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Friction performance of carbon/silicon carbide ceramic composite brakes in ambient air and water spray environment

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ABSTRACT

We have examined friction performance, friction surface structure and chemistry of a carbon/silicon carbide ceramic brake disc tested against an organic pad in air, and water spray environment. An average friction coefficient of 0.52 and 0.4 for a braking stop is achieved after bedding in air for a composite disc comprising 53.1% and 17.7% SiC/Si, respectively. It is identified that 100% SiC/Si and $\sim 50\%$ C_f/C regions contribute the friction measurement. Tested in water spray, both brakes show a substantial fall of friction coefficient to a level < 0.1. Evidences are provided for the existence of hydrodynamic friction. Friction transfer materials removal, SiC region polishing, and lower real contact pressure reinforce hydrodynamic process that a ceramic composite brake can experience.

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1. Introduction

Carbon fibre reinforced carbon–silicon carbide (C_f/C–SiC), also called carbon/silicon carbide (C/SiC), ceramic composite has been progressively used as a replacement of cast iron for producing brake discs used in high performance cars since such application was successfully demonstrated more than a decade ago [1]. By now, almost all commercial C_f/C–SiC brake discs are paired with pads that are made of so-called low metallic friction material (also called organic pad), a type of composite that all abrasives, lubricants, fillers and reinforcements are bonded by resin. Metallic ingredients are included to improve the wear resistance, thermal diffusivity and mechanical robustness [2]. Organic pads themselves are widely used to pair with a cast iron brake disc for a brake in a road vehicle. As known already, friction performance of a brake is highly sensible to the composition of such type of friction material [3–7]. However, there is not yet sufficient tribological knowledge published about a friction pair that consists of C_f/C–SiC and low metallic friction material, whilst one may expect that extensive testing must have been done in industry to achieve/optimise the required friction performance of a carbon ceramic brake, as noted by Krenkel in the early time [8].

In the past years, a number of papers have been published on the tribological performance of carbon ceramic composite tested against itself under specific testing conditions, aiming for self-mated friction application. In general, cracking damage induced by abrasion in the contact regions, and oxidation caused by friction heat are the essential tribological mechanisms that govern the friction performance of a brake and its variation with testing conditions [9–11]. However, such knowledge can hardly be transferred and applied to a carbon ceramic disc paired with an organic pad, because the structure and chemistry of the friction contact regions are changed, leading to different chemical and mechanical processes involved in braking.

C_f/C–SiC composite brake disc was recently tested and studied against organic pads [12–14], and sintered metallic materials [15], on a testing car, full-scale dynamometer, or laboratory-scale dynamometer. The studies have demonstrated that testing results generated from laboratory-scale dynamometer can provide sufficient understanding for predicting what could happen for a brake tested on a testing car, or a full-scale dynamometer [12,13]. It was found that, among all tests, there exists a clear bedding stage that significant numbers of braking stop are needed for a brake to achieve a stable friction coefficient. Examination of friction surface has revealed that in general friction transfer layer is not easily deposited on the friction surface of a carbon ceramic disc with a strong bond [16]. Based on such prior knowledge, we are further motivated to know how the variation of ceramic constituents in C_f/C–SiC composites would influence the friction coefficient at bedded stage, and the bedding process as well.

For a traditional cast iron brake disc, when it is tested against typical organic or sintered pads, a friction transfer layer, typically composed of a dense mixture of iron oxides and compounds such as lubricants, fillers and abrasives that originated from pads [4,17], is fairly easily developed with a strong bond through fusing with iron matrix. Therefore, the focus of a cast iron brake has always been on the friction layer development on the contact surface of a pad, because it is the friction surface of a pad that largely dictates

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the bedding time required for a cast iron brake, as well as the level of friction coefficient after bedding. For a carbon ceramic brake, however, this is not the case, as demonstrated already [14,18], and brake disc could take longer time than pad to complete the bedding. Therefore, attention on friction surface of the disc is necessary.

On the other hand, the weak bond of a friction transfer layer on surface of a carbon ceramic disc likely makes the layer very susceptible to solvents [16], like water, when they are involved in friction contact regions. When friction transfer layer becomes a key factor in defining the friction performance of a brake, the loss of a friction transfer layer might bring significant change of friction coefficient of a carbon ceramic composite brake. By now, all studies on carbon ceramic composite brakes are conducted in ambient air atmosphere, their friction behaviour in wet is remained as unknown at least in literature, if not in industry. We will therefore examine its friction behaviour when a carbon ceramics brake is tested in a wet environment.

However, friction performance in solvent for a cast iron brake does not seem to be a main concern. For the mostly used testing standard, SAE J2522 [19], testing in wet environment is not even included in the suggested testing programme. However, recent studies [20,21] demonstrated that friction coefficient of a cast iron brake could fall in wet environment, and the fall was enhanced by the increase of sliding speed or the reduction of braking pressure. The underpinned mechanism for the fall was believed to be associated to (a) the loss of friction transfer layer from friction surfaces of disc and pads; (b) the formation of water film that can reinforce the hydrodynamic process of contact surfaces; (c) the cooling of the friction surfaces that might reduce friction contact region. Therefore, it is interesting to know how the friction coefficient of a carbon ceramic composite brake is governed when it is operated in a wet environment.

2. Experimental procedures

2.1. Materials for brakes

Two commercial C_f/C–SiC composites were chosen to be brake discs on the basis that they provide significantly different contents of SiC/Si and carbon fibre/carbon (C_f/C) constituents. Information on their microstructure was analysed, and is reported in Results and discussion section. For a brake including a composite disc with a high fraction of SiC/Si, we hereafter called Brake-H, and the one with a low fraction called Brake-L. Grade BS EN 1561 grey cast iron was chosen to be manufactured into a brake disc, and then tested under same conditions as for the composite discs.

A commercial brake pad (Pagid PV30 V3, TMD Friction, Inc.) was selected, and machined into a pad fitting to the testing set up. Same pad was tested against all ceramic composite and cast iron discs. Due to commercial reasons, it is unlikely to know the details of chemicals in this pad. However, its main chemical elements and microstructure were analysed, and are reported in Section 3.

2.2. Brake disc and pad manufacture

All testing discs have a diameter of 60 mm and thickness of 15 mm, and were directly cored from the as-supplied material blocks by using core drill, followed by grinding to achieve the flatness and parallel requirements on friction surface. All testing surfaces were polished using a KEMET lapping machine (Kent, UK). Polishing was carried out using three grades of diamond slurry: 68, 8 and 3 μm, started from the coarse one and finished with the finest. The fine surface finish was adapted to minimise the difference of surface topography among the as-finished friction

surface, which might influence the friction measurement. The drawing of the disc is shown in Fig. 1(a).

The as-acquired pads were first cut into a ring shape with outer diameter (OD) of 50 mm, inner diameter (ID) of 38 mm and height of 4 mm, followed by further machining to remove material off from the ring to achieve two symmetrically positioned arc segments; each segment corresponds to a quarter of the total length of the ring. The drawing of the pad is shown in Fig. 1(b). The surface of the as-machined pad was finished by 500 grade SiC sand paper before being used for test.

2.3. Braking test

The friction testing was conducted on a laboratory-scale dynamometer with inertia of 4.70 g m^2. Details on this testing rig are available in reference [14]. The testing procedure used in this study is summarised here. For each braking stop execution, a disc was firstly accelerated to a rotation speed of around 10,000 rpm ± 10% by compressed air, equivalent to a sliding speed of 20 m/s at the circular position having an effective radius of the friction contact track. Such a sliding speed is close to the motor-way braking speed of a front brake designed for high end automotive vehicles [22]. Then, a pad was pushed onto the disc with a constant brake pressure of 3.6 MPa to decelerate the spinning of the disc until it was completely stopped. Note, braking pressure for a typical automotive vehicle is > 1.2 MPa, and could be close to 10 MPa in extreme situations [23], and the chosen pressure is inside this region. Same execution was repeated
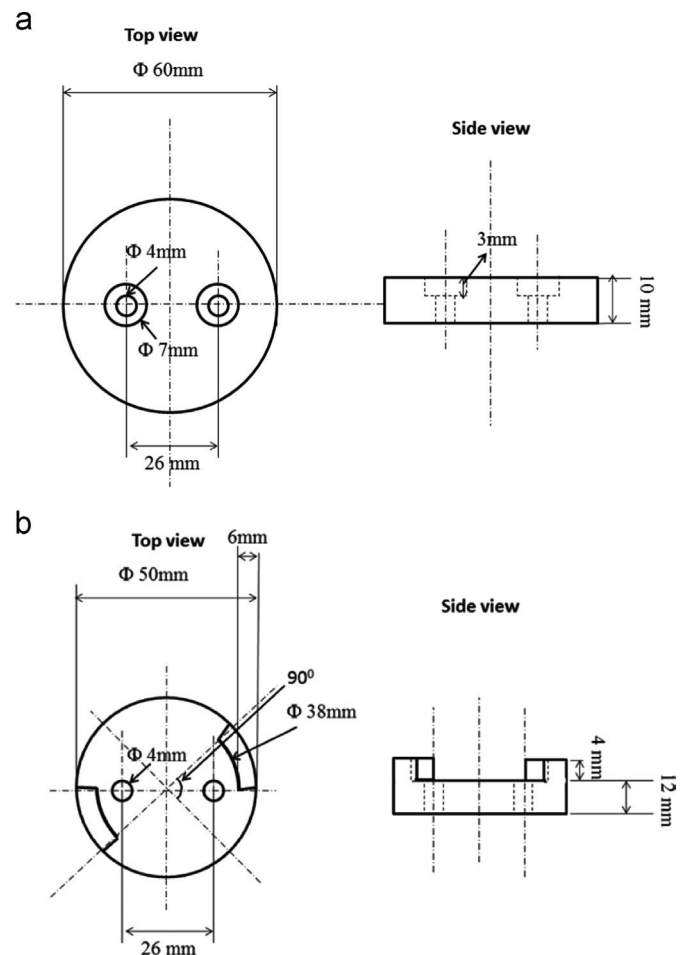

Fig. 1. Drawing of (a) brake disc, and (b) pad used for braking study on a laboratory-scale dynamometer.