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Short communication

Friction and wear behaviour of polymers in liquid hydrogen

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ABSTRACT

The tribological behaviour of polymer composites were investigated in liquid hydrogen at −253 °C and compared with previous results obtained in gaseous hydrogen at ambient temperature. Experiments reveal that the friction and wear mechanisms in cryogenic conditions are related to the low temperature properties of polymers and to the formation or inhibition of the transfer film. For chemically stable polymers such as PEEK, that does not transfer in hydrogen gas, the tribological behaviour is improved in cryogenic liquids compared to ambient temperature. For tribo-reactive materials and graphite filled polymers that form a homogenous lubricating film in gaseous hydrogen, the sliding performance declines under cryogenic condition. The influence of hydrogen temperatures is discussed in this paper in relation to material compositions and transfer film formation.

1. Introduction

The development of hydrogen technologies is a key strategy to reduce greenhouse gas emission worldwide. One of the leading countries is Japan that first launched hydrogen-powered fuel cell cars [1] and aims to realize by 2020 a “Hydrogen Society” for the upcoming Olympics in Tokyo. Another leader in this field is Germany, that aims to reduce greenhouse gas emissions by at least 80 percent by 2050 compared to 1990 [2]. Power to Gas is a particularly promising system solution, in which hydrogen and methane from renewable electricity can be used equally in mobility, industrial, heat supply and electricity generation applications [2]. In the near future, a total of 400 hydrogen refueling stations are to ensure nationwide coverage across Germany by 2023 [3].

The booming of hydrogen applications implies new material combinations for cost-effective constructions that insure high safety and reliabilities in distribution and delivery. In tribosystems, polymers are used in joints, compression equipment, and valves as seals, rider rings or seats. Therefore, many efforts are being made to investigate material compatibility and performances in hydrogen [4,5], including tribological properties [6–11].

Author’s previous study on polyimides at ambient temperature showed that the chemical structure of the polymer as well as the counterpart’s roughness have a major influence on their tribological behaviour [10]. It was also observed that the lubricity of graphite was found to be more effective in hydrogen than in moist air. A further study on the sliding behaviour of PEEK composites indicated that the formation and adhesion of a thin and homogeneous transfer film strongly depends on the environment [11].

Many studies report on the tribological properties of materials in cryogenic liquids [12–18], fewer in vacuum or inert gas [19–21]. Attempts to find an empirical relationship between the friction force and the temperature were made in the past decades and summarised in [22]. Most experiments showed lower friction and wear in LN_2 compared to room temperature, attributed to the decreasing deformation.

Concerning the friction and wear behaviour of polymers in LH_2, only few studies are available [9,17,18,23]. The aim of this work is to compare tribological processes of polymer materials in liquid hydrogen at −253 °C with the ones observed in gaseous hydrogen at ambient temperature.

2. Experimental details

The materials investigated in this study were co-polyimides based on benzophenonetetracarboxylic dianhydride and pyromellitic dianhydride (PI1, PI2) and PEEK polymers described in [10] and [11], respectively. Pure and graphite filled PI sintered composites were provided by Ensinger Sintimid GmbH. PEEK materials (Victrex 450G) were prepared by injection molding by the Institute for Composite Materials (IVW, Kaiserslautern). Material compositions and nomenclature are presented in Table 1. The sliding performances of these composites in various environments at ambient temperature have been previously reported in [10,11].

Shore D hardness was measured in air (~22 °C) and liquid nitrogen (−196 °C) with a test setup corresponding to EN ISO 868.

Pin-on-disc tests were performed in the cryogenic tribometer (CT2) described in [15] at 0.2 m/s and 1 m/s under 50 N. Experiments were conducted in high purity hydrogen gas at room temperature and in high

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Table 1
List of materials and nomenclature.

PI1	unfilled PI1	PI2	unfilled PI2	PEEK	unfilled PEEK
PI1Gr	PI1 + 15 wt% graphite	PI2Gr	PI2 + 15 wt% graphite	PEEKGr	PEEK + 15 wt% graphite

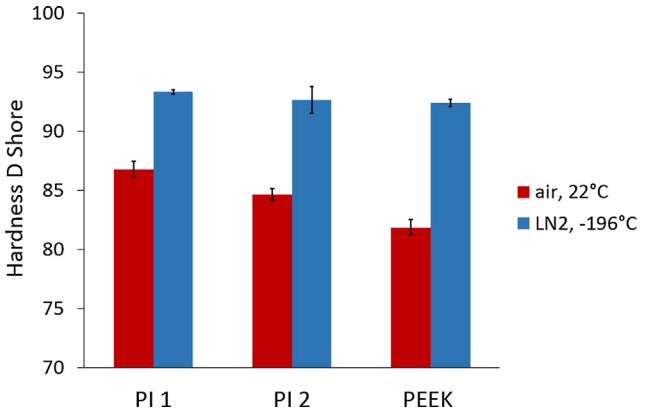

Fig. 1. Hardness measurement in air (~22 °C) and in liquid nitrogen (−196 °C).

purity LH_2 at −253 °C (H_2O < 5 ppm; O_2 < 2 ppm). Before testing, the cryogenic chamber was purged 3 times with high purity N_2 to eliminate any environmental contamination. The contact area of the polymer composite is 4 × 4 mm^2. Steel discs (AISI 52100, Ra = 0.22 µm) were used as counterbody. The wear of the composites was determined by the total weight loss after 5000 m sliding. At least two (in cryogen liquid) or four (at room temperature) experimental values were available to calculate the average friction coefficient and wear rate. Error bars indicate the variations of the friction or wear measurements.

After sliding, worn surfaces of the polymer composites and discs were examined by means of optical microscope (Keyence, VHX-500) and scanning electron microscope (SEM, Zeiss Supra™40) equipped with energy dispersive X-ray spectrometer (Thermo NSS). Polymer samples were thinly coated with gold or platin before SEM analysis. Micro-ATR-IR analyses (attenuated total reflection) (Hyperion 3000, Bruker) were performed on the counterface with a germanium crystal. The wavelength range was set from 4000 cm^{-1} to 500 cm^{-1}.

3. Results and discussion

3.1. Unfilled polymers

Fig. 1 shows the results of the hardness tests. Each value is the arithmetic mean of 5 indents. As expected, the hardness of the polymers

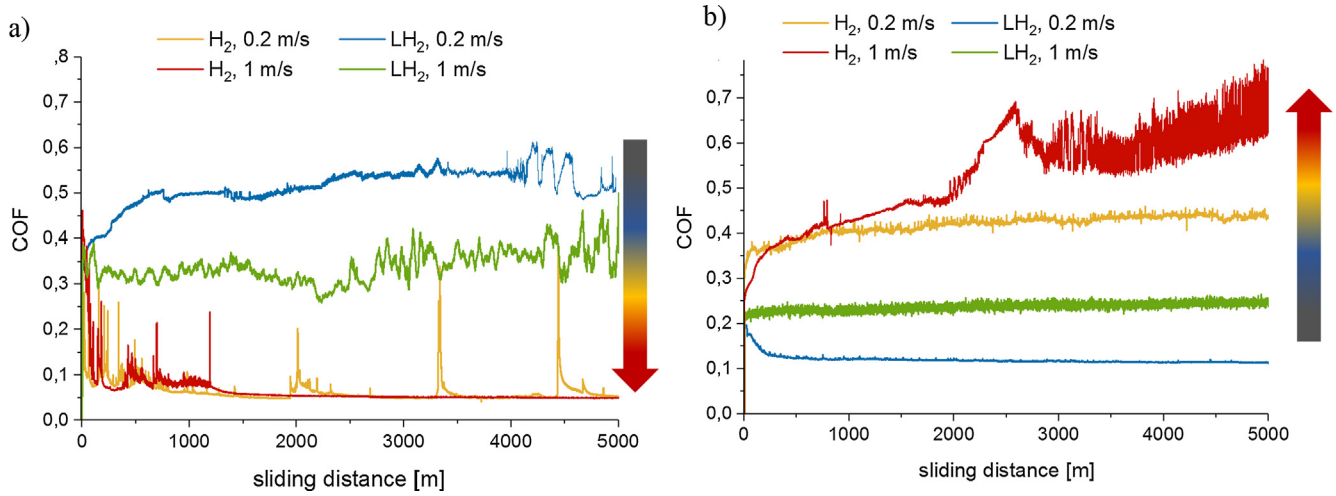

Fig. 2. Progression of the friction coefficient of (a) PI1 and (b) PEEK in hydrogen at ambient and cryogenic temperature, at v = 0.2 m/s or 1 m/s.

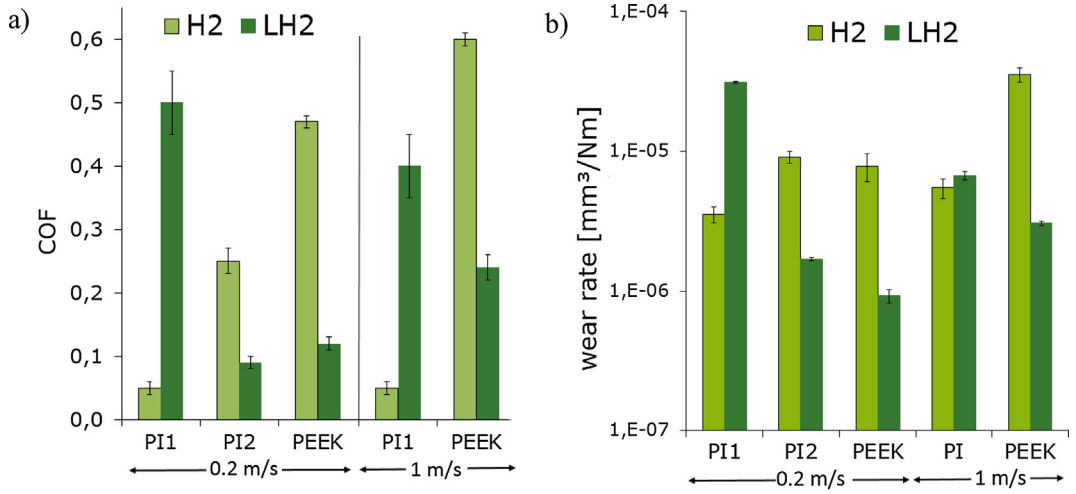

Fig. 3. Friction (a) and wear rate (b) of unfilled polymers at ambient and cryogenic temperature in hydrogen at v = 0.2 m/s and 1 m/s.