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Short Communication

Dynamic friction coefficient of two plastics against aluminum under impact loading

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ABSTRACT

We present a new dynamic friction coefficient testing device modified from the conventional split Hopkinson pressure bar (SHPB). In the experiment, the normal pressure and friction force are applied to the tribo pair simultaneously via the wedge structure of the incident bar. The geometry of tribo pairs can be cylindrical or cuboid which can be as simple as the samples in SHPB experiments, and the time-resolved interfacial friction coefficient can be directly calculated without any assumptions or theoretical derivation. The interfacial friction between two plastics and aluminum was tested by the novel setup, the normal pressure and friction force histories were measured, and the time-resolved dynamic friction coefficient was obtained.

1. Introduction

Friction phenomena widely exist in our day-to-day life. It is complex and uncertain due to many factors such as the roughness of the contacting surface, the time scale of contact, relative interfacial slipping velocity, the response of interface to normal pressure, rate and history of loading and so on. When the material pairs are under impact loading, for example the vehicle impact, packaging dropping, etc., the interfacial dynamic friction will be more complex, and the friction coefficient may change during the loading process. In order to measure the dynamic friction coefficient, a few experimental techniques have been developed by researchers, which are mainly modified from some traditional experimental techniques.

The split Hopkinson bar has been modified to measure the dynamic friction coefficient under high pressure loading [1–5]. Ogawa realized the dynamic friction coefficient test of a brass/brass tribo pair with SHPB by rotating the transmission bar and impacting the incident bar, and the normal pressure can reach to 100 MPa [1]. Rajagopalan et al. modified the split Hopkinson torsional bar to measure the dynamic friction. They adopted a hydraulic device to apply normal pressure to the tribo pair, which is supported by a rigid body rather than the transmission bar. The 6061-T6 Al/1018 steel and CH steel/7075-T6 Al tribo pairs were tested at normal pressure up to 100 MPa by the modified setup [2,3]. Espinosa et al. also modified the split Hopkinson torsional bar for dynamic friction test, in which a special friction clamp was used to apply dynamic compressive and shear loading to the tested tribo pair. The dynamic friction coefficient of Ti–6Al–4V against WC/Co and 4340 steel against WC/Co was tested [4]. Huang et al. similarly modified the Kolsky torsion bar to test the dynamic friction parameters of flat-surface tribo pairs of 7075-T6 Al [5]. In these experiments, the friction force needs to be deduced under some assumptions because the tribo pairs (or one half of the tribo pair) are thin-walled tubular, just like the samples in the torsional Kolsky bar experiments [6]. And also, the thin-walled tubular tribo pairs can be difficult to process for some soft materials and brittle materials. Furthermore, due to the different propagation speed of compression pulse and shear pulse, the normal pressure will be loaded on the interface before the shear force is applied, which may change the interface condition.

Researchers have also utilized the plate impact pressure-shear technique in the study of interfacial dynamic friction [7–14]. Prakash and his research partners have carried out continuous works [7–13]. In the plate impact pressure-shear friction experiments, higher normal pressures and interfacial slipping velocities were obtained than those in modified SHPB. Irfan et al. tested a CH tool-steel/Ti6Al4V tribo pair and investigated the time-resolved sliding characteristics at normal pressures around 1.5 GPa [11]. Yuan et al. realized the interfacial normal stress up to 5 GPa with the tribo pair of a hard tool-steel and 7075-T6 Al alloy [13]. Frutschy et al. applied the pressure-shear plate technique for dynamic friction tests under high temperatures [14]. However, the compressive wave can only last several microseconds, which is not enough in some cases because the flier plate is thin.

Philippon et al. designed an experimental device to study the dry friction of metal tribo pairs under both static and dynamic loading, in which a hydraulic machine was used to supply normal

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pressure, and an air gun set-up was used to launch the projectile to impact the metal tribo pair. In their experiments, the maximum value of normal pressure is 33.15 MPa, and the range of the slipping velocities is from 0 to 60 m/s. The friction coefficient value was given, rather than the time-resolved friction coefficient curves [15]. Lai et al. designed a friction testing fixture, which can apply normal interfacial pressure of 1–100 MPa. They fitted the configuration to a standard material test machine to study the static friction properties of steel sheet couples; and to a drop tower to study the dynamic friction properties [16].

As stated above, extensive attention to the dynamic friction has been focused on the metal tribo pairs. Benabdallah studied the static friction property of four engineering thermoplastics against steel and aluminum alloy. The influence of normal pressure, contact area, lubrication of the interface etc. was evaluated in his work [17].

In this work, the dynamic coefficient of two plastics against aluminum alloy is tested by a modified SHPB setup, in which the tribo pair can be loaded by the normal pressure and friction force simultaneously. Just like the SHPB experiments [18], the amplitude and duration of normal pressure can be adjusted by changing the speed and length of strike bar. The geometry of tribo pairs is simple, which can be prepared as cylinders or cuboids. The stress state of the tribo pair is also simple; the time-resolved dynamic friction coefficient can be directly calculated from the normal and shear stress histories of the pairs without any assumptions or theoretical derivations.

2. Experimental designs

2.1. Experimental device

The dynamic friction coefficient testing device is developed from the split Hopkinson pressure bar. The device consists of an incident bar, two transmission bars and a strike bar, as shown in Fig. 1. The incident bar's end face near the specimen is wedge-shaped, and the angle of the wedge is 90∘.

An elastic compression pulse is generated when the strike bar is launched by gas gun at a certain speed and impacts the incident bar. Sometimes, a pulse shaper will be added to the end of incident bar, which can be made by copper or rubber. The plastic deformation of the shaper smoothens the incident pulse, slows the rising speed of incident pulse, and widens the incident pulse [19]. The incident pulse will propagate through the incident bar, which is the same as in SHPB experiments [18]. In the new experimental setup, when the incident pulse arrives at the wedge-shaped surfaces of incident bar, a normal compressive load and a transverse shear load will be applied simultaneously to the specimens sandwiched between the incident bar and transmission bars, due to the special shape of incident bar, which is different from that in traditional SHPB experiment. It can be found that the interfacial friction between the specimen and the bars is the source of the transverse shear load. So the time-resolved interfacial friction coefficient can be deduced as long as the compressive and shear loading histories are obtained.

In this study, the bars of the experimental setup in the laboratory of National University of Defense Technology are all made of aluminum 7075. The diameters of the strike bar and incident bar are 37 mm, and the length of them are 200 mm and 1800 mm, respectively. The dimension of transmission bars is $\Phi 20 \times 1000$ mm.

In order to investigate the dynamic friction coefficient between materials, a tribo pair is designed as shown in the highlighted part in Fig. 1. The specimen is made of plastic and the interfacial friction between the specimen and AL platen 2 is the object of study. To eliminate the influence of other interfaces, platen 1 is glued to the incident bar and the specimen, and platen 2 is glued to the transmission bar by superglue.

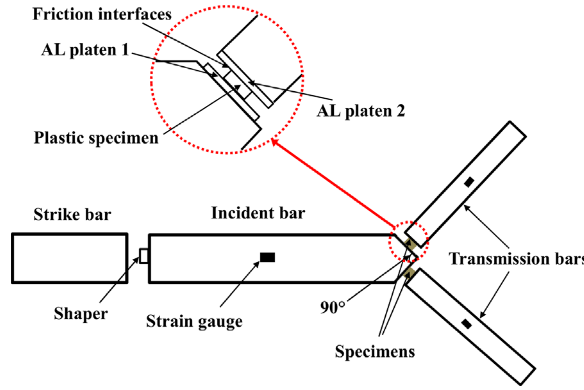

Fig. 1. Schematic of the developed experimental setup.

Table 1
Characteristics of the plastics.

Designation	Density (g/cm^3)	Modulus of elasticity (GPa)	Compressive strength (MPa)
Soft rubber	1.40	_	2.50 (20% strain)
PTFE	2.20	0.50	19.52 (10% strain)

2.2. Tribo pairs

A soft rubber and a poly tetra fluoro ethylene (PTFE) were selected in the experiments. The main material properties of the plastics are listed in Table 1. The specimens made of soft rubber are processed into cylinders with dimension of $\Phi 10.05 \times 2.05$ mm, while the PTFE ones are processed into cuboids with dimension of $10.10 \times 9.90 \times 2.30$ mm. The soft rubber and PTFE specimens are processed with surface roughness of 4.16 μm and 6.39 μm, respectively, which are measured with the Form Talysurf PGI 1240 from Taylor Hobson. The platens are both made of aluminum 7075 with dimension of $\Phi 20.00 \times 2.90$ mm, and the value of surface roughness of platen 2 is 2.92 μm.

2.3. Friction coefficient testing

The stress state of the tribo pair in the test is plotted in Fig. 2. If the effect of stress wave propagation in the tribo pair can be ignored, which is the basic assumption in conventional SHPB experiments [18] and can be achieved in many cases, the dynamic stress equilibrium in the tribo pair will be realized. Some thinner specimens should usually be used to ensure the stress equilibrium. According to Newton's second law, the tribo pair will be compressed by the normal pressure N, and sheared by the interfacial friction force F. If the normal pressure N and interfacial friction force F are obtained, according to the Coulomb's law of friction [20], the dynamic friction coefficient can be calculated as

$$\mu = \frac{F}{N} \quad (1)$$

The normal pressure N can be deduced by the transmitted compressive strain measured by the strain gauges mounted on transmission bar. However, since the strength of the soft rubber is very low, the signal to noise ratio of the transmitted strain measured by the strain gauges is not good, which will affect the testing accuracy. Therefore an X-cut quartz transducer ($\Phi 20$ mm $\times$ 0.5 mm)