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Friction performance assessment of Non-Asbestos Organic (NAO) composite-to-steel interface and Polytetrafluoroethylene (PTFE) composite-to-steel interface: Experimental evaluation and application in seismic resistant structures

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HIGHLIGHTS

- The performance of two types of friction interfaces were investigated.
- The friction interfaces were further utilized in a damping device.
- The effectiveness of the proposed damping device was confirmed.

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ABSTRACT

This paper presents an experimental research program for assessing the mechanical performance of two types of friction interfaces: i.e. Non-Asbestos Organic (NAO) friction composite against steel and Polytetrafluoroethylene (PTFE) composite against steel. A shear device was designed for testing the friction interface, and the compressive force on the interface was realized by a pretension high strength bolt. Cyclic loading tests were conducted for evaluating the friction performance of the interfaces, and loading frequency, loading amplitude, and magnitude of compressive force on the interface were considered as main influencing parameters. Experimental results showed that with the same magnitude of compressive force on the interface, the sliding shear force of the PTFE-steel interface was much smaller than that of the NAO-steel interface. An average friction coefficient of 0.12 was obtained for the NAO-steel interface, while an average friction coefficient of 0.025 was obtained for the PTFE-steel interface. Both friction interfaces exhibited stable and predictable behavior. The interfaces were further utilized in a slip friction damping device developed for upgrading the seismic performance of a novel timber-steel hybrid seismic resistant structure, and analytical results revealed that both structural damage and unrecoverable deformation of the structure were significantly decreased with the application of the damping devices.

1. Introduction

Friction mechanism is commonly utilized in engineering systems for various purposes. In structural engineering, friction devices have been developed for vibration control and energy dissipation, and the performance of these devices are essentially determined by the characteristics of the friction interfaces. Friction interfaces can be further divided into several categories, e.g. metallic friction interface, composite friction interface, etc. Extensive research programs have been conducted to characterize the friction performance and hysteretic behavior of sliding metallic interfaces with different superficial treatments. Tremblay [1] performed tests with steel-to-steel interface. The slippage was mobilized by slotted bolt holes and the normal pressures on the sliding interfaces were applied by pretension bolts with disc spring washers. Morgen and Kurama [2] conducted a serious of triangular and sinusoidal loading tests on two types of friction interfaces (i.e. leaded-bronze against stainless steel and leaded-bronze against alloy cast steel), the interfaces were further used to develop friction dampers for earthquake resistant buildings. Test results showed that both friction interfaces could provide consistent levels of energy dissipation that was almost independent of experimental loading frequency and velocity within the ranges expected to occur during

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earthquakes. Metallic friction interface is also widely applied in steel connections with shim plates to increase energy dissipation performance. The influence of shim plate properties (e.g. material type, hardness, etc.) on the friction behavior of the sliding interface under low-frequency and dynamic loading were comprehensively investigated by Khoo et al. [3] and Borzouie et al. [4].

In parallel with the research into the behavior of metallic interfaces, the friction performance of steel to other friction composite material have also been studied. Pall et al. [5] developed a friction device to be installed at the intersection of braces, and asbestos brake lining pad-to-steel interface was applied to provide energy dissipation. Due to environmental concerns, asbestos based brake lining pads are no longer produced and asbestos-free friction materials have been developed as replacements. Among these asbestos-free friction materials, the Non-Asbestos Organic (NAO) materials have displayed a very stable friction behavior against metallic surfaces [6]. NAO material is multi-component composite which is composed of a resin system, fiber-reinforcement, metallic friction modifiers, abrasive, and inorganic filler. From the perspective of material science, the mechanical performance and thermal conductivity of NAO material with different ingredient proportions have already been studied [7,8]. Previous test results also showed that under uniform normal pressures, the behavior of NAO-to-steel interfaces presented good friction performance without significant strength degradation [5,6,9]. Latour et al. [10] investigated the hysteretic behavior of three types of metallic interfaces including steel-to-steel, brass-to-steel, sprayed aluminum-to-steel, and other three composite friction materials including a kind of NAO material from braking industry. Results showed that the steel-to-steel interface had large friction coefficients but quite unstable hysteretic behavior, and the NAO-to-steel interface exhibited a better performance with high friction coefficient and very small strength degradation.

Polytetrafluoroethylene (PTFE) is carbon and fluorine based high molecular composite material that is known to undergo thermally activated structural transformations at certain temperatures [11]. PTFE is also a kind of non-reactive material, and it is widely used in pipework for reactive and corrosive chemicals. The friction behavior and wear behavior of PTFE are closely associated with its mechanical characteristics [12]. Recently, research programs have been conducted with particular emphasis on the preparation of PTFE with various novel reinforcements and on the evaluation of mechanical and tribological properties of these composite materials [13–15]. PTFE registers a low friction coefficient when rubbed against metallic engineering surfaces, which may allow the PTFE-to-steel interface to behave in a different way when being utilized in mechanical and structural engineering systems. However, little research attention has been paid for accessing the sliding behavior (including hysteretic characteristics and energy dissipation) of PTFE-to-steel interface, and the effectiveness of using PTFE as a sliding surface for energy dissipation has not been investigated and verified.

In this study, friction performance of two types of friction interfaces were experimentally investigated. The first one is NAO friction composite material-to-steel interface, and the other one is PTFE-to-steel interface. Then the interfaces are used in a friction damper, which is further incorporated into a case study in structural engineering with the purpose of dissipating seismic input energy and reducing structural damage.

2. Characterization of friction interface

This section presents the conducted experiments to characterize the aforementioned friction interfaces. Commercially available friction materials were used in the specimens, and attention was mainly paid on the hysteretic performance of the friction interfaces.

2.1. Specimens

Fig. 1 shows the configuration of the specimen. Slotted bolted connection was used for the specimens to allow the relative movement of the steel on the interposed friction material. The inner steel plate is realized with a slotted hole, which was machined in the center of the plate to allow ±20 mm of slip for the bolt. Each outer steel plate has a regular size bolt hole. Two types of steel surfaces (i.e. mill steel and stainless steel) were considered, and two types of friction materials (i.e. NAO and PTFE) were used for the specimens. Thus, four different types of friction interfaces as listed in Table 1 were tested. In this study, NAO780 material produced by CARLISLE from Motion Control Industries was selected as the friction pad for the dampers. The NAO780 pad is composed of a resin system, fiber-reinforcement, metallic friction modifiers, abrasive, and inorganic filler. The PTFE material used in this study was produced by the Chemours, and it is a fluorocarbon solid with a high-molecular-weight compound consisting wholly of carbon and fluorine. Table 2 gives the mechanical properties of NAO780 and PTFE as provided by the manufacturer. Each specimens consists two friction pads, each has a dimension of 70 mm by 30 mm and a thickness of 5 mm. In order to accommodate the friction pad, a pair of recesses was introduced to the steel plate as shown in Fig. 2(a). The recesses were machined on both outer steel plates and the thickness of the recesses was set as half the thickness of the friction pad. Due to the existence of these recesses, the friction pads can be easily fastened to the steel plate with only a small amount of structural epoxy. Fig. 2(b) shows the specimen with NAO friction pad, and Fig. 2(c) shows the specimen with PTFE friction pad.

M16 and M20 high strength bolts with the grade of 8.8 (equivalent to ASTM A325 bolts), conforming to Chinese Standard GB\T1231-2006 [16], were used as fasteners for the specimens. The tensile strength of the bolts is between 830 MPa and 1030 MPa, and such bolts are especially for preload according to [16]. M16 or M20 indicates the bolt has a diameter of 16 mm or 20 mm, respectively. Pretension force was applied to the bolts through torque method according to Chinese Code of Design for Steel Structures [17]. For each M16 bolt, the supposed applied tightening torque is 180 N · m which will result in a pretension force of 90 kN in the bolt. For each M20 bolt, the supposed applied

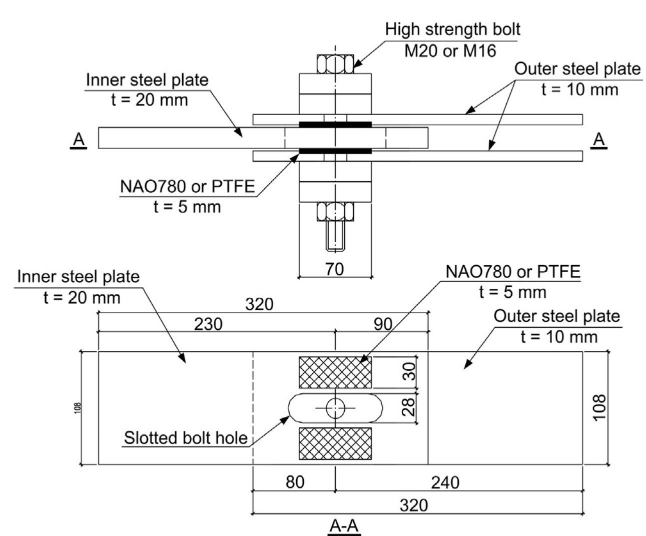

Fig. 1. Specimen configuration (all dimensions are in mm).