19

Frictional Properties of Non-Metallic Materials for Use in Sliding Bearings: An Experimental Study

Daniel Fenz

Department of Civil, Structural & Environmental Engineering, University at Buffalo

Research Supervisor: Michael C. Constantinou, Professor and Chairman

Summary

The purpose of this study is to investigate the frictional properties of several low-friction, non-metallic materials in contact with stainless steel in order to determine their usefulness for base isolation systems. In addition, modifications made to the lateral bracing of the existing isolation testing machine constructed in 1999 at the University at Buffalo's Structural Engineering and Earthquake Simulation Laboratory are discussed as well. Several tests were performed using the improved isolation testing machine to measure dynamic coefficients of friction and their relationships with sliding velocity and normal pressure. Results will be used to evaluate the potential of the materials for use in seismic applications, where low friction and acceptable wear characteristics are desirable.

Introduction

Sliding bearings with a restoring force element are a very useful type of isolation hardware. During earthquakes, they transmit shear force from the ground to the structure above up to the point at which sliding initiates. After this point, the force transmitted depends on the dynamic coefficient of friction of the sliding interface, not on the magnitude of the earthquake itself. This is a very attractive property, as it allows structures to be designed independently of the seismicity of the area. By lowering the friction of the sliding interface, forces transmitted to the structure are lowered as well.

In this study, friction in Axon bearings was tested. Small scale Axon bearings, previously used in the shaking table tests performed by Wolff (2001), consist of a flat sliding interface and a urethane ring to provide damping and restoring force. Past studies of the sliding interface have focused on the use of high friction materials in hopes of providing increased energy dissipation. Instead, this study concentrates on low friction materials, which provide a greater reduction of transmitted forces.

Behavior of PTFE in Contact with Stainless Steel

The most common interface in sliding bearings consists of sheet-type PTFE (Teflon^{TM}) in contact with polished stainless steel. Constantinou et al., (1987) and Mokha et al., (1988) were among the first to report extensively on the behavior of the PTFE – stainless steel interface under dynamic conditions. They determined that the sliding velocity and normal pressure are the two key parameters affecting friction at the sliding interface. Their major conclusions, summarized in Figures 1 and 2, are the following:

1. Friction increases with increasing sliding velocity up to a certain point after which it remains constant. The point at which friction plateaus is dependent on the normal pressure.
2. Friction decreases with increasing normal pressure.

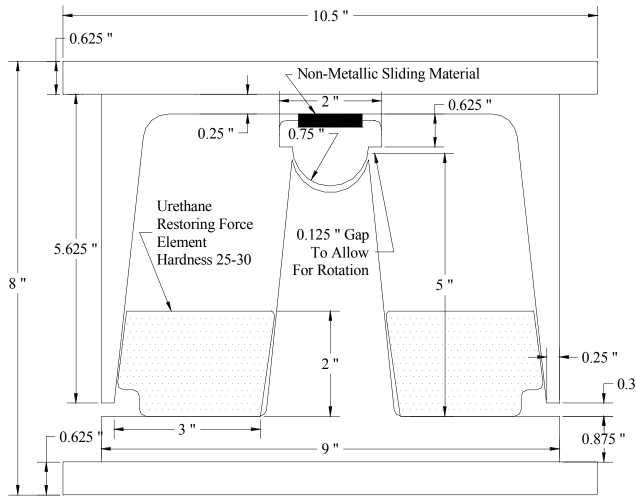

Figure 1. The small scale Axon sliding bearing

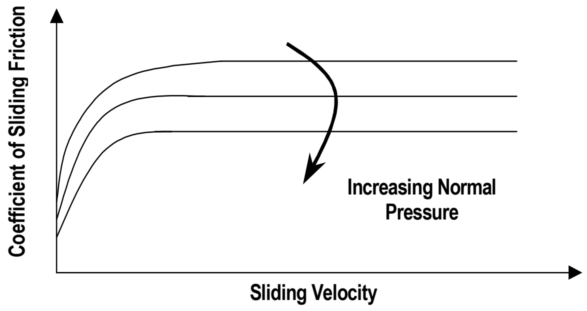

Figure 2. Dependence of friction at the PTFE stainless steel interface on sliding velocity and normal load.

Test Apparatus

The original configuration of the isolator testing machine is shown in Figure 3. The key components are the horizontal actuator (used to impose a predefined displacement history), the two vertical actuators (used to apply normal loads) and the reaction load cell (which measures shear and normal forces at the bearing). The original lateral bracing scheme, also shown in Figure 3, consisted of two sleeved threaded rods attached only at the top flange of the loading beam. They were connected to a weak steel frame made of Uni-Struts.

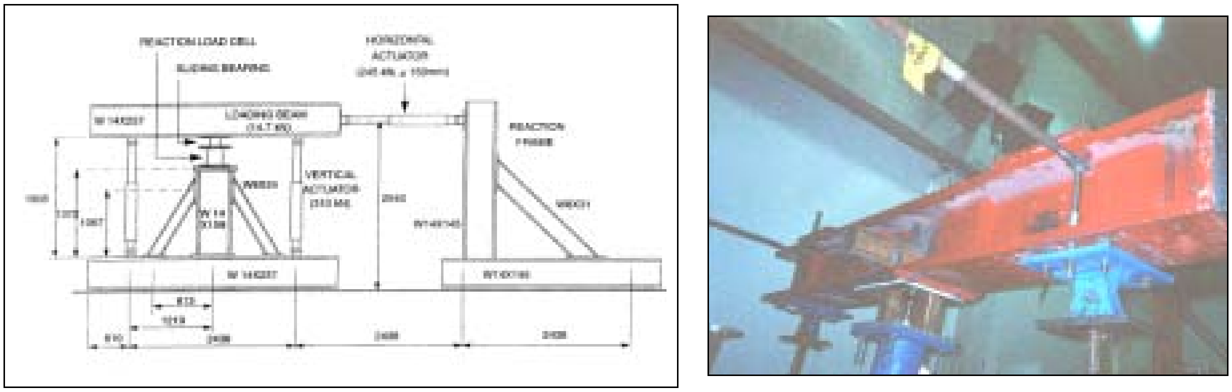

Figure 3. Schematic of the original configuration of the isolator testing machine (all dimensions in mm) and a photograph of the original lateral bracing configuration. Note the connection only at the top flange of the loading beam.

Due to a combination of factors, namely the eccentricity and small point of application of the bearing's reaction force as well as the low friction of the sliding interface, the original lateral bracing proved insufficient to prevent rotation of the loading beam. Since the force that could be exerted by the bracing was limited by the friction at the sliding interface, the reaction couple was insufficient and resulted in a near disastrous rotation of the beam. This is shown in the free body diagram in Figure 4.

Consequently, a new lateral bracing configuration was developed with emphasis on preventing rotation of the loading beam. The new system had to be able to permit horizontal and vertical displacements of the loading beam in addition to being rotationally adjustable. Furthermore, the new system could not interfere with existing components in a manner that would constrain the apparatus' performance. For example, it was necessary to maintain the proper clearance around the vertical actuators needed for the loading beam's maximum 6" displacement.

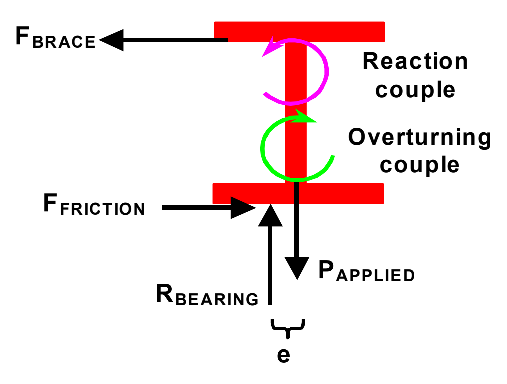

Figure 4. Free body diagram demonstrating how the small frictional force of the sliding interface limited the reaction couple and led to rotation of the loading beam

In the new scheme, shown in Figure 5, bracing is provided at eight points by spherical rollers mounted at the top and bottom flanges on opposing sides of the loading beam. This configuration prevents rotation and transverse movement while providing minimal opposition to vertical and horizontal displacements during testing. In addition, the rotational capability of the loading beam is still maintained by mounting the rollers on adjustable threaded rods. The bracing's supporting structure consists of two stiff U-shaped frames. Vertical members are 6"x4"x3/16" steel tubing oriented along the strong axis in the transverse direction. These are welded to a 4"x4"x1/2" bottom cross member and the entire frame is bolted to the existing bottom support beam. Furthermore, a length of 1' square tubing is welded at mid-height to provide further stiffening. The system is prestressed with Dywidag bars against the strong floor to prevent rigid body rotation.

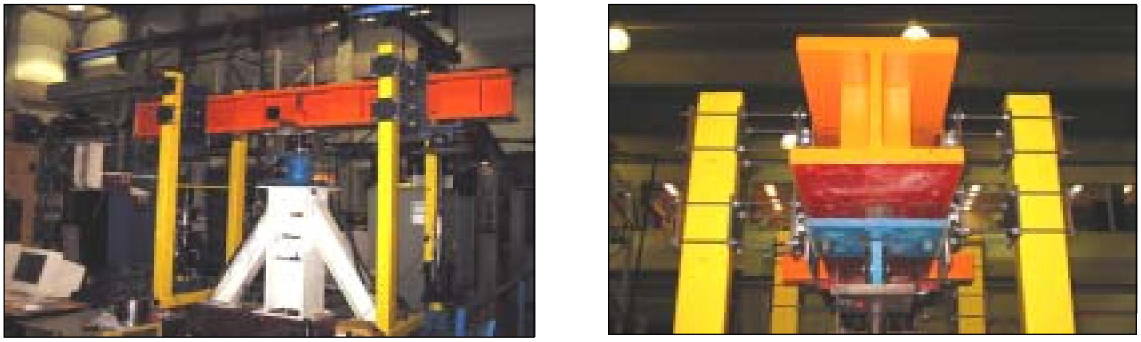

Figure 5. Photographs of the improved lateral bracing scheme

Test Specimens

In all, thirteen different specimens having a wide range of commercially available low friction materials were tested. However, the experiments focused on woven PTFE (Teflon™) composites and self-lubricating cast nylon specimens (see Figure 6). PTFE composites are manufactured by weaving PTFE fibers together with other strengthening fibers and by embedding the resulting fabric in an epoxy resin matrix. Three different strengthening fibers were tested: glass, polyester and Nomex, a very strong heat-resistant material. Self-lubricated cast nylon specimens have liquid or a combination of liquid and solid lubricants embedded during the manufacturing process.

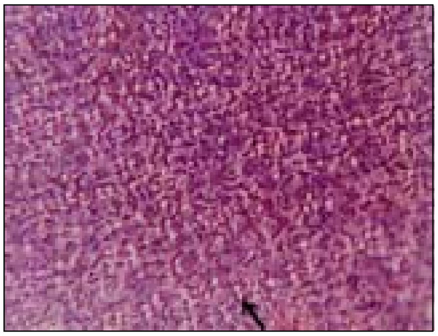

Figure 6. A microscopic view of self-lubricated cast nylon. The highlighted circles are internally embedded lubricant. (Courtesy Nylacast Ltd.)

Testing Procedure

Several tests were required to completely capture each material's behavior regarding the dependence of friction on sliding velocity and normal load. Twelve tests were performed on each specimen, and the sliding coefficient of friction was measured at four velocities for each of three levels of normal load (Table 1). The interface was cleaned with a dry rag after every four tests to prevent any wear debris from affecting the test results. Normal pressures were chosen to be representative of the service loads that the bearing may be subjected to and sliding velocities were chosen over a broad range to completely capture the material's behavior. Sliding velocities were based on a sinusoidal displacement history of 1" amplitude and varying frequency. In addition, each specimen's thickness was also measured prior to and upon completion of testing. This gave information on the wear characteristics of the material in order to evaluate its suitability for various seismic applications. Data analysis entailed plotting normalized friction force (i.e., the coefficient of friction) vs. displacement loops and then extracting the dynamic coefficient of friction. Plots showing the sliding (dynamic) coefficient of friction vs. sliding velocity were then made.

Experimental Results

The frictional behavior of woven PTFE in contact with polished stainless steel is similar to the behavior of plain sheet-type Teflon. Tests show that the coefficient of friction initially increases with increasing sliding velocity and decreases with increasing normal pressure, as shown in Figure 2. Mokha et al., (1988) have shown that friction becomes independent of the sliding velocity above a certain "threshold" velocity. This study found that no such plateau exists for woven PTFE composites. Instead, friction actually decreases at higher sliding velocities. This is attributed to frictional heating, which led to a deposition of PTFE film on the stainless steel plate. In essence, the frictional interface consists of PTFE sliding over PTFE at this point, which results in lower friction.

Table 1. Summary of tests performed on each specimen.

Normal load [kips]	Pressure [psi]	Amplitude [in]	Frequency [Hz]	Peak velocity [in/sec]	Number of Cycles
4.42	2,500	1.0	0.01	0.06	1.5
			0.20	1.25	3.0
			1.00	6.28	3.0
			2.00	18.85	3.0
8.84	5,000	1.0	0.01	0.06	1.5
			0.20	1.25	3.0
			1.00	6.28	3.0
			2.00	18.85	3.0
17.68	10,000	1.0	0.01	0.06	1.5
			0.20	1.25	3.0
			1.00	6.28	3.0
			2.00	18.85	3.0

Not surprisingly, the use of different strengthening fibers does affect the frictional properties of the composite. The results of testing the woven PTFE composites (see Figure 7) are the following:

1. Qualitatively, polyester and glass composites behave similarly. Their behavior is characterized by an increase in friction with increasing sliding velocity and by a slight

decrease at higher sliding velocities. In the case of the Nomex composite, friction increases slightly with increasing velocity and then levels out at higher sliding velocity. Friction decreases with increasing pressure for all fibers.

2. Friction in the polyester composite was slightly less than that in the glass composite. Wear however, was significantly greater in the polyester. The Nomex composite exhibits the highest friction coupled with less wear than those for glass and polyester composites from the same manufacturer.

3. Woven PTFE/glass composites from different manufacturers exhibited essentially the same frictional behavior with respect to dependence on sliding velocity and normal pressure. However, the sample from one manufacturer had only a 10% reduction in thickness contrasted to a 35% reduction in wear for the other manufacturer's sample.

Frictional behavior of cast nylon specimens (see figure 8) is markedly different from that of woven PTFE. These specimens show a very small dependence of friction on sliding velocity. The gap between the minimum and maximum values of friction is much smaller than that in woven PTFE samples. In addition, friction varied much more in cast nylon specimens as the normal load increased. At lower pressure, friction in cast nylon is comparable to that in woven PTFE. At higher pressures, however, cast nylon demonstrates much lower friction than woven PTFE.

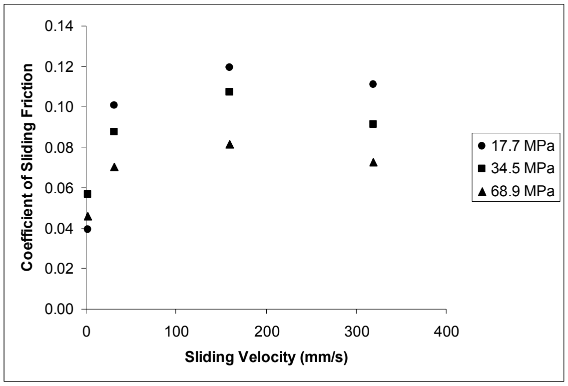

Figure 7. Typical behavior of a woven PTFE composite material (PTFE/glass/phenolic)

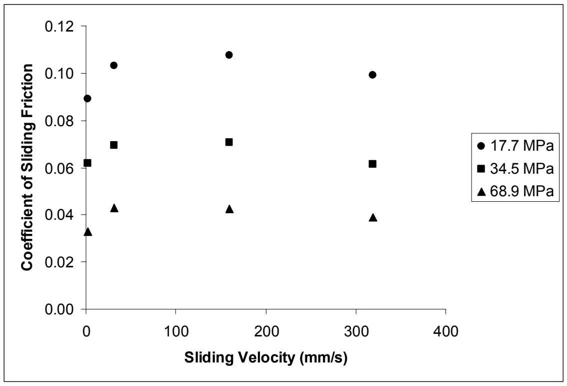

Figure 8. Typical behavior of a cast nylon material

References

Constantinou MC, Caccese J, Harris HG (1987): Frictional characteristics of teflon-steel interfaces under dynamic conditions. *Earthquake Engineering and Structural Dynamics*, **15** (6), 751-759.

Mokha A, Constantinou MC, Reinhorn AM (1988): Teflon bearings in aseismic base isolation: experimental studies and mathematical modeling. *Technical Report NCEER-88-0038*, Multidisciplinary Center for Earthquake Engineering Research, Buffalo, NY.

Wolff ED (2001): Large scale experimental study of the Axon seismic isolation system. *Ph.D. Dissertation (draft)*, Department of Civil, Structural & Environmental Engineering, University at Buffalo, Buffalo, NY.