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THE COEFFICIENTS OF STATIC AND KINETIC FRICTION USING ARDUINO

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ABSTRACT

The friction coefficient plays an essential role in various aspects of daily life. The friction coefficient between vehicle tires and the road is critical in transportation safety. In design and construction, friction between structural components contributes to building stability. The appropriate friction coefficient between machine parts reduces wear and extends machine life in industries and machinery. Therefore, determining the static and kinetic friction coefficients is challenging and requires direct experimental observation of friction. Thus, a better method is needed to measure the friction coefficient accurately. Several previous studies have been conducted to determine the coefficient of friction using auxiliary tools. Measuring the friction coefficient using auxiliary tools is necessary to obtain accurate results and save time. It can also avoid misconceptions due to complicated and inefficient manual measurements. This study measured by pulling a block with a pulley on a flat surface using Arduino Uno and an ultrasonic sensor HC-SR04. The research method used in this study is an experiment conducted in the IPSE Physics Laboratory. The experimental results show that the static friction coefficient is greater than the kinetic friction coefficient.

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Introduction

The coefficient of friction is a parameter that measures the magnitude of frictional force between two surfaces in contact. In various aspects of daily life, the coefficient of friction plays an essential role. The friction coefficient between vehicle tires and the road is critical for transportation safety (Ergun et al., 2005). Friction is a highly complex phenomenon, and due to its importance, it has been studied over the centuries by many researchers (Marques et al., 2016). High friction is necessary for vehicles to stop effectively and prevent slipping.

Additionally, when an aircraft lands, the friction coefficient between the aircraft's wheels and the runway helps the plane stop safely (Jiang & Wang, 2023). In design and construction, friction between structural components contributes to building stability. For instance, friction between a foundation and the ground is vital to prevent the slipping or shifting of buildings during seismic events (Gandelli et al., 2020). In industries and machinery, the appropriate friction coefficient between machine parts reduces wear and extends machine life (Ray & Remine, 1998). Lubrication is often used to manage friction.

Frictional force can be described as the mechanism of friction between two surfaces in contact that generates a force acting between the atoms of one surface against those of the other (Humairo et al., 2018). Friction is the force acting on two touching objects where its direction is opposite to the movement of the object when the velocity is $v \neq 0$ (Amirudin et al., 2018; Pennestrì et al., 2016). Friction arises due to the relative movement between two contacting surfaces, restricting the movement of one relative to the other. The greater the frictional force, the stronger or tighter the contact (Andriani et al., 2021). A stationary object has static friction force opposing the tendency of its direction of movement. When an object on a surface is given a parallel force and does not move, the frictional force is greater than zero, up to the maximum static friction force. The object starts moving when the driving force exceeds the maximum static friction force; in this case, the frictional force at play is kinetic friction.

When an object moves on a surface or within a fluid such as air or water, it encounters resistance due to its interaction with the environment. Such resistance is known as frictional force. Frictional force is crucial in daily life, enabling activities like walking or running and the movement of various vehicles. Friction is defined as the force acting on two touching objects where its direction is opposite to the movement of the object (Amirudin et al., 2018). Friction arises from the relative movement between two contacting surfaces, restricting the movement of one relative to the other. The greater the frictional force, the stronger or tighter the contact (Andriani et al., 2021).

Friction is categorized into two types: static friction and kinetic friction. Static friction occurs between two stationary surfaces, such as an object resting on the floor. In contrast, kinetic friction arises between two surfaces in motion or sliding (Yuliani et al., 2022). For example, when moving a heavy table across a rough floor, it requires a more significant force to initiate movement than to maintain it once it starts sliding. To understand this phenomenon, observe a book on a table as shown in Figure 1 (a). If a horizontal force F is applied to the right, the book remains stationary if F is not too large. The force opposing F and holding the book in place, acting to the left, is called the frictional force f (Halliday et al., 2013).

As long as the book does not move, f = F. Since the book is stationary, this frictional force is called static friction fs. This scenario shows that the force arises from the contact points of the surfaces, even for seemingly smooth surfaces. When the book moves, a decelerating force known as kinetic friction fk acts on it. If F = fk, the book moves to the right at a constant velocity. If F > fk, an unbalanced force F – fk acts in the positive x-direction, accelerating the book to the right. If the applied force F is removed, the kinetic friction force fk acting to the left will decelerate the book in the negative x-direction, eventually bringing it to a stop.

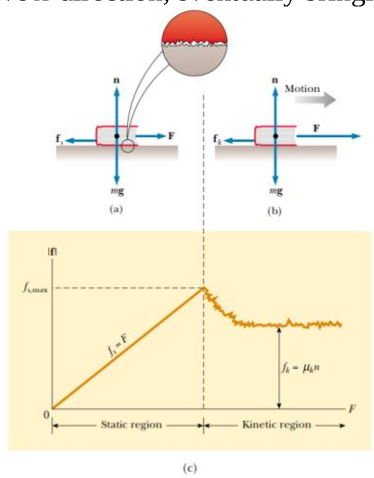

Figure 1. Mechanism of frictional force on contacting objects (Halliday et al., 2013)

10.21107/jps.v12i1.27762 Hartono & Prima E-ISSN: 2527-7634

The ratio of the static or kinetic frictional force to the normal force is called the static friction coefficient and the kinetic friction coefficient, respectively. These values depend on various factors such as material properties, surface temperature, and contamination (Amirudin et al., 2018).

Friction is an interesting topic in physics education. Theoretically, the static friction coefficient tends to be greater than the kinetic friction coefficient, and often, the magnitude of the friction coefficient is closely related to the surface roughness of objects. Determining the static and kinetic friction coefficients is challenging and requires direct experimental observation of friction. Therefore, a better method is needed to measure the friction coefficient accurately.

Several previous studies have been conducted to determine the coefficient of friction, including research by Kurniawan & Handayani (2018) and Yuliani et al. (2022), which developed physics teaching aids for frictional force using ultrasonic sensors and Arduino to measure acceleration and friction coefficients on inclined planes. Then, Humairo et al. (2018) analyzed static and kinetic friction coefficients on inclined planes using video tracker analysis applications. This study showed that the static friction coefficient is higher than the kinetic friction coefficient. Next, research by Amirudin et al. (2018) investigated the effect of the surface area of objects on static and kinetic friction coefficients on inclined planes using video trackers. Based on the experiments conducted, it can be concluded that surface area affects both static and kinetic friction coefficients. Similar research was also conducted by Andriani et al. (2021). This research demonstrated that the video tracking method consistently provides reliable measurements in determining kinetic friction coefficients and other kinematic experiments. Tracker is a specialized software designed to track the movement of objects, generating parameters such as position, velocity, acceleration, kinetic energy, momentum, and so on, enabling a more detailed analysis of each motion parameter.

The measurement of the friction coefficient using auxiliary tools is indeed necessary to obtain accurate results and save time. Using auxiliary tools in measurements can also avoid misconceptions due to complicated and inefficient manual measurements (Yuliani et al., 2022). One of the measurement tools developed is based on Arduino, as researched by Deliana & Sugianto (2020) regarding the needs analysis for developing the design of Arduino-based friction coefficient practical tools. Their study showed that it is indeed necessary to develop manual friction practical tools into Arduino-based ones to enhance students' understanding of physical concepts. With current technological advancements, experimental tools are developed not only in software-based but also Arduino-based tools.

Arduino Uno is an electronic circuit board or commonly referred to as an electronic kit. This board has 14-digital I/O pins, where 6-pins can be used as PWM, 6-analog inputs, a reset button, a power jack, a USB connection and more (Kaswan et al., 2020). Arduino Uno is a microcontroller module that has many advantages, including being affordable and able to work quite well or obtain accurate data. Arduino can control how the component in the circuits are connected or disconnected independently (Yasin et al., 2018). Arduino has inputs and outputs that can be used to get information and based on received data Arduino can send output. Arduino microcontrollers can be programmed easily using the C or C++ language in the Arduino IDE (Ismailov & Jo‘Rayev, 2022). Therefore, Arduino makes the procedure of working with microcontrollers simpler while offering huge benefits to teachers, students, and hobbyists when compared with similar systems (Kondaveeti et al., 2021).

Arduino is widely used worldwide due to its simplicity of use and the large number of sensors and libraries available to extend the basic capabilities of this microcontroller (Barbon et al., 2016). Arduino can be applied in various measurements, including measuring the position and distance of objects (Çoban & Salar, 2023; Olayinka et al., 2021), vibration measurement (Hasibuzzaman et al., 2020), electrical resistance measurement (Ahied, 2016), electric current measurement (Bradley & Wright, 2021), temperature measurement (Rahimoon et al., 2020), light spectrum measurement (Di Nonno & Ulber, 2022), sound speed measurement (Çoban & Çoban, 2020), liquid density measurement (Megantoro et al., 2020), and so on. In this study, Arduino's ability to measure the position of objects will be utilized. The quantities obtained will be used to determine the friction coefficient of the object.

The coefficient of friction can be determined using three methods. First, by pulling a block with a pulley on a flat surface. Second, by sliding a block without a pulley on an inclined plane. And third, by pulling a block with a pulley on an inclined plane (Yuliani et al., 2022). From several previous

10.21107/jps.v12i1.27762 Hartono & Prima E-ISSN: 2527-7634

studies, there has been no development of a practicum that measures friction force by pulling a block with a pulley on a flat surface using a combination of Arduino and ultrasonic sensors. For that, the first method is used in this experiment, where a block is pulled by a pulley on a flat surface. This practical experiment introduces a new way to determine the friction coefficient of an object using Arduino with the HC-SR04 ultrasonic distance sensor. The use of the Arduino microcontroller and ultrasonic sensor allows for more precise control of the object's position and time. The Arduino application is also an open-source application that can be used by anyone. This research is expected to be one of the practical models for friction force applied in junior high schools.

In the 2013 Curriculum for Junior High School Science, the topic of friction is studied with basic competencies in knowledge, such as analyzing linear motion, the effect of force on motion based on Newton's laws, and its application to the movement of objects and living beings, as well as basic skills competencies in presenting the results of investigations on the effect of force on the motion of objects. In the Merdeka Curriculum, it is studied under the learning outcomes where students are able to measure physical aspects they encounter and utilize various motions and forces. The independent variable used is the surface of the object, represented by the sandpaper grit number. The dependent variables are the static friction coefficient and the kinetic friction coefficient. The control variables are the mass of the load and gravitational acceleration.

Research Methods

The research method used in this study is an experiment conducted in the IPSE Physics Laboratory. The experiment on static and kinetic friction coefficients begins with measuring the acceleration of an object using Arduino and an ultrasonic distance sensor. This experiment measures the friction force between the table and the object on a flat surface. The equipment and materials used include a pulley, wooden block, weights, digital scale, string, Arduino, HC-SR04 ultrasonic sensor, cables, and sandpaper. The first step is to set up the equipment, as shown in the following figure:

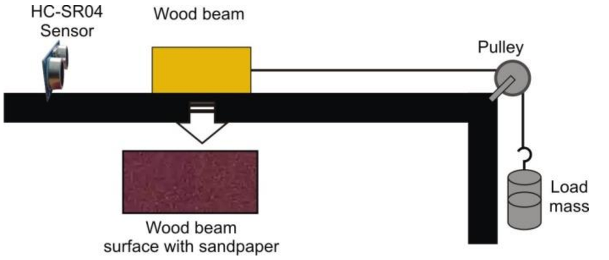

Figure 2. Experimental Setup for Friction Force

The next step is to assemble the Arduino with the ultrasonic distance sensor, as shown in the following figure:

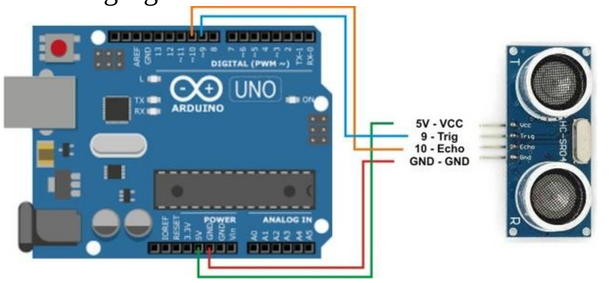

Figure 3. Arduino Circuit with HC-SR04 Ultrasonic Distance Sensor

Next, enter the following code into the Arduino IDE application to obtain position measurements as the object moves with constant acceleration:

```
const int trigPin = 9;
const int echoPin = 10;
long duration;
float distance;
void setup() {
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  Serial.begin(9600);
}
void loop() {
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  duration = pulseIn(echoPin, HIGH);
  distance = duration * 0.034 / 2;
    Serial.print(millis()/1000.00,1);
  Serial.print("  ");
  Serial.println(distance,1);
  delay(200);
}
```

Figure 4. The code used to determine the position of an object

After all equipment is prepared, data recording can be conducted, and the time and position data of the object are stored on the computer. The time and position data will then be analyzed using Microsoft Office Excel graphs. In creating the graph, the x-axis represents time (t), and the y-axis represents the object's position (x). From the generated graph, the equation for position

10.21107/jps.v12i1.27762 Hartono & Prima E-ISSN: 2527-7634

concerning time for motion with constant acceleration is determined in the form of a quadratic polynomial equation with the general form [1].

$$x(t) = at^2 + bt + c \qquad [1]$$

Where a, b, and c are constants of motion. This equation is subsequently differentiated to determine the equation for velocity and then differentiated again to obtain the object's acceleration. The obtained acceleration of the object is then used to calculate the coefficient of kinetic friction. To calculate the coefficient of static friction, the equation

$$\mu_s = \frac{m_2}{m_1} \qquad [2]$$

is used, while to calculate the coefficient of kinetic friction, the equation

$$\mu_k = \frac{m_2 g - (m_1 + m_2)a}{m_1 g} \qquad [3]$$

Result and Discussion

In this study, four types of sandpaper with varying roughness levels (AA60, AA240, AA400, and AA600) were tested by rubbing them against a laboratory table in the IPSE Laboratory. The first experiment focused on measuring the acceleration of a wooden block, which had its surface covered with AA60 sandpaper, as it moved across the table. Using a distance sensor, the position and time of the block were tracked and transmitted to a laptop via an Arduino system. The data collection started from the moment the block began to move, capturing its position and time as it accelerated uniformly. The collected data, illustrating the block's motion with constant acceleration, is shown in the figure below.

t (s)	x (cm)
8.3	10.0
8.5	10.4
8.7	11.2
8.9	13.2
9.1	16.9
9.3	22.0
9.5	28.6
9.7	37.5
9.9	39.1

Figure 5. Screenshot of collected data from Arduino IDE

This screenshot is from the Arduino IDE, the application used to program the Arduino device. The Arduino IDE allows users to write and upload code to the Arduino easily, enabling data collection from the external environment. In this case, the serial communication feature is activated using the command 'Serial.begin (9600)', allowing the Arduino to send data back to the computer. Before uploading the code to the Arduino, it is first checked for errors by clicking the "verify" icon in the top left of the Arduino IDE. Once verified, the code is uploaded, and the serial monitor can be used to display data. In this study, the sensor's distance values and the corresponding time are printed on the serial monitor in real-time. The time intervals for data collection are set to 0.2 seconds (200 ms) using the 'delay (200)' command. The recorded time and distance values for the block's movement with acceleration are displayed on the serial monitor, as seen in Figure 5. These values are then transferred to Excel for further analysis. The equation that describes the position of an object moving with constant acceleration as a function of time is a quadratic polynomial. This equation is commonly expressed as:

$$x(t) = at^2 + bt + c \qquad [4]$$

In this context, a, b, and c represent the constants of motion in the quadratic equation. By plotting a position-time graph, these constants can be determined. The resulting graph and equation, as shown in Figure 6, illustrate the relationship between position and time, confirming that the motion follows a quadratic pattern,

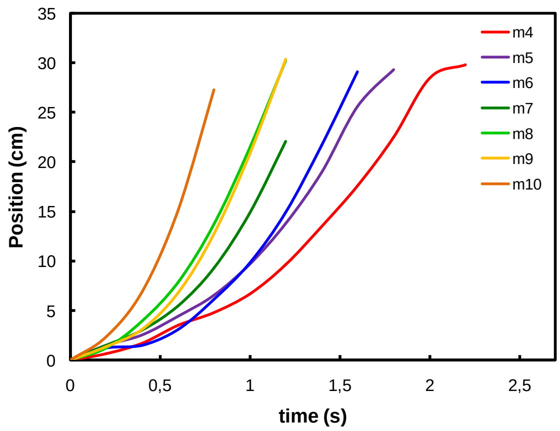

Figure 6. The position versus time graph for AA60 sandpaper

The graph above displays the motion of the block with added loads, ranging from the fourth experiment (m_4) to the tenth experiment (m_{10}). In the first three experiments (m_1 to m_3), the block did not move or experience any acceleration, meaning the position x remained constant at 0. Since the block didn't move, both speed and acceleration were also

10.21107/jps.v12i1.27762 Hartono & Prima E-ISSN: 2527-7634

0. For the experiments where the block did move with constant acceleration, such as in the 4th experiment, the data was analyzed using Excel. From this analysis, the position equation with respect to time was derived. For example, in the 4th experiment, the equation for the block's position as a function of time is:

$$x = 5{,}81t^2 + 1{,}62t - 0{,}02 \qquad [5]$$

This equation shows how the position x changes over time t, with the quadratic term indicating the constant acceleration experienced by the block. Next, the position-time equation x is derived with respect to time t to determine the velocity equation. By taking the first derivative of the position-time equation, we can find how the block's velocity changes over time. Using this method, the velocity-time equation is derived as follows:

$$v = \frac{dx}{dt} = 11{,}62t + 1{,}62 \qquad [6]$$

The first derivative of the velocity-time equation with respect to time gives the acceleration. Since the motion occurs with constant acceleration, the acceleration remains the same over time.

$$a = \frac{dv}{dt} = 11{,}62 \qquad [7]$$

In this case, the acceleration is 11,62 cm/s². This value is then used to calculate the kinetic friction coefficient between the block and the table. By applying this constant acceleration, the kinetic friction coefficient can be determined, and for this case, it is calculated as follows:

$$\mu_k = \frac{0{,}190.9{,}8 - (0{,}425 + 0{,}190)0{,}01162}{0{,}425.9{,}8} = 0{,}43 \qquad [8]$$

Meanwhile, the value of the static friction coefficient is determined by comparing the load masses m_2 and m_1. This comparison helps identify the point at which the block begins to overcome static friction and start moving. Based on this analysis, the static friction coefficient is calculated as follows:

$$\mu_s = \frac{0{,}190}{0{,}425} = 0{,}45 \qquad [9]$$

This step is carried out for each experiment conducted. For one type of sandpaper, data is collected from ten experiments by varying the added mass on m_2. The graph in Figure 6 illustrates that adding mass to the block as it begins to move causes an increase in the acceleration value. This can be seen in the graph from the fourth experiment to the tenth experiment. The acceleration values for each of these experiments can be found in Table 1.

Table 1. Experimental friction data of AA60 sandpaper with the table surface

No	m_1 (g)	m_2 (g)	x (cm)	v (cm/s)	a (cm/s^2)	μ_s	μ_k
1	0,425	0,170	0	0	0	0,40	-
2	0,425	0,180	0	0	0	0,42	-
3	0,425	0,185	0	0	0	0,44	-
4	0,425	0,190	$x = 5{,}81t^2 + 1{,}62t - 0{,}02$	$v = 11{,}62t + 1{,}62$	11,62	0,45	0,43
5	0,425	0,195	$x = 8{,}44t^2 + 1{,}37t + 0{,}38$	$v = 16{,}88t + 1{,}37$	16,88	0,46	0,43
6	0,425	0,200	$x = 13{,}60t^2 - 4{,}14t + 0{,}69$	$v = 27{,}20t - 4{,}14$	27,20	0,47	0,43
7	0,425	0,205	$x = 15{,}36t^2 - 0{,}68t + 0{,}46$	$v = 30{,}72t - 0{,}68$	30,72	0,48	0,44
8	0,425	0,215	$x = 19{,}82t^2 + 1{,}39t + 0{,}06$	$v = 39{,}64t + 1{,}39$	39,64	0,51	0,44
9	0,425	0,220	$x = 23{,}04t^2 - 2{,}64t + 0{,}35$	$v = 46{,}08t - 2{,}64$	46,08	0,52	0,44
10	0,425	0,225	$x = 41{,}61t^2 + 0{,}46t + 0{,}17$	$v = 83{,}22t + 0{,}46$	83,22	0,53	0,40

10.21107/jps.v12i1.27762 Hartono & Prima E-ISSN: 2527-7634

The same steps were followed using AA240, AA400, and AA600 sandpapers. In each experiment, the position versus time graphs for the object were obtained as follows:

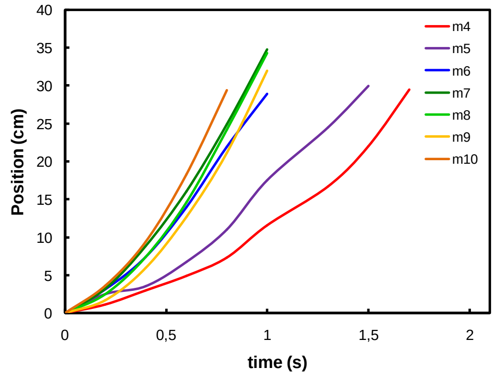

Figure 7. The position versus time graph for AA240 sandpaper

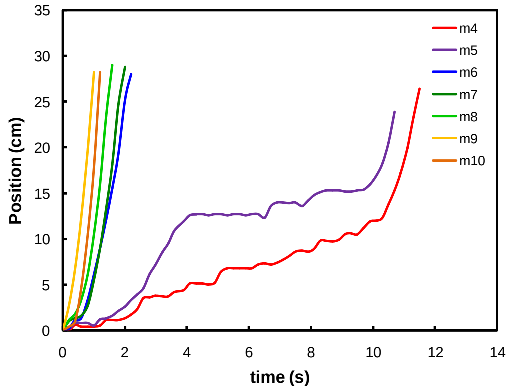

Figure 8. The position versus time graph for AA400 sandpaper

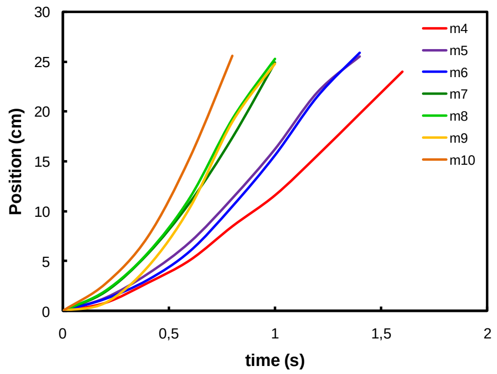

Figure 9. The position versus time graph for AA600 sandpaper

Table 2. Experimental friction data of AA240 sandpaper with the table surface

No	m_1 (g)	m_2 (g)	x (cm)	v (cm/s)	a (cm/s^2)	μ_s	μ_k
1	0,442	0,220	0	0	0	0,50	-
2	0,442	0,230	0	0	0	0,52	-
3	0,442	0,240	0	0	0	0,54	-
4	0,442	0,245	$x = 8{,}56t^2 + 2{,}09t + 0{,}34$	$v = 17{,}12t + 2{,}09$	17,12	0,55	0,53
5	0,442	0,250	$x = 12{,}72t^2 + 3{,}99t + 0{,}26$	$v = 25{,}44t + 3{,}99$	25,44	0,57	0,52
6	0,442	0,255	$x = 15{,}13t^2 + 14{,}51t - 0{,}25$	$v = 30{,}26t + 14{,}51$	30,26	0,58	0,53
7	0,442	0,260	$x = 20{,}67t^2 + 14{,}53t - 0{,}21$	$v = 41{,}34t + 14{,}53$	41,34	0,59	0,51
8	0,442	0,265	$x = 25{,}36t^2 + 9{,}47t - 0{,}20$	$v = 50{,}72t + 9{,}47$	50,72	0,60	0,52
9	0,442	0,270	$x = 28{,}04t^2 + 4{,}11t - 0{,}10$	$v = 56{,}08t + 4{,}11$	56,08	0,61	0,52
10	0,442	0,275	$x = 32{,}32t^2 + 10{,}89t + 0{,}03$	$v = 64{,}64t + 10{,}89$	64,64	0,62	0,52

Table 3. Experimental friction data of AA400 sandpaper with the table surface

No	m_1 (g)	m_2 (g)	x (cm)	v (cm/s)	a (cm/s^2)	μ_s	μ_k
1	0,437	0,210	0	0	0	0,48	-
2	0,437	0,220	0	0	0	0,50	-
3	0,437	0,230	0	0	0	0,53	-
4	0,437	0,240	$x = 0{,}12t^2 + 0{,}16t + 1{,}00$	$v = 0{,}24t + 0{,}16$	0,24	0,55	0,55

10.21107/jps.v12i1.27762 Hartono & Prima E-ISSN: 2527-7634

5	0,437	0,245	$x = 0{,}14t^2 + 3{,}22t - 1{,}35$	$v = 0{,}28t + 3{,}22$	0,28	0,56	0,56
6	0,437	0,250	$x = 5{,}82t^2 + 0{,}49t - 0{,}26$	$v = 11{,}64t + 0{,}49$	11,64	0,57	0,55
7	0,437	0,255	$x = 9{,}24t^2 - 3{,}98t + 0{,}68$	$v = 18{,}48t - 3{,}98$	18,48	0,58	0,55
8	0,437	0,260	$x = 11{,}38t^2 - 2{,}57t + 0{,}63$	$v = 22{,}76t - 2{,}57$	22,76	0,59	0,56
9	0,437	0,270	$x = 18{,}93t^2 + 9{,}39t$	$v = 39{,}86t + 9{,}39$	39,86	0,62	0,55
10	0,437	0,275	$x = 24{,}82t^2 - 7{,}22t + 0{,}35$	$v = 49{,}64t - 7{,}22$	49,64	0,63	0,55

Table 4. Experimental friction data of AA600 sandpaper with the table surface

No	m_1 **(g)**	m_2 **(g)**	x **(cm)**	v **(cm/s)**	a **(cm/s^2)**	μ_s	μ_k
1	0,425	0,150	0	0	0	0,35	
2	0,425	0,160	0	0	0	0,38	
3	0,425	0,170	0	0	0	0,40	
4	0,425	0,180	$x = 5{,}82t^2 + 6{,}11t - 0{,}37$	$v = 11{,}64t + 6{,}11$	11,64	0,42	0,41
5	0,425	0,185	$x = 7{,}59t^2 + 8{,}62t - 0{,}50$	$v = 15{,}18t + 8{,}62$	15,18	0,44	0,41
6	0,425	0,190	$x = 9{,}73t^2 + 5{,}71t - 0{,}33$	$v = 19{,}46t + 5{,}71$	19,46	0,45	0,42
7	0,425	0,195	$x = 14{,}91t^2 + 5{,}83t + 0{,}19$	$v = 29{,}82t + 5{,}83$	29,82	0,46	0,41
8	0,425	0,200	$x = 16{,}25t^2 + 10{,}04t - 0{,}34$	$v = 32{,}50t + 10{,}04$	32,50	0,47	0,42
9	0,425	0,210	$x = 20{,}09t^2 + 6{,}28t - 0{,}61$	$v = 40{,}18t + 6{,}28$	40,18	0,49	0,43
10	0,425	0,220	$x = 32{,}68t^2 + 5{,}81t + 0{,}05$	$v = 65{,}36t + 5{,}81$	65,36	0,52	0,42

From the four experiments conducted, the average static and kinetic friction coefficients were calculated. The data for the static and kinetic friction coefficients obtained are as follows:

Table 5. The static and kinetic friction coefficient from the experiment results

No	**Surface**	**Static Friction Coefficient**	**Kinetic Friction Coefficient**
1	Sandpaper AA60 - Table	0,561 ± 0,015	0,430 ± 0,005
2	Sandpaper AA240 - Table	0,568 ± 0,013	0,521 ± 0,003
3	Sandpaper AA400 - Table	0,561 ± 0,015	0,553 ± 0,002
4	Sandpaper AA600 - Table	0,438 ± 0,016	0,417 ± 0,003

The data in the table demonstrate the intriguing variability of friction coefficients. The static friction coefficient consistently exceeds the kinetic friction coefficient. When the static friction coefficients are arranged from largest to smallest, they follow this order: AA240 sandpaper > AA60 sandpaper > AA400 sandpaper > AA600 sandpaper. Similarly, the kinetic friction coefficients follow a distinct order: AA400 sandpaper > AA240 sandpaper > AA60 sandpaper > AA600 sandpaper. However, the friction coefficient values for each type of sandpaper cannot be generalized based solely on roughness level. This is due to several factors, including the varying masses of the wooden blocks used in each experiment, which affect the frictional forces involved, and the wearing down of the table surface by the sandpaper during multiple repetitions of the experiments. Moreover, the coefficient of friction is also influenced by the surface area of the objects in contact (Amirudin et al., 2018).

This study's experimental results for both the static and kinetic friction coefficients align well with the theoretical values. These precise measurements were achieved using an Arduino and ultrasonic distance sensors. Arduino enhances the accuracy of observations (Yuliani et al., 2022). The distance measurements conducted using Arduino can be observed for short paths and events that occur briefly. Similar studies often use Arduino microcontrollers to ensure accurate data collection in physics experiments, highlighting the reliability and precision of these tools in measuring and analyzing physical phenomena (Çoban & Salar, 2023).

10.21107/jps.v12i1.27762 Hartono & Prima E-ISSN: 2527-7634

Conclusion

Based on the experiment results, the static friction coefficient is greater than the kinetic friction coefficient. This can be observed from the static and kinetic friction coefficient values obtained from all experiments. Furthermore, the roughness level of the sandpaper affects the values of both static and kinetic friction coefficients.

However, a generalized conclusion cannot be drawn from this experiment. The varying masses of the wooden blocks used in each experiment affect the frictional forces involved and the wearing down of the table surface by the sandpaper during multiple repetitions of the experiments. In further research, the variation in the mass of the wooden block can be adjusted to obtain a conclusion on the friction coefficient based on the sandpaper number. Moreover, the coefficient of friction is also influenced by the surface area of the objects in contact.

Therefore, further development of experiments to determine these coefficients using technologies such as Arduino and ultrasonic sensors can enhance efficiency and measurement accuracy. This practical lab development can also serve as an educational tool in schools to help students understand the effects of forces on objects, especially in the context of frictional forces.

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