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A Study on the Friction Characteristics and Design Applicability of PE and PA Materials Applied to Friction Pendulum Systems (FPS) for Bridge Bearings

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Abstract

This study examines the frictional behavior of polyethylene (PE) and polyamide (PA) materials used in friction pendulum systems (FPS) for bridge bearings under various contact pressures (20, 40 and 60 MPa) and sliding velocities (1–200 ㎜/s). The friction coefficients were measured experimentally, and a logarithmic regression model was applied to assess velocity sensitivity. Based on the measured coefficients, FPS designs were conducted to evaluate effective stiffness, energy dissipation capacity, and equivalent damping ratio under identical design conditions. Results indicate that PA consistently exhibited higher friction coefficients, greater energy dissipation, and superior damping performance compared to PE. These findings provide practical insights into selecting optimal friction materials for seismic isolation bearings, enabling enhanced damping capacity and compact bearing designs.

Keywords: *Friction pendulum system, Friction material, Polyethylene, Polyamide, Coefficient of friction, Seismic isolation.*

Introduction

Bridge bearings serve as critical structural components that transfer loads from the superstructure to the substructure while accommodating horizontal and vertical displacements as well as rotational movements [1]. Their performance and reliability have a direct impact on the overall safety and durability of the bridge.

In recent years, seismic isolation bearings have been increasingly adopted to improve the seismic resilience of bridges. Among various types, FPS have gained significant attention due to their ability to provide both restoring force and energy dissipation during seismic events [2]. The dynamic behavior of FPS is primarily governed by the curvature radius of the sliding surface and the friction coefficient between the sliding interface materials [3]. which directly influence damping capacity and displacement response [4].

The selection of appropriate friction materials is therefore essential to ensure optimal FPS performance. While polytetrafluoroethylene (PTFE) has been traditionally used [5], engineering plastics such as polyethylene (PE) and polyamide (PA) offer potential advantages, including higher wear resistance, reduced manufacturing cost, and suitability for high contact pressures [6, 7]. However, their frictional characteristics under varying pressure and velocity conditions require systematic evaluation.

In this study, the friction coefficients of PE and PA were experimentally measured under multiple contact pressure (20, 40, 60 MPa) and sliding velocity (1, 5, 10, 25, 50, 100, 200 mm/s) conditions. A logarithmic regression model was used to characterize velocity-dependent behavior. Additionally, based on the measured coefficients, FPS designs were developed to compare effective stiffness, energy dissipation capacity (EDC), and equivalent damping ratio for each material. The outcomes provide quantitative guidance for selecting optimal friction materials in seismic isolation bearings.

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Materials and Methods

Materials

Friction Materials

Two types of engineering plastics, polyethylene (PE) and polyamide (PA), manufactured by Company M (Germany), were selected for testing. The specimens were fabricated without dimples, with a thickness of 8.4 ㎜ and a diameter of 300 ㎜. Table 1 summarizes the key mechanical and physical properties of each material, including density, tensile strength, elongation at break, Rockwell hardness, and water absorption rate.

Table 1. Physical Properties of Friction Materials

Material	Density(g/㎤)	Tensile strength(MPa)	Elongation at break(%)	Rockwell hardness	Water absorption(%)
PE	0.93	34.5	264	41	0.01
PE	1.12	76.2	96	115	1.29

PE is characterized by moderate vertical stiffness, a friction coefficient typically ranging from 3% to 10%, and good wear resistance, although its performance can be affected by temperature changes. In contrast, PA exhibits high stiffness and hardness, a friction coefficient exceeding 10%, and excellent abrasion resistance; however, its relatively high water absorption rate may cause changes in friction coefficient and potential stick–slip phenomena during long-term service.

Stainless Steel Plate

The counterface for the friction test consisted of an STS316 stainless steel plate with a thickness of 2 mm. The surface roughness was finished to an arithmetic average roughness (Ra) of less than 0.08 μm by buffing with an abrasive of at least 800 mesh.

Test Conditions

The friction specimens were mounted in a jig with a dimensional tolerance of ±0.1 mm to minimize slip during testing. The stainless steel plate was firmly fixed to the jig using bolts to prevent displacement. The protrusion height of the friction material was set to 2.4 ㎜ in accordance with EN 15129-2, Clause 6.2.

Tests were conducted under three nominal contact pressures (20, 40, and 60 MPa) and seven sliding velocities (1, 5, 10, 25, 50, 100, and 200 ㎜/s). The friction coefficient was determined in the last cycle of each test by dividing the horizontal force by the vertical force at zero displacement. The laboratory temperature was maintained at 23 ± 2 °C. To reduce thermal effects, a cooling period of 30 minutes was provided between tests, and for high-velocity tests, a buildup time of 60 seconds and an idle time of 10 seconds were used to gradually reach the target velocity, thereby minimizing the influence of static friction.

Table 2. Test Conditions

Pressure(MPa)	Wave	Velocity(㎜/s)	Amplitude(㎜)	Cycle	Build up time(s)
20, 40, 60	sine	1, 5, 10, 25, 50, 100, 200	50	2.5	10

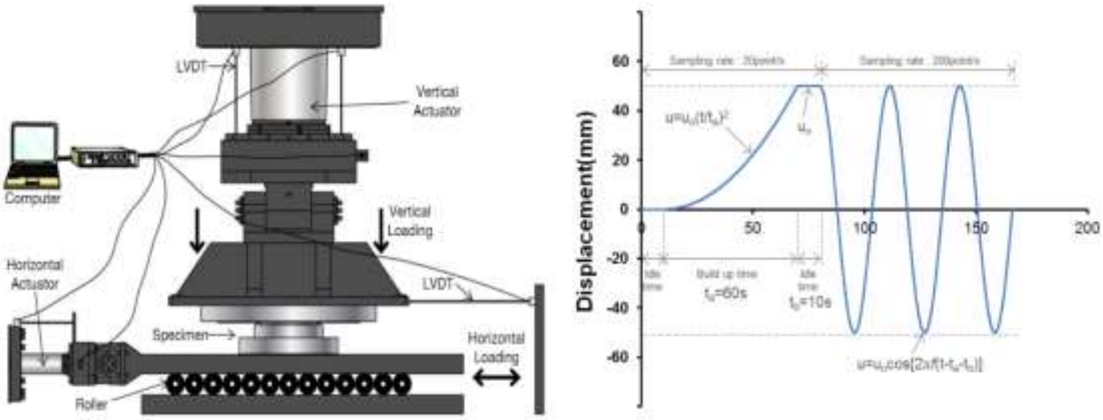

Figure 1. Test Evaluation System & Displacement Hysteresis Loop

Results and Discussion

Friction Coefficient Characteristics

Table 3 presents the variation of friction coefficients for PE and PA under different contact pressures and sliding velocities.

Polyethylene (PE): The maximum friction coefficient was approximately 4.15%. A gradual increase in friction coefficient was observed with increasing velocity, while sensitivity to contact pressure remained relatively low. Due to its lower hardness and smoother surface, PE is more prone to surface deformation under high contact pressure, which may enlarge the real contact area and reduce pressure sensitivity.

Polyamide (PA): The maximum friction coefficient reached approximately 11.9%, nearly 2–4 times higher than that of PE. The coefficient increased sharply with velocity but tended to decrease as contact pressure increased. This reduction at higher pressures may be related to surface softening caused by frictional heating, given PA’s higher stiffness and hardness.

Table 3. Result Of Friction Coefficient

Velocity(㎜/s)	20MPa		40MPa		60MPa	
	PE	PA	PE	PA	PE	PA
1	2.14	7.96	1.38	5.97	1.28	5.03
5	1.85	9.08	1.34	6.97	1.67	5.76
10	1.82	9.48	1.66	7.32	2.05	6.24
25	2.05	10.44	2.27	7.95	2.48	6.65
50	2.35	10.98	2.62	8.40	2.92	6.89
100	3.01	11.86	3.12	8.49	3.27	7.02
200	4.15	11.90	3.51	8.99	3.62	7.52

Logarithmic Regression Analysis

The relationship between sliding velocity and friction coefficient was modeled using a logarithmic regression function of the form:

$$\mu = a \cdot \ln(v) + b$$

where, μ is the friction coefficient, v is the sliding velocity(㎜/s), and a and b are regression constants. The results are summarized in Figure 2.

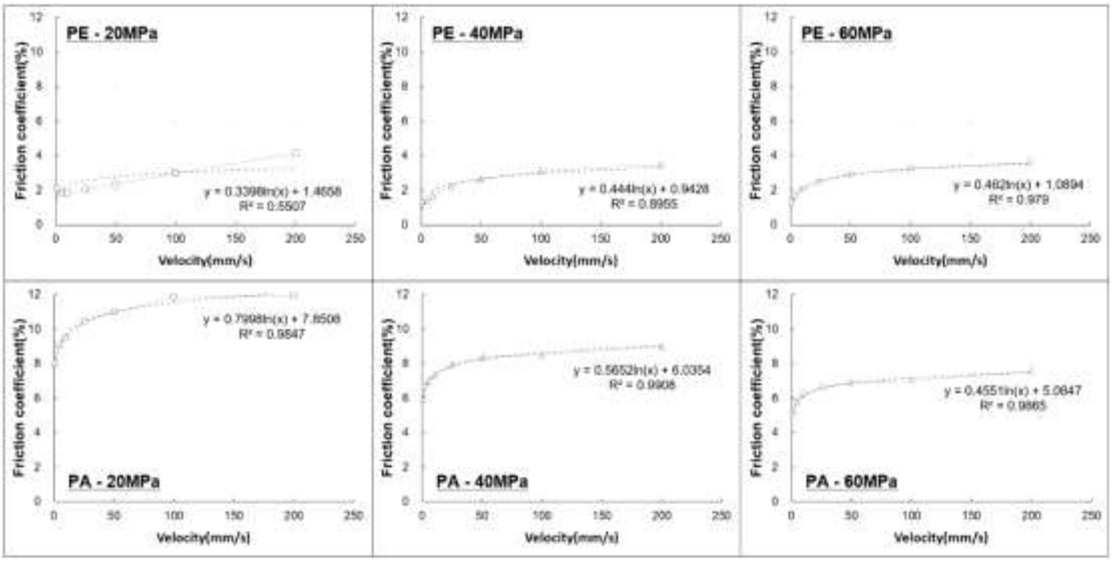

Figure 2. Regression Coefficients and Coefficient of Determination (R^2) For PE And PA Under Different Contact Pressures

PA exhibited a high degree of correlation ($R^2 > 0.98$) across all pressure conditions, indicating stable model applicability.

For PE, correlation improved significantly at higher pressures, with R^2 increasing from 0.55 at 20 MPa to 0.96 at 60 MPa.

Application to FPS Design

To evaluate the impact of friction coefficient on seismic isolation performance, FPS designs were carried out under a uniform set of parameters: contact pressure of 40MPa, sliding velocity of 100 ㎜/s, curvature radius of 2400 ㎜, and design displacement of ±100 ㎜.

The comparative results are shown in Table 4 and Figure 3.

Table 4. Result of FPS Design

Properties	PE	PA
Vertical load (kN)	2,827	2,827
Coefficient of friction	0.0312	0.0849
Radius of friction sliding concave surface (mm)	2,400	2,400
Movement (mm)	±100	±100
Characteristic strength (kN)	88.2	240.1
Yield strength (kN)	90.3	241.5
Yield displacement (mm)	1.80	1.25
Initial shear stiffness (kN/mm)	50.19	193.22
Post-yield shear stiffness (kN/mm)	1.18	1.18
Design lateral load (kN)	206.0	357.9
Energy dissipation per cycle (kN/mm)	34,651	94,819
Effective stiffness (kN/mm)	2.06	3.58
Effective period (s)	2.35	1.78
Equivalent damping ratio (%)	26.77	42.17

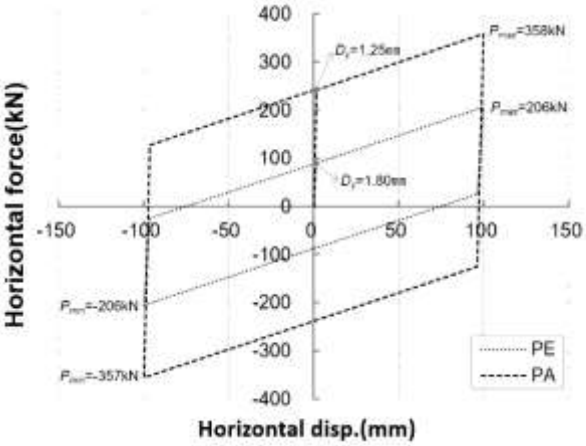

Figure 3. Shear Characteristics from FPS Design

At a contact pressure of 40 MPa and a sliding velocity of 100 mm/s, the FPS design results showed that, due to its higher hardness and friction coefficient, PA outperformed PE, exhibiting approximately 173% greater effective stiffness, about 274% higher energy dissipation per cycle, and 158% higher equivalent damping ratio, respectively.

We propose a simple and reasonable approach to improving multiple alignments of TM protein data sets by pre-selecting sequences, albeit with fewer sequences. During this process, the indices for TMS location and gap insertion become valuable, provided that the TMS regions are correctly predicted. It can be assumed that the proteins selected share high structural similarity.

4. Conclusions

In this study, the friction coefficients of polyethylene (PE) and polyamide (PA), materials used in friction pendulum systems (FPS), were evaluated under varying contact pressure and sliding velocity conditions. Regression analysis was conducted to determine the coefficient of determination (R^2), and FPS designs were carried out under identical conditions to assess effective stiffness, energy dissipation per cycle (EDC), and equivalent damping ratio. The main findings can be summarized as follows:

For PE, the friction coefficient exhibited a clear increasing trend with velocity, while its dependence on contact pressure was relatively low. In contrast, PA was highly sensitive to changes in velocity but showed a decreasing friction coefficient as contact pressure increased. This behavior indicates that PA's material properties—such as hardness, localized heating, plastic deformation, and changes in the contact surface—respond sensitively to variations in load conditions.

The logarithmic regression analysis revealed that PA achieved a high degree of fit ($R^2 > 0.98$) for all contact pressures, with velocity sensitivity ranging from 0.45 to 0.80. For PE, the correlation was relatively low at 20 MPa ($R^2 = 0.55$) but improved markedly to 0.85 at 40 MPa and 0.96 at 60 MPa. The logarithmic coefficient for PE also showed a gradual increase with rising contact pressure. These results suggest that PE maintains a pronounced velocity-dependent increase in friction coefficient even under high-pressure conditions, thereby potentially contributing to improved damping performance.

Under identical FPS design conditions, PA's higher hardness and friction coefficient resulted in substantially greater damping performance and energy dissipation capacity compared to PE.

Overall, the comparative evaluation confirmed that PA, as a high-hardness and high-friction material, outperforms PE in terms of energy dissipation capacity and damping performance. The use of high-hardness materials may allow for reductions in FPS size while still achieving the required energy dissipation capacity. However, given PA's relatively high water absorption rate, the potential impact of moisture uptake on the friction coefficient should be considered in design and application.

Acknowledgments

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