, high resistance to temperature and good compatibility. Compared to other polymers, PTFE has high density and high melting point (around 330 °C).

According to the information obtained from the producer (Polifluor, 20159 Asteasu, Spain), the PTFE sample comes from a process of compression molding of the PTFE powder with subsequent sinterization and cooling. The PTFE dispersion has a median particle size of 0.25 μm . The thermal properties of the samples are reported in Table 1.

The PTFE undergoes several phase changes at atmospheric pressure from sub-ambient temperature to the melting point. DSC analysis was carried out by heating the sample in the temperature range of 30–350 °C with a heating rate of 10 °C/min (Fig. 1) using nitrogen as inert gas.

Above 30 °C the material converts into a pseudo-hexagonal disordered phase from a partially ordered hexagonal phase, so thermal diffusivity temperature dependence above 25 °C is low [9]. Therefore the thermal properties of virgin PTFE cannot be considered to be independent of temperature; measurement of its diffusivity, specific heat and density is needed.

Table 1
Thermal properties of virgin PTFE.

Property	Value
Thermal conductivity K at 30 °C (W/m K)	0.14
Thermal diffusivity χ (m^2/s)	1.11×10^{-7}
Melting temperature T_m (°C)	330
Heat of fusion H (J/g)	24.80

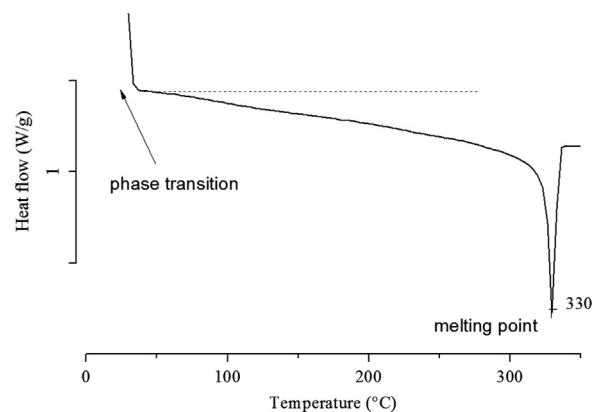


Fig. 1. DSC analysis of virgin PTFE.

Download English Version:

<https://daneshyari.com/en/article/614752>

Download Persian Version:

<https://daneshyari.com/article/614752>

[Daneshyari.com](https://daneshyari.com)