THESIS

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Hungarian University of Agriculture and Life Sciences

Szent István Campus

Mechanical Engineering Course

EFFECT OF DIFFERENT FORCE AMPLITUDE VIBRATIONS TO FRICTION

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INSTITUTE OF TECHNOLOGY

INSTITUTE OF TECHNOLOGY MECHANICAL ENGINEERING (BSC)
Machine Production Technologies specialization

THESIS

worksheet for

Josefa Ucamba

(BSc) student

Entitled:

Effect of different force amplitude vibrations to friction

Task description:

Perform friction tests using different force amplitudes on a selected material. In my case I will use Polytetrafluoroethylene (PTFE) and High-density Polyethylene (PE HD 1000).

Department: Mechanical Engineering

Consultant: *PhD Ádám Sarankó Associate Professor,* MATE, Institute of Technology

Submission deadline: 03 day 05 month 2023.

Gödöllő, 27 day 04 month 2023.

Approved **Received**

(head of department) (host course leader) Josefa Ucamba (student)

As an independent consultant of the author of this thesis I hereby declare that the student took part in the planned consultations.

Gödöllő, 27 day 04 month 2023.

(Consultant)

Table of Contents

1. Introduction

According to Fridman and Levesque in 1959, vibration can be used to reduce friction significantly has been known since at least the 1950s. [1] Process vibration and friction are important process phenomena because the impact of vibrations can cause significant changes in the process. We know that vibration and friction are interrelated. Friction creates different forms of vibration, and vibration affects friction in concerning. During the last few decades, many studies have been done on the effect of vibration on friction. These studies show that friction can be reduced by tangential vibrations to the contact surface. The phenomenon of reduced friction during vibrations has been used in many technical fields for many years. The most important low frequency applications are vibratory compressors and plate compactors. [2] High frequency vibrations are used to reduce friction in metalworking, drawing, cutting and nanoscience equipment such as atomic force microscopes. In recent years, vibration has been used in oil drilling to reduce the friction between the drill string and the well wall. This idea was first proposed by Roper in 1983, but until recently several methods have been used to reduce friction based on this principle. The vibration technology has successively developed related drilling tools, and the vibration modes include axial vibration, torsional vibration and lateral vibration. For all these vibration applications, it is important to understand how friction depends on the vibration mode, frequency, and amplitude.

I chose materials such as PTFE and PE HD 1000 for their quality, the excellent properties and the countless advantages they present as the multiple applications both in industries and in our daily lives. PTFE commonly known as Polytetrafluoroethylene is one of the most useful materials in the plastics industry. They are practical, durable plastics, resistant to heat and external elements. It is a synthetic plastic with very good heat resistance (between -200 and 260°C). It is also highly resistant to exposure to chemical solvents, making it safe and easy to use. [3] PE HD 1000, commonly known as high density polyethylene, is a highly abrasion and impact resistant thermoplastic. Unlike low-density polyethylene, it is obtained using varying amounts of ethylene to obtain the molecular hardness that makes it resistant to high temperatures. It is a polymer used in the manufacture of plastic bottles, food containers and caps. This type of material is considered one of the most recommended materials for human use due to its long life, since it does not contain chemical components that affect health. [4]

1.1. Importance of work

Depending on the characteristics of the tribological contact condition, materials can behave very differently. Understanding what determines the behavior in the intended application is required in order to determine how something should be tested. The capacity to theoretically estimate the performance, durability, and frictional behavior of tools or mechanical components is severely constrained by the complexity of tribological contacts. By carefully examining contact surfaces, tribological testing aims to better understand the basic mechanisms that explain friction and wear behavior.

1.2. Objective of work

The fundamental objective of this work is to perform friction using different amplitudes of force on the selected material. In my case, I am using polymers as specimens. I set the radius of the sliding path, the sliding velocity, the normal direction force to fix values, and I investigated how the coefficient of friction is affected by the amplitude of normal vibration. I am using S235 as the disc and two different types of polymers as the pin. The specific objective is to fix input parameters to investigate only the variation of friction coefficient (output parameter) with the effect of amplitude on two types of material such as Polytetrafluoroethylene (PTFE), and High-density Polyethylene (PE HD 1000). For this, a pin-on-disc apparatus having the facility of vibrating the test samples at different amplitudes of vibration was designed and fabricated.

2. Literature Review

This chapter gives a description of polymers, their properties, materials used, industrial applications, what they are, how they are made, and how they are found in nature. Some important concepts such as polymerization, polycondensation, and polyaddition will be defined. I also describe vibration in machines, what it is, how to reduce vibration in milling and turning, the biggest challenges in friction-vibration interaction problems, and an overview. I also will define important concepts such as friction, lubrication, and wear.

2.1. Polymers

Polymers are substances made up of very large molecules called macromolecules, that consisting of many repeating subunits. They can be both synthetic and natural polymers and play an important role in everyday life due to their wide range of properties. Polymers are found in nature. The final natural polymers are deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) that represent life. Polymers natural or synthetic are made by polymerizing, many small molecules called monomers. Its high molecular weight gives it unique physical properties compared to other small molecule compounds, such as hardness, high flexibility, and a tendency to form amorphous semicrystalline structures rather than crystals. [5]

The term polymer comes from the Greek words (polus: meaning "many, much") and meros (meaning "part"). The term was coined by Jöns Jacob Berzelius in 1833, although the definition differs from the modern IUPAC (International Union of Pure and Applied Chemistry). Hermann Staudinger introduced the modern concept of polymers as large covalently linked molecular structures in 1920 and spent the next decade searching for experimental evidence of this hypothesis. They conduct research in the field of polymer science, including polymer chemistry, physics, biophysics, and materials science and engineering. Historically, products derived from the conjugation of repeating units via covalent chemical bonds have been the primary focus of polymer science. An important emerging field is now focusing on supramolecular polymers composed of non-covalent compounds. Polyisopropyl alcoholprene from rubber latex is an example of a natural polymer and polystyrene from Styrofoam is an example of a synthetic polymer. In a biological context, all biological macromolecules, proteins (polyamides), nucleic acids (polynucleotides), and sugars are pure polymers or consist primarily of polymeric components. [6] Natural polymers or biopolymers are polymers produced by the cells of living organisms, such as hemp, shellac, wool, silk, and natural rubber that have been used for centuries. There are many other natural polymers, such as cellulose, which is an important component of wood and paper. In case of synthetic polymer can be including polyethylene, polypropylene, polystyrene, polyvinyl chloride, synthetic rubber, phenolic, resin, neoprene, nylon, polyacrylonitrile, PVB, silicone resin and more. More than 330 million tons of these polymers are produced annually.

Polymerization: this is a chemical reaction, generally carried out in the presence of a catalyst, where identical or non-identical basic units, each containing one double bond, are linked together to form linear macromolecules. No by-products are produced. Examples: polyethylene, (PE) polystyrene (PS), polyvinylchloride (PVC).

Polycondensation: identical or different basic units, each having at least two reactive end-groups, are brought together. Low molecular weight by products such as water, alcohol, hydrochloric acid, are produced. Example: polycondensation of PA 66.

Polyaddition: chemical reaction between identical or different basic units, each having at least two reactive end-groups. No by products are produced. Example: polyurethane (PUR) and epoxides (PE). [7]

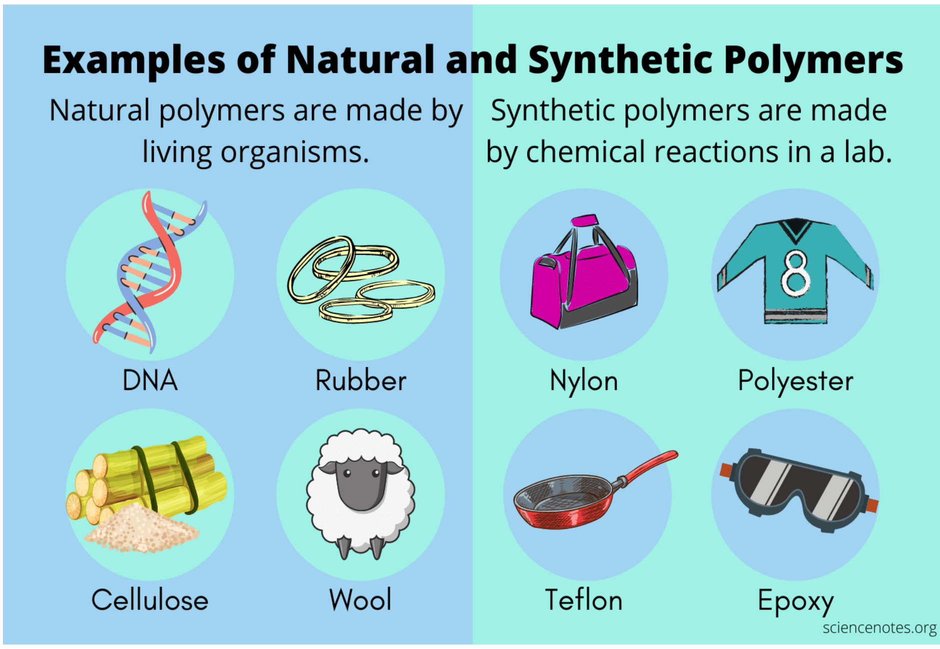

figure 2.1. Examples of natural polymers and their monomers (source:33)

2.1.1. PTFE

PTFE (Polytetrafluoroethylene), commonly known as Teflon, is a thermoplastic polymer polymerized from tetrafluoroethylene. PTFE has a very high degree of crystallinity, in the range of 92% to 98%, which is consistent with the unbranched structure. It has a high melting point of about 342°C, which indicates that PTFE has good thermal stability and has the best chemical and solvent resistance of any thermoplastic. PTFE is the best anti frictional material to operate without lubrication. It has a density in the range of 2.1 - 2.3 g/cm^3 and melt viscosity in the range of 1 -10 GPa per second. [8]

Some of the basic properties of PTFE make it an attractive material with high commercial value are: Excellent chemical resistance, good heat and low temperature resistance, good electrical insulation in hot and humid environments, low water absorption, low coefficient of friction and good fatigue resistance under low stress.

figure 2.1.1. PTFE (source:34)

PTFE has beneficial mechanical properties in its operating temperature range. The mechanical properties of PTFE are also affected by processing variables such as forming pressure, sintering temperature, cooling rate, etc. It has excellent electrical properties such as high insulation resistance and low dielectric constant macromolecule, it has an extremely low dielectric constant. Conventional PTFE has certain limitations in its application, such as: Inability to use traditional casting treatment methods and the difficulty and cost of suitable specific methods, susceptibility to creep and corrosion, large temperature changes (19 °C), difficulties of joining, corrosive material, easy to produce toxic fumes and low resistance to radiation. [9] PTFE is used in the food industries to produce on-stick and heat-resistant coatings on pots, and other kitchen and cuisine appliances like coffee makers, blenders, and indeed blin irons. In construction assiduity, it can serve effectively as an electrical insulator. Gas line pipes and hoses can also be made out of PTFE. Chemical manufacturing and processing diligence also use PTFE because of it is capability to transport sharp chemicals and accouterments. PTFE uses also extend to automotive industries due to its high-temperature resistance and thermal stability for machine corridors as well as vehicle surfaces. operations of PTFE in the automotive assiduity include gaskets, O- rings, valve stem seals, and shalt seals. PTFE is also part of particulars that are used regularly in medical assiduity similar to medical instruments and testing outfits, similar as sutures, catheters, and forceps. Solar panel manufacturing uses PTFE because it can regularly withstand temperatures as high as 260 degrees Celsius. PTFE has good light and UV resistance, and strong resistance to heat and cold waves. [10]

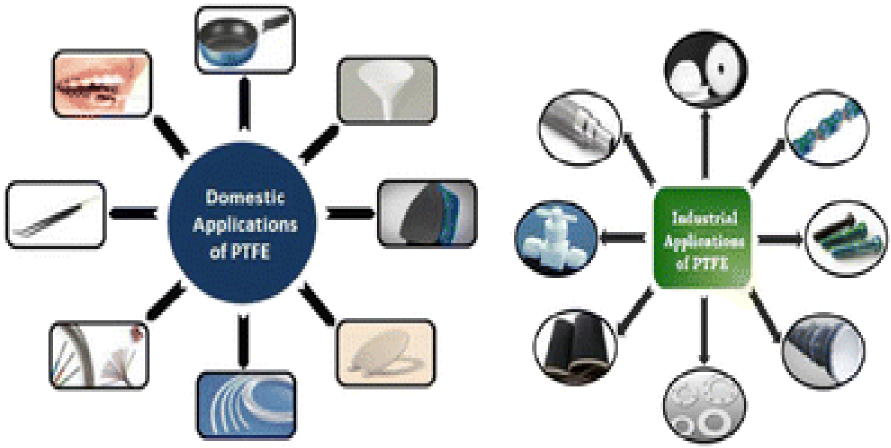

figure 2.1.1 Domestic and industrial applications of PTFE (source: 35)

2.1.2. PE HD 1000

PE HD 1000, also known as high-density polyethylene, is a thermoplastic material with high abrasion resistance and high impact resistance. It is obtained using varying amounts of ethylene to get the molecular hardness that makes it resistant to high temperatures, unlike low-density polyethylene. The density of PE HD ranges from 930 to 970 kg/m^3 and is a polymer used in the manufacture of bottles, plastic containers, and bottle caps. [11]

Due to its longevity, it is considered one of the most recommended products for human use because it does not contain chemicals harmful to health. The use of this type of material is very extensive, for applications that fall within the properties of other polymers, the choice to use HDPE is usually economic: 3D printer filament, arena board, backpacking frames, ballistic plates, banners, bottle caps, boats, chemical containers, chemical-resistant piping, coax cable inner insulator, conduit protector for electrical or communications cables, corrosion protection for steel pipelines, electrical and plumbing boxes, far-IR lenses, fireworks, folding chairs and tables, fuel tanks for vehicles, geomembrane for hydraulic applications, geothermal heat transfer piping systems, heat-resistant firework mortars, house wrap, microwave telescope windows, piping for fluid, slurry and gas purposes. [12]

figure 2.1.2 PE HD 1000 (source: 36)

2.1.3. Polymer vs Metal

On this page I will talk about polymers and metals, focusing on the important differences between both materials. Polymer is a macromolecular material with many repeating units linked together by covalent chemical bonds, while metals are pure elements or alloys. Therefore, they have different physical and chemical properties. The main difference between polymers and metals is that polymers are lighter, so they can be transported more easily and are cheaper to produce than metals. But metals have a shiny appearance and high thermal and electrical conductivity. In addition, polymer materials have a higher strength-to-weight ratio than metals. Another important difference between polymers and metals is also that metals are very flexible and malleable while most polymers are not. Materials worldwide are switching from metals to polymers to reduce environmental impact and reap various benefits. Polymeric materials can replace metals to make products that are safer and easier to recycle. In addition, they do not release harmful toxins or pollutants when used or discarded. This means that polymeric materials are a better choice for long-term sustainability. [13] There are several reasons why polymers are often used instead of metals: Polymer has high tensile strength, making it ideal for biomedical applications and automotive parts, they are used as electrical connectors, heat exchangers, water filters and many other industrial applications, polymers last much longer than metal and are less likely to pollute the environment, polymer has good heat and electrical resistance, effect of temperature on mechanical properties. [14]

2.2. Vibration in machines

Vibration is a mechanical phenomenon that occurs around the balance point. These oscillations can be periodic, like the swing of a pendulum, or random, like the movement of a tire on a dirt road. Vibration can indicate a problem that, if left unchecked, can cause damage, or accelerate deterioration. Vibration can be caused by one or more factors at any time, the most common being imbalance, misalignment, wear, and looseness. [15]

- Imbalance can be caused by manufacturing defects: machining errors, casting defects, or maintenance problems: deformed or dirty fan blades, missing balance weights.
- Misalignment: Vibration can occur when the machine shaft is misaligned. They can be created during assembly or can occur over time due to thermal expansion, component movement, or improper reassembly after maintenance. [16]
- Wear: In ths case components such as ball and roller bearings, drive belts and gears can cause vibration. [17]
- Looseness: If a vibrating component has loose bearings or is loosely attached to its mount, an otherwise unnoticed vibration becomes apparent and destructive. [18]

In a machine can be occur free vibration, forced vibration and resonance vibration in machining. [19]

Free vibration occurs when the first input initiates vibration in a mechanical system, which is then free to vibrate.

Forced vibration occurs when a time-varying disturbance is applied to a mechanical system.

Resonance vibration in machining: resonances in mechanical systems can lead to system failures. Vibration analysis therefore needs to predict when this type of resonance will occur and determine how to prevent it.

It is necessary to consider the respective steps to reduce vibration in milling:

- Select cutting edges with positive geometries.
- Choose smaller diameter cutters, especially when using stationary cutters.
- Select a smaller cutting radius.
- If there is vibration, do not reduce the feed per tooth.
- Reduces axial and radial cutting depth.
- Apply up-milling techniques. [20]

It is necessary to consider the respective steps to reduce vibration in turning:

- Select a basic tooling system and dimensions to maximize strength and stiffness.
- Carefully select insert type, size, and nose radius. Select the smallest possible tip radius, smaller than the depth of cut, when possible, to reduce passive cutting forces.
- Carefully select cutting data to minimize depth of cut. Use a feed that is at least 25% of the nose radius if there is a significant risk of vibration. Evaluate cutting speeds to avoid working in RPM ranges where the machine tool is less stable. [21]

2.2.1. Friction-vibration interactions

Modeling friction-vibration interactions is a complex multidisciplinary problem involving contact mechanics, tribology, and nonlinear dynamics at the nano, micro, and macro levels. The friction-vibration interaction problem is usually associated with time-varying boundary conditions and large spatial and temporal scales, as well as a wide frequency range from tens of Hertz to ultrasound. The effect of vibration on static friction force and friction force in sliding motion is well known and has been theoretically analyzed and used for decades. One of the biggest challenges in friction-vibration interaction problems is to create a proper system model that describes the system in terms of friction-vibration interaction effects. The most prominent are as follows: stick- slip due to difference between static and dynamic frictions, self- excited vibrations due to velocity- dependent friction with negative slope, modal couplings, non- smoothness, vibro- impact, random excitation, impact and sprag- slip. [22]

2.3. Tribology

Tribology is defined as the science and technology of the interaction of surfaces in relative motion and related subjects and practices (Standard DIN 50323). This science combines the knowledge acquired in various scientific fields such as chemistry, mechanics, physics, and materials science to predict and explain the physical behavior of mechanical systems. The phenomena that make up tribology existed before it was defined as a science. In other words, the study of the phenomenon of lubrication, friction, and wear. Tribology was formally identified by Peter Jost in 1966 as an important and unified technical field in a report of the British Education and Science Committee. [23]

Friction: The force that resists relative motion between two surfaces sliding against each other.

Lubrication: Can be defined as the application of certain substances between two objects in relative motion to enable smooth operation when necessary.

Wear: Loss of material or deformation of an object when there is relative movement between two continuous surfaces. [24]

Tribology operates in several areas, which are of extreme importance, such as Bio-tribology: the term "bio-tribology," which deals with the tribological characteristics of biological systems, was originally used by Dowson in 1970. These systems contain a wide variety of synthetic components as well as natural tissues like the heart, tendons, ligaments, cartilage, blood vessels, and skin.

Wind turbines: Using non-renewable energy sources like the wind, wind turbines are frequenly employed to generate electricity.

Automotive tribology: The efficiency of the engine is primarily impacted by a number of processes, including the bearing, piston ring, valve train, and crankshaft. Steel is the most often used material in the bearing industry. Industries manufacture a variety of bearing types, including thrust bearings, ball bearings, and roller bearings.[25]

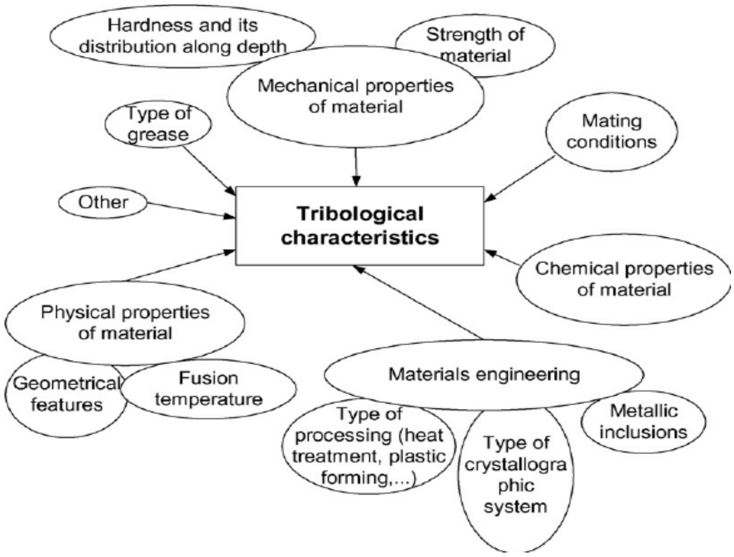

figure 2.3. Factors determining the wear and friction behavior (source: 37)

2.3.1. Friction as an area of tribology

Friction is a force that acts in the opposite direction to relative motion. Friction increases at the interface between bodies but can also develop within bodies. Friction is not a fundamental force, but a manifestation of electromagnetism and gravity. According to Halliday(1996), from the relationship between the friction force and the normal force, a dimensionless quantity called the coefficient of friction (μ) arises. The coefficient of friction always depends on the materials involved, and since it is an empirical quantity, its value is determined from experimental data. [26]

French physicist Guillaume Amontons in 1699 rediscovered the rules of friction after he studied dry sliding between two flat surfaces. He postulated three laws which is only applicable to dry friction:

- The force of friction is directly proportional to the applied load. (Amontons' 1st Law).
- The force of friction is independent of the apparent area of contact. (Amontons' 2nd Law).
- Kinetic friction is independent of the sliding velocity. (Coulomb's Law). [27]

2.3.2. Friction of polymers

The frictional behavior of polymers is very different from that of metals and ceramics. Due to their low modulus of elasticity and low resistance, they have a very low coefficient of friction.

The concept of coefficient of friction was first proposed by Leonardo da Vinci and was defined according to the following equation:

$$\boldsymbol{\mu = F_f / F_N}$$

Where: $\boldsymbol{F_f}$ is the friction force and $\boldsymbol{F_N}$ is the applied normal load.

There are also factors such as deformation agility, sliding speed and temperature that affect the tribological properties of polymers. [28]

Effect of normal load on asperity deformation: The increase in the normal load causes the large asperity deformation which results in a decrease in friction coefficient.

Effect of sliding velocity and temperature: In polymers, there are various materials that react differently with the sliding velocity and temperatures. In Viscoelastic materials, the increase in temperature causes deformation which is equivalent to a decrease in sliding velocities that affects the frictional behaviors. [29]

2.4. Tribology test (Pin-on-disc)

A tribometer is a device intended to measure tribological quantities such as friction force, friction coefficient, and wear volume between two surfaces in contact. Its origin dates to the 16th century. XVII was originally developed by Da Vinci. Tribometers are the basic technology used in most tribological investigations. [30]

The pin-on-disc method consists of bringing a pin close to a rotating disk, which will result in a wear track on the disk. The test intends to analyze the friction forces developed with different materials (in my case the material of the pin will be some kind of polymer and the disc will be made of metal) in contact, and for that, the diameter of the pin, the load applied to it and the relative position of the pin to the center of the disc are varied. On the disc, it is possible to change its rotation speed. [31]

Pin: cylindrical body composed of a certain material and it is also called the test body.

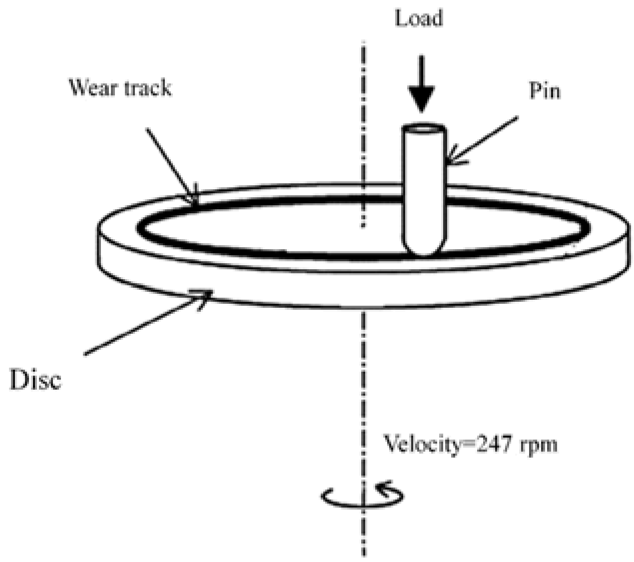

figure 2.4. Pin-on-disc testing schematics (source: 38)

Important parameters: The ASTM G99 standard highlights some relevant parameters for the pin-on-disc test that follow below:

- Load: Value of applied force in Newton [N]
- Sliding speed: speed of sliding between contacting surfaces in meters per second. [m/s]
- Distance: Distance traveled in meters. [m]
- Temperature: Temperature close to the contact.
- Atmosphere: Test environment (air, humidity, lubricant, etc.)

The purposes of tribological testing are: quality control, investigating real-life problems, solving real-life problems learning to apply tribological principles and research to extend fundamental understanding. [32]

3. Material and method

Small-scale tribotests were carried out at the Institute of Technology in the Mechanical Engineering department in Gödöllő on engineering plastic samples. In the experiments of this study, the tribological behavior of polymeric materials in dry sliding contacts was analyzed.

3.1. Characteristics of the Specimens

Cylindrical polymer specimens as the pin which measure 16 mm in length and 8 mm in diameter were used. They were Polytetrafluoroethylene (PTFE) and High-density Polyethylene (PE HD 1000). The accuracy of tribology testing is greatly improved by the high tolerance with which these materials may be made. PE HD 1000, also known as high-density polyethylene, is a thermoplastic material with high abrasion resistance and high impact resistance. The density of PE HD ranges from 930 to 970 kg/m^3 . It is obtained using varying amounts of ethylene to get the molecular hardness that makes it resistant to high temperatures, unlike low-density polyethylene. PTFE (Polytetrafluoroethylene), commonly known as Teflon, is a thermoplastic polymer polymerized from tetrafluoroethylene. PTFE has a very high degree of crystallinity, in the range of 92% to 98%. It has a high melting point of about 342°C, which indicates that PTFE has good thermal stability and has the best chemical and solvent resistance of any thermoplastic. PTFE is the best anti frictional material to operate without lubrication. It has a density in the range of 2.1 - 2.3 g/cm^3 and melt viscosity in the range of 1 -10 GPa per second. The PTFE and PE HD 1000 cylindrical specimens that were used in the pin-on-disc tests is seen in the following figure.

figure 3.1 PTFE and PE HD 1000 cylindrical specimens that were used in the pin-on-disc tests (source: MATE, Tribology lab)

3.2. Measurement of surface roughness

Surface roughness is a calculation of the relative smoothness of a surface's profile. The numeric parameter is Ra. The average roughness of a surface is Ra.

Rz is the difference between the tallest "peak" and the deepest "valley" on the surface.

We cannot use them at the same time Ra vs Rz. For example, it is like comparing inches to meters. They are not compatible. Use one or the other, not both.

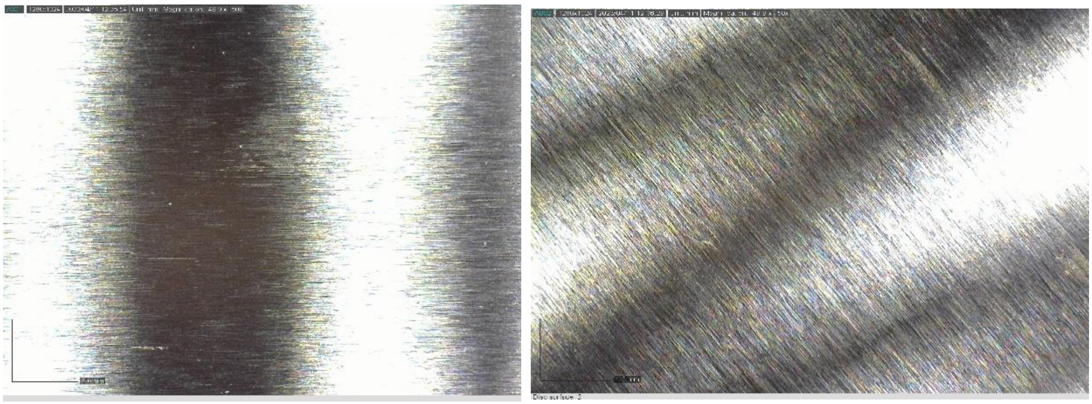

figure 3.2. Dine-lite Edge microscope pictures to observe both sides of the steel disc (Source: MATE, Tribology lab)

The average roughness (Ra) was 0.10-0.17 μm and this steel disc roughness was measured using Mitutoyo SJ-201P measuring device as seen in the following figure.

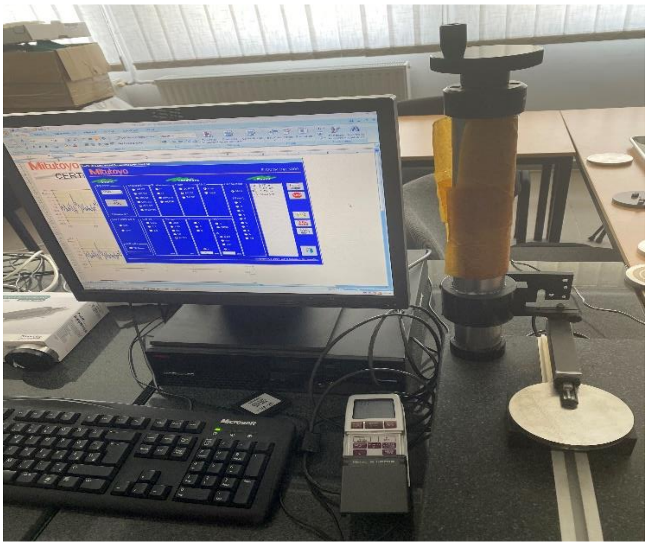

figure 3.2. Surface roughness measurement result process (source: MATE, Tribology lab)

3.2.1. Pin-on-disc tribometer

The tribological performance of polymer materials can be measured with this tribometer since it simulates and characterizes friction and wear behavior. During the test, both specimens' normal load and friction force are continuously measured. The polymer specimen is supported by a holder over the rotary steel disc. The force sensor on the load lever measures the applied load. The speed of the disc can be changed. The configuration of the Pin on the disc tribometer is shown in the following figure.

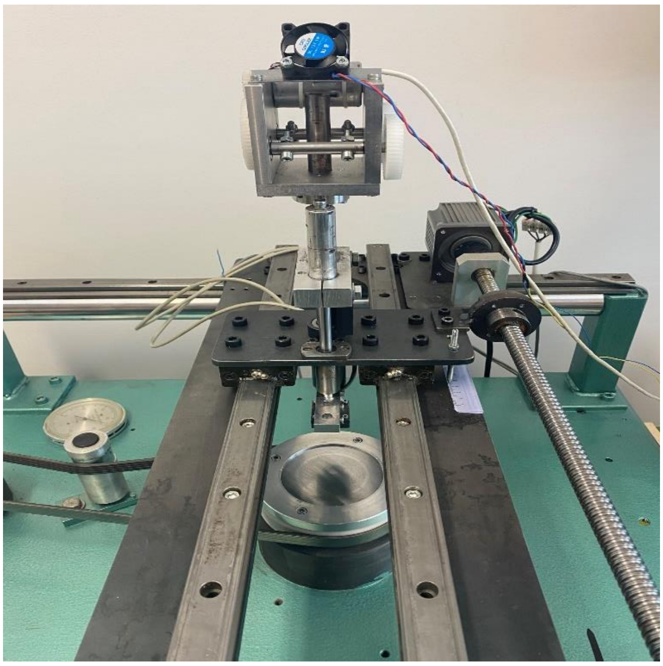

figure 3.2.1 Setup of pin-on-disc tribometer (source: MATE, Tribology lab)

3.2.2. Data collection

The radius of the pin route and the disc revolution, which were detected by sensors and continually monitored by a computer, was used to calculate the peripheral sliding speed. Friction forces were studied while the test was running. In order to transform the analog impulses into digital ones, which are subsequently sent to the computer, strain gauges on the force sensors and a Spider amplifier were wired together. The use of Catman software allowed for the representation of the digital signals in a chart-like format. During the measurements, the measuring frequency was set to 23 Hz.

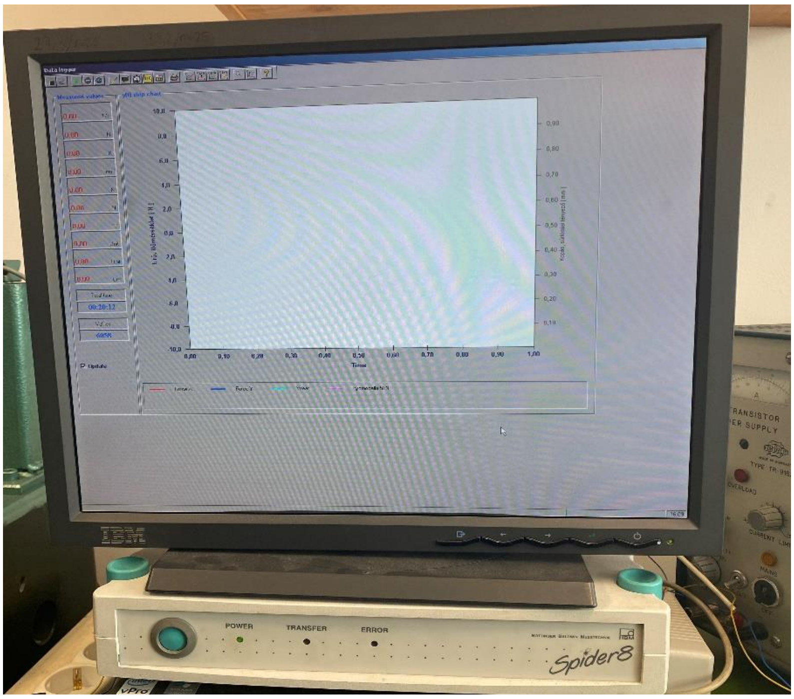

figure 3.2.2 Catman software where the necessary values for the calculation of the coefficient of friction and force amplitude vibration were collected (Source: MATE, Tribology lab)

3.2.3. Test procedure

Two test categories were used in the experiment: dry contact and low-frequency vibration addition, with a frequency value of 23 Hz. For testing purposes, a 21N external load and a 48 RPM rotational speed were applied to the steel disc. In order to get a better coefficient of friction result, the tests lasted 20 minutes. Three levels of testing have been performed on each test. To ensure better results each time the test begins, the steel disc surface and the specimen of polymers surface were re-machined and set up after each test. The vibration unit with a cooling fan was started, and the test lasted for 20 minutes. The resulting friction forces in the X and Y axes were recorded before each test, the two surfaces were machined, and cleaned with isopropyl alcohol. The testing process started by preparing the contact surfaces and subsequently setting up the polymer specimen in the holder against the steel disc.

3.2.4. Vibration unit

The vibration unit was put into the top of the system. The electric motor drives a little gear which drives a big gear and the big gear is connected to one shaft. At the end of the shaft, there is another gear and it also connects to another one and the ratio between the two gears is 1 and 1. If one of the shafts where are the two gears (the bigger and smaller) rotate for example 20

RPM, then the other shaft which also a bigger and smaller gears will rotate at 20 RPM, and because of the gear connection the 2 shafts will rotate in the opposite side and it will generate movement, so that is why it was added extra movement vibration on my measurements.

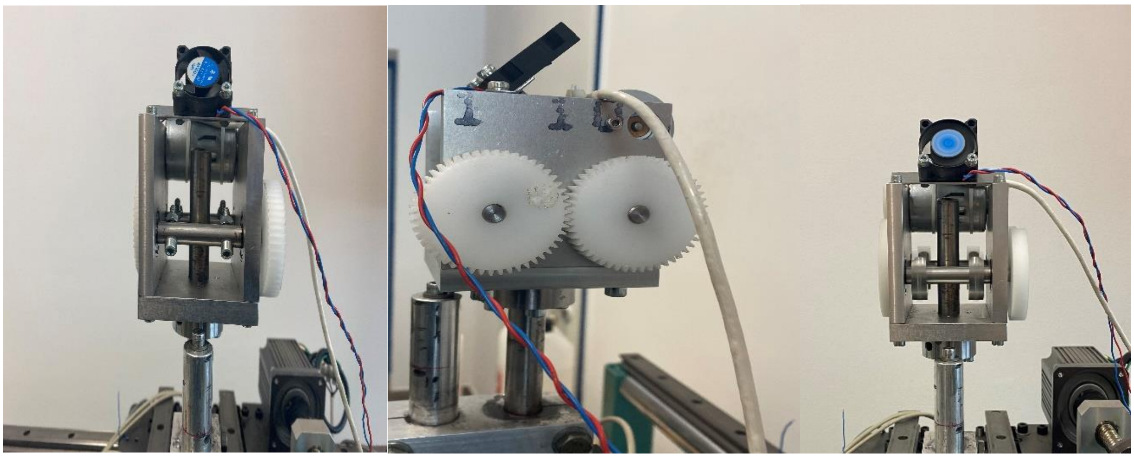

figure 3.2.4 Vibration unit (source: MATE, Tribology lab)

3.2.5. Measurements levels

I used 3 levels of vibration to measure the amplitude of the friction coefficient. The first level was zero because I just left the weight on the compression sensor force. In the second level, I put the vibration on top of the measuring system and started the vibration unit, but only with 4 screws (without weight) and it generated a very slight vibration. In the third level, I used the same frequency, but instead of only using the 4 screws I used mass (that was normal load because of the structure) and it generated a bigger amplitude force. I only used 3 levels because it is new research and I do not know if anybody ever investigated the effect of amplitude of the coefficient of friction. This topic is not for Bachelor students, it is higher than Bachelor's level.

3.2.6. Vibration load

In the case of vibration load, I measured it three times. Because the initial level was stationary, almost nothing happened. I just set the weight on the compression sensor force and examined the data, which indicated a normal load of 21N. The frequency of vibration was zero because there was no vibration. In the level 2 vibration load, the graph is not as visible as in level 3 because the difference in the force in Newton was so small or very close sensitive to the system sensor compression force. In this case, I zoomed it from 8 to 9 (x direction) and from 20 to 22 (y direction). In the level 2 vibration load, the amplitude force was 1.2N the normal force was 21 ± 0.6N and the frequency of vibration was 23 Hz.

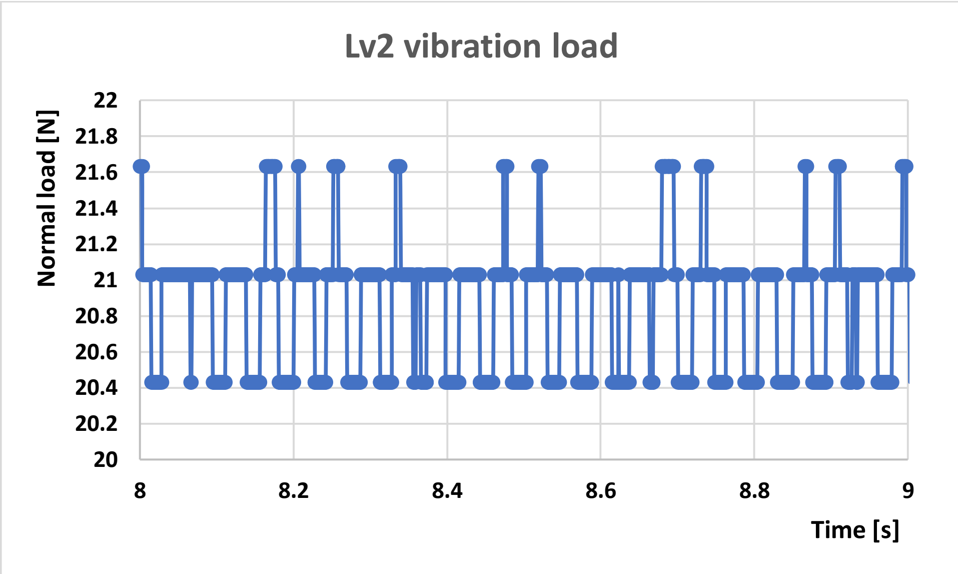

figure 3.2.6 Level 2 vibration load graph measured between 8 to 9 seconds to illustrate amplitude force in N (Source: Excel)

I showed below the level 3 vibration load graph but is not informative, because it generates 1200 lines per second (in Excel), which is why I showed the same graph and made zoom from 10 to 11 seconds (x direction) and from 12N to 32N (y direction). From these charges was possible to figure out the real value of amplitude force and the frequency of vibration which is the main goal of my task in the thesis. In the level 3 vibration load, the amplitude force was 20N, the normal force was 21 ± 10N, and the frequency of vibration was 23 Hz.

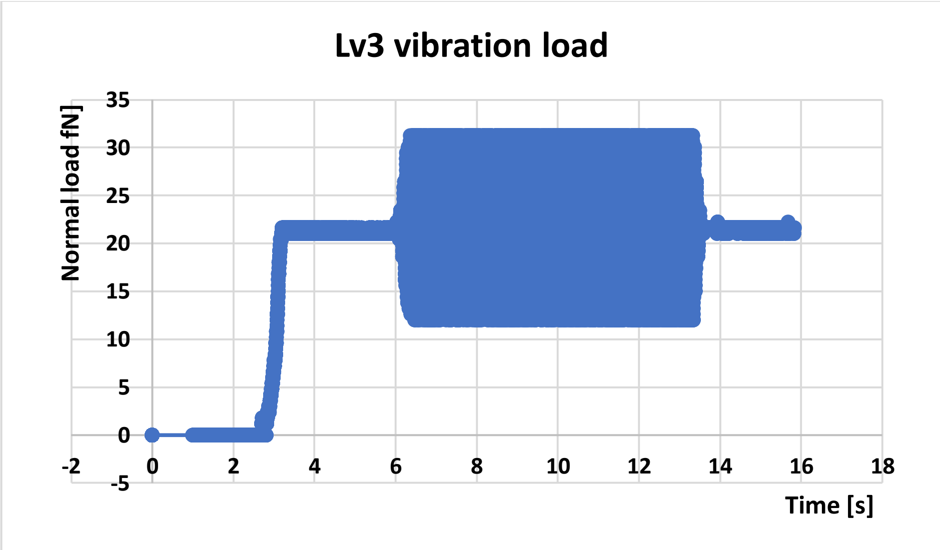

figure 3.2.6 Chart of vibration, the frequency sample rate was 1200 Hz just to measure the vibration effect (Source: Excel)

In the graph below, I have zoomed in on the x and y directions. It is possible to count the points, and this is how we can figure out the frequency value. The amplitude force is more visible between 10 and 11 seconds and 10N to 32N.

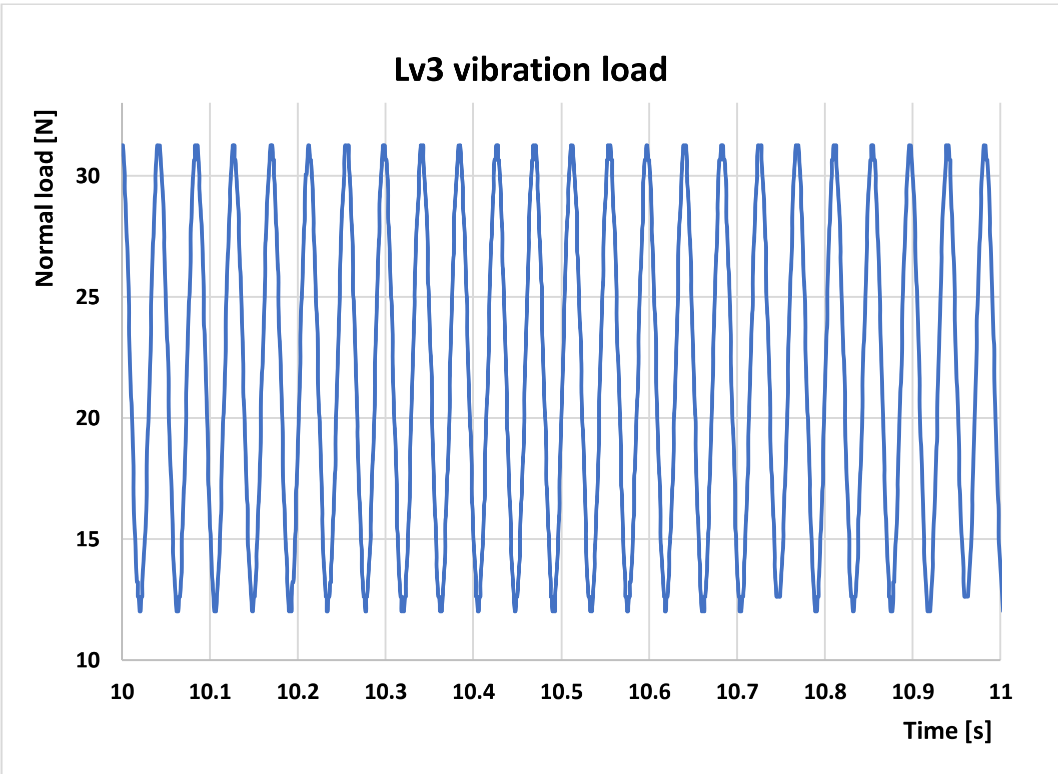

figure 3.2.6 Level 3 vibration load graph measured between 10 to 11 seconds to illustrate amplitude force in N (Source: Excel)

4. Results and Discussions

The findings of measurements taken in the Hungarian University of Agriculture and Life Sciences' Tribology Laboratory will be reported in this chapter. The main objective of this study is to fix input parameters to investigate only the variation of friction coefficient (output parameter) with the effect of amplitude on two types of material such as Polytetrafluoroethylene (PTFE), and High-density Polyethylene (PE HD 1000) against the S235 steel disc during dry sliding contact.

4.1. Friction coefficient

In this topic, the results will be presented in graphs illustrating the friction coefficient measured between an S235 steel disk rotating at 48 RPM and an external load of 21N in two different materials (PE HD 1000 and PTFE) with and without vibration being considered as level 1 (without vibration), level 2 (with additional vibration) and level 3 (with additional vibration and weight). With the software (Catman) I obtained all the necessary values and with the help of Excel I calculated the coefficient of friction that will be shown in this chapter, where I will make some comparisons of the behavior of the coefficient of friction for the two elements and at each level.

4.1.1. Level 1 comparative analysis results

During the study, a comparisopropyl alcoholn study was made between PE HD 1000 and PTFE at level 1.

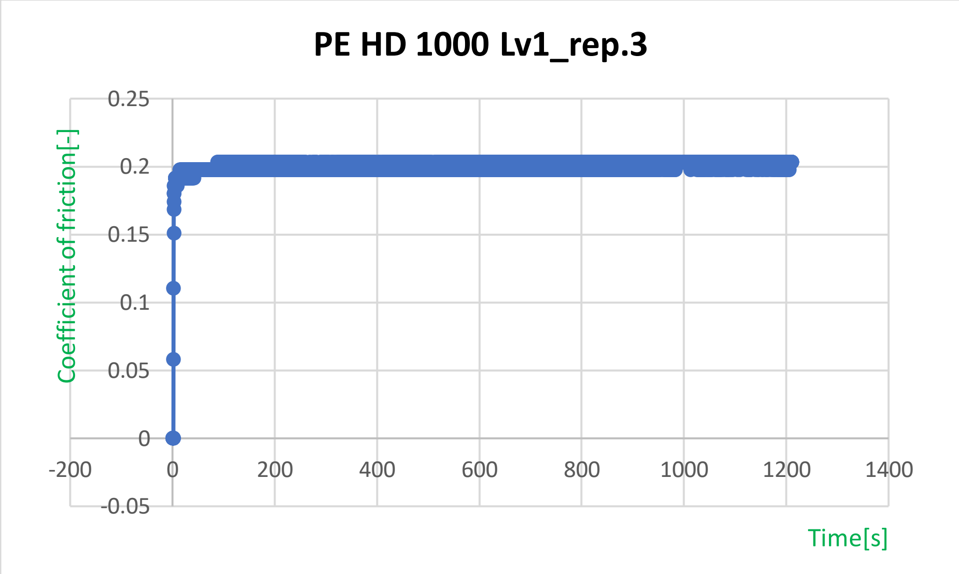

figure 4.1.1 Coefficient of friction in dry contact in the case of PE HD 1000 without vibration with an external load of 21N, 48 RPM, and 23 Hz during the third repetition (Source: Excel)

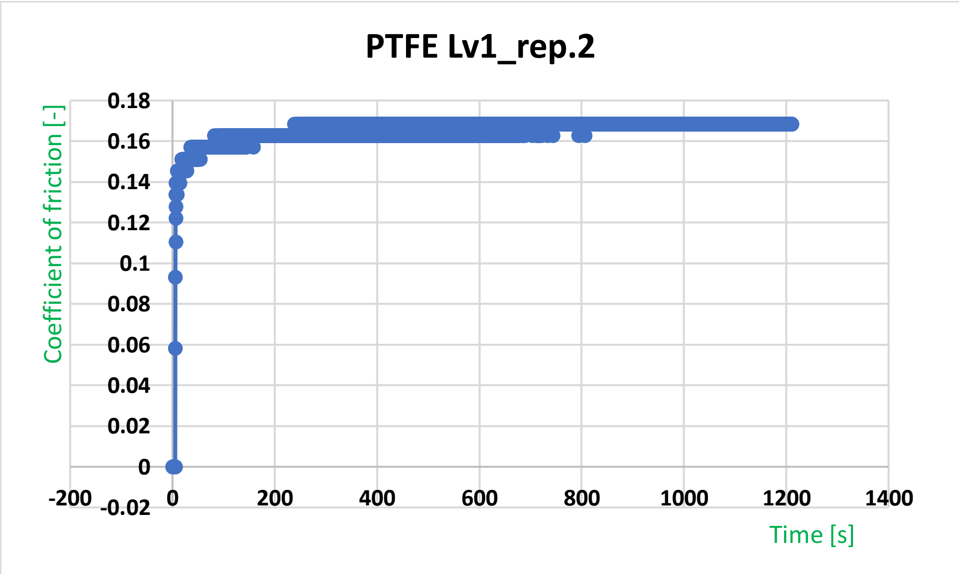

figure 4.1.1 Coefficient of friction in dry contact in the case of PTFE 1000 without vibration with an external load of 21N, 48 RPM, and 23 Hz during the second repetition (Source: Excel)

The coefficient of friction of the PE HD 1000 level 1 was higher than the friction coefficient of the PTFE level 1. The characteristic of the diagram was completely the same in the case of this level because no vibration was used, only the additional weight of the system. Because

PTFE has a lower value, in the case of dry sliding contact, PTFE had a better tribological value (best anti frictional material to operate without lubrication) compared to PE HD 1000.

4.1.2. Level 2 comparative analysis results

During the study, a comparisopropyl alcoholn study was made between PE HD 1000 and PTFE at level 2.

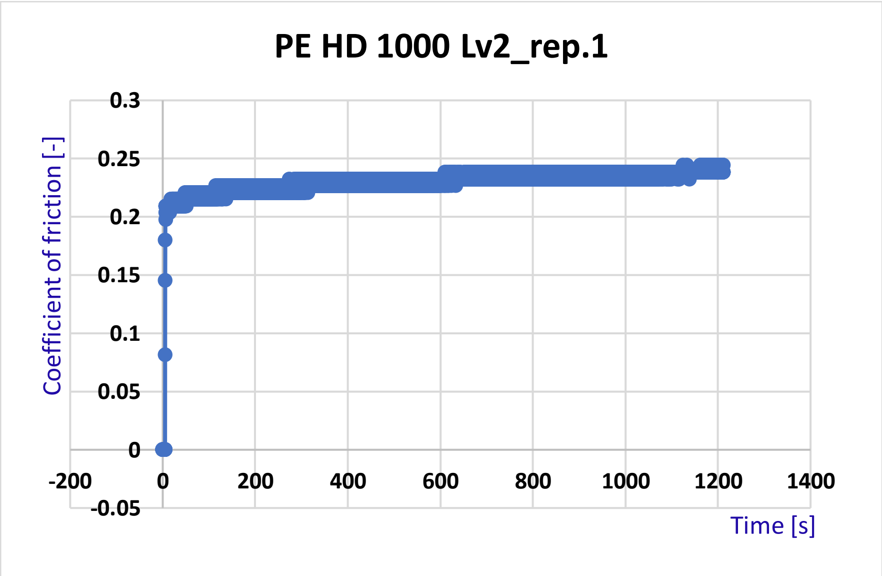

figure 4.1.2 Coefficient of friction in dry contact in the case of PE HD 1000 with vibration with an external load of 21N, 48 RPM, and 23 Hz during the first repetition (Source: Excel)

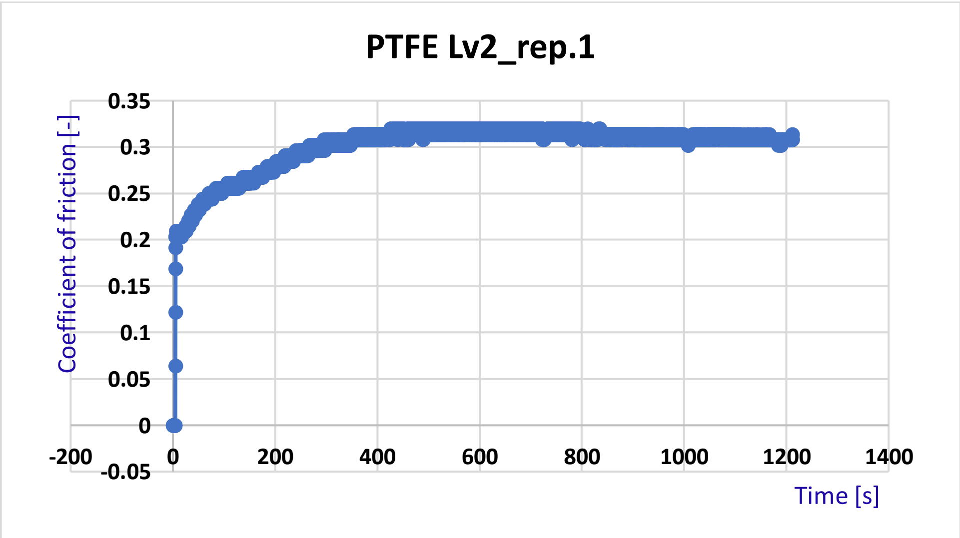

figure 4.1.2 Coefficient of friction in dry contact in the case of PTFE 1000 with vibration with an external load of 21N, 48 RPM, and 23 Hz during the first repetition (Source: Excel)

The coefficient of friction of PE HD 1000 level 2 was lower than the coefficient of friction of PTFE level 2. A vibration with low amplitude was added (without additional weight) and this caused a negative effect on PTFE level 2 in the case of dry sliding contact because of the amplitude force. In the case of PE HD 1000, the amplitude force also caused a negative effect but it was smaller compared with PTFE.

4.1.3. Level 3 comparative analysis results

During the study, a comparisopropyl alcoholn study was made between PE HD 1000 and PTFE at level 3.

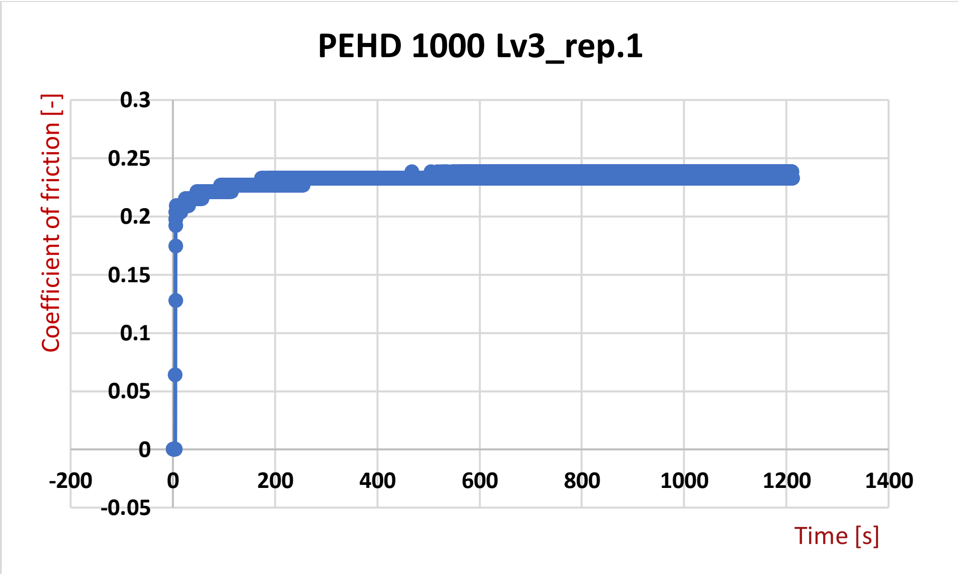

figure 4.1.3 Coefficient of friction in dry contact in the case of PE HD 1000 with vibration and with an external load of 21N, 48RPM, and 23Hz during the first repetition (Source: Excel)

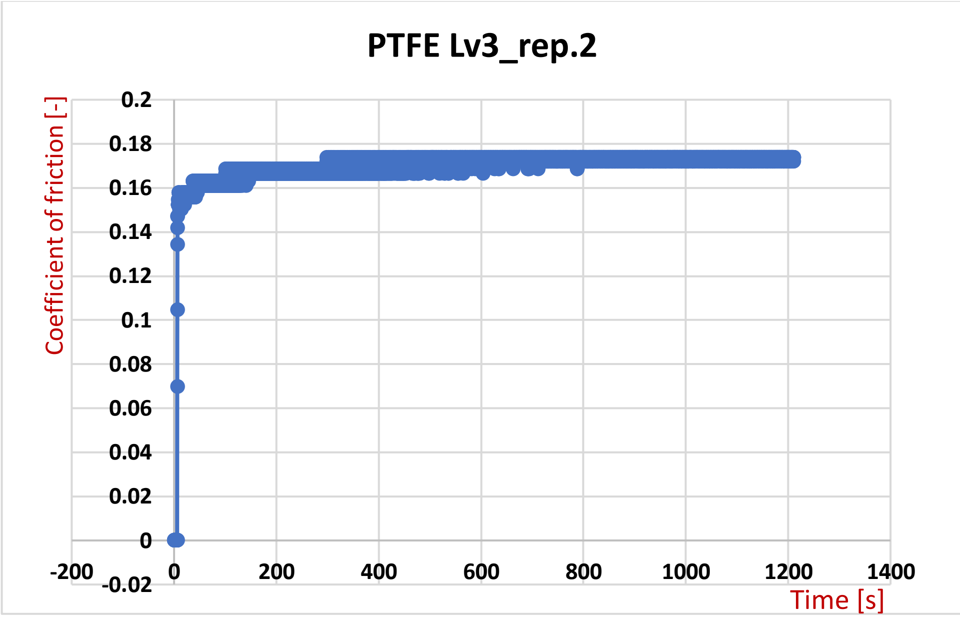

figure 4.1.3 Coefficient of friction in dry contact in the case of PTFE with vibration and with an external load of 21N, 48RPM, and 23Hz during the second repetition (Source: Excel)

The coefficient of friction of the PE HD 1000 level 3 was higher than the friction coefficient of the PTFE level 3. A vibration with low amplitude was added (with additional weight) in the case of the level 3. The characteristic of the diagram was completely the same in the case of this level because vibration was used, only of the system. Because PTFE has a lower value, in the case of dry sliding contact, PTFE had a better tribological value (best anti frictional material to operate without lubrication) compared to PE HD 1000.

4.2. Results of the comparative analysis of the PE HD 1000 in the 3 levels

- PE HD 1000 level 2 and level 3 both with additional vibration the maximum value of the coefficient of friction was the same (0.25).
- In the case of amplitude force for levels 3 and 2, the values were the following: 20N for amplitude force for level 3 and 1.2N for amplitude force for level 2.
- In the case of normal force for levels 3 and 2, the values were as follows: normal load was 21 ± 10N for level 3 and 21 ± 0.6N for normal load level 2.
- The characteristic of the diagram was completely the same in the case of 3 levels, even with added vibration or not, but the coefficient of friction of level 1 was better because it was lower than both levels (3 and 2).

- The amplitude vibration force for levels 2 and 3 significantly was not affected the coefficient of friction increasing only 0.05 in relation to level 1 (when no vibration was used). The maximum value of the coefficient of friction at level 1 was 0.2 and 0.25 at levels 2 and 3.

4.3. Results of the comparative analysis of the PTFE in the 3 levels

- PTFE level 2 with additional vibration the maximum value of the coefficient of friction was (0.31) and in the case of levels 1 and 3, it was 0.16. The coefficient of friction of level 1 and 3 was better, because it was lower than level 2.
- In the case of amplitude force for levels 3 and 2, the values were the following: 20N for amplitude force for level 3 and 1.2N for amplitude force for level 2.
- In the case of normal force for levels 3 and 2, the values were as follows: normal load was 21 ± 10N for level 3 and 21 ± 0.6N for normal load level 2.
- The characteristic of the diagram was completely the same in the case of levels 1 and 3, but the coefficient of friction of level 2 was higher, increasing from 0.2 to 0.31 and thereafter remaining constant. The maximum friction coefficients of both levels (1 and 3) were lower than the friction coefficient of level 2.
- The amplitude vibration force for level 2 significantly affected the coefficient of friction increasing by 0.15 compared to levels 1 and 3. The maximum value of the coefficient of friction at level 2 was 0.31 and 0.16 at levels 1 and 3.

5. Conclusions

In this final project for the course, tribological tests were conducted to examine the tribological behavior of two different polymeric materials (PE HD 1000 and PTFE) sliding against an S235 steel disc without lubrication. In order to figure out how the amplitude vibration levels affect the coefficient of friction values, some tests were carried out. The key findings were:

It was possible to demonstrate with tests that PTFE performs better in the dry sliding contact test in terms of tribological value.

Regarding the impact of amplitude force, PTFE and PE HD 1000 showed different behaviors. When a small amount of vibration was introduced, the coefficient of friction for PTFE greatly increased, almost two times the maximum value when a typical load of 0.6N was applied.

When a small vibration was added and a normal load of 10 N was applied, the effect of force amplitude for PTFE on the coefficient of friction for PE HD 1000 was very insignificant.

I also concluded that some of the basic properties makes PTFE an attractive material is the high commercial value such as: Excellent chemical resistance, good heat and low temperature resistance, good electrical insulation in hot and humid environments, low water absorption, low coefficient of friction and good fatigue resistance under low stress.

6. Resume

The increasing use of polymers as tribological materials in recent years, seeking to replace metals and other materials, has contributed to the development of new engineering polymers. Green (PE HD 1000) and white (PTFE) cylindrical polymer samples were used to carry out the study and test some parameters. The studies were divided into 3 different levels and for each level, the tests were repeated 3 times for each polymer and lasted 20 minutes. In the last two levels, low vibrations were used to study the behavior of the coefficient of friction when a normal load was applied. Level 1 was considered the stationary level, where no vibration was used. In this case, the vibration frequency was zero. In the second and third levels, low vibration was used and there was a variation in the coefficient of friction for each material, allowing a certain point to analyze in the graph the value of the coefficient friction, the total value of the amplitude force, which results from the difference of the maximum and minimum value.

7. Summary

I started this project work by giving a short introduction to the phenomenon of friction and vibration in the first chapter, describing how vibration affects friction, the studies done to reduce friction during vibration, and how vibration has been used to reduce friction in recent years. Still, in this chapter, I explained why I chose PTFE and PE HD 1000 as materials for the tests (for example, for their quality, the excellent properties, and the countless advantages they present as the multiple applications both in industries and in our daily lives). In chapter 1.1 I briefly described the importance of this work and the objective of the work in chapter 1.2. The fundamental objective of this work is to perform friction using different amplitudes of force on the selected material. In my case, I used polymers as specimens. I set the radius of the sliding path, the sliding velocity, the normal direction force to fix values, and I investigated how the coefficient of friction was affected by the amplitude of normal vibration. I used S235 as the disc and two different types of polymers as the pin. In the second chapter of this work, there is a literature review in which important sub-themes are divided, which allowed me to elaborate a more complete work. This chapter gives a description of polymers, their properties, materials used, industrial applications, what they are, how they are made, and how they are found in nature. Some important concepts such as polymerization, polycondensation, and polyaddition were defined. I also described vibration in machines, what it is, how to reduce vibration in milling and turning, the biggest challenges in friction-vibration interaction problems, and an overview. I also defined important concepts such as friction, lubrication, wear, tribology (the science and technology of the interaction of surfaces in relative motion and related subjects and practices (Standard DIN 50323). Also in this chapter, I made a small comparison between polymers and metals, focusing on the important differences between both materials. Polymer is a macromolecular material with many repeating units linked together by covalent chemical bonds, while metals are pure elements or alloys. The main difference between polymers and metals is that polymers are lighter, so they can be transported more easily and are cheaper to produce than metals. But metals have a shiny appearance and high thermal and electrical conductivity. In addition, polymer materials have a higher strength-to-weight ratio than metals. Another important difference between polymers and metals is also that metals are very flexible and malleable while most polymers are not. On the sub-theme about vibrations in machines, important concepts were defined such as imbalance, misalignment, wear, and looseness because these are some factors that can cause vibration in machines. In the last sub-themes in the literature review, I described what is tribometer that was originally developed by Da Vinci and explained the pin-on-disc method that consists consists of bringing a pin close to a rotating disk, which will result in a wear track on the disk. In the third chapter, I presented the materials and the method that was used to carry out the tests. Small-scale tribotests were carried out at the Institute of Technology in the Mechanical Engineering department in Gödöllő on engineering plastic samples. In the experiments of this study, the tribological behavior of polymeric materials in dry sliding contacts was analyzed. Surface of roughness was calculated and the alverage roughness was 0.10-0.17 μm. Also in the third topic, I presented the pin setup on the tribometer disk, how the collected data was made. Two test categories were used in the experiment: dry contact and low-frequency vibration addition, with a frequency value of 23 Hz. For testing purposes, a 21N external load and a 48 RPM rotational speed were applied to the steel disc. In order to get a better coefficient of friction result, the tests lasted 20 minutes. Three levels of testing have been performed on each test. A vibration unit was put into the top of system and the electric motor drives a small gear which drives a big gear and the big gear is connected to one shaft. 3 levels of vibration ws used to measure the amplitude of the friction coefficient. The first level was zero because it was stationary level. In the second level, I put the vibration on top of the measuring system and started the vibration unit, only with 4 screws.

In the third level, I used mass and it generated a bigger amplitude force. I only used 3 levels because it is new research and I do not know if anybody ever investigated the effect of amplitude of the coefficient of friction. In case of vibration load I measured it three times.

Not least, in the last chapters I presented the conclusions in chapter 5, resume in chapter 6, summary in chapter 7, references in chapter 8 and appendix in chapter 9. As conclusion, I figure out how the amplitude vibration levels affect the coefficient of friction values, some tests were carried out. The key findings were: It was possible to demonstrate with tests that PTFE performs better in the dry sliding contact test in terms of tribological value. Regarding the impact of amplitude force, PTFE and PE HD 1000 showed different behaviors. When a small amount of vibration was introduced, the coefficient of friction for PTFE greatly increased, almost two times the maximum value when a typical load of 0.6N was applied. When a small vibration was used and a normal load of 10 N was applied the effect of force amplitude for PTFE on the coefficient of friction for PE HD 1000 was very insignificant.

DECLARATION

on authenticity and public assess of final thesis

Student's name: Josefa Ucamba
Student's Neptun ID: TOG9JT
Title of the document: Effect of different force amplitude vibrations to friction
Year of publication: 2023
Department: Mechanical Engineering

I declare that the submitted final thesis is my own, original individual creation. Any parts taken from an another author's work are clearly marked, and listed in the table of contents.

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Student's signature

STATEMENT ON CONSULTATION PRACTICES

As a supervisor of Ucamba Josefa (T0G9JT), I here declare that the final thesis has been reviewed by me, the student was informed about the requirements of literary sources management and its legal and ethical rules.

I recommend/don't recommend the final thesis to be defended in a final exam.

The document contains state secrets or professional secrets: yes no

Place and date: 2023.05.01

Internal supervisor

8. References

In this chapter, I present the references that I had as a basis for the preparation of this course completion project. I chose to present the references in alphabetical order, just for the purpose of the organization.

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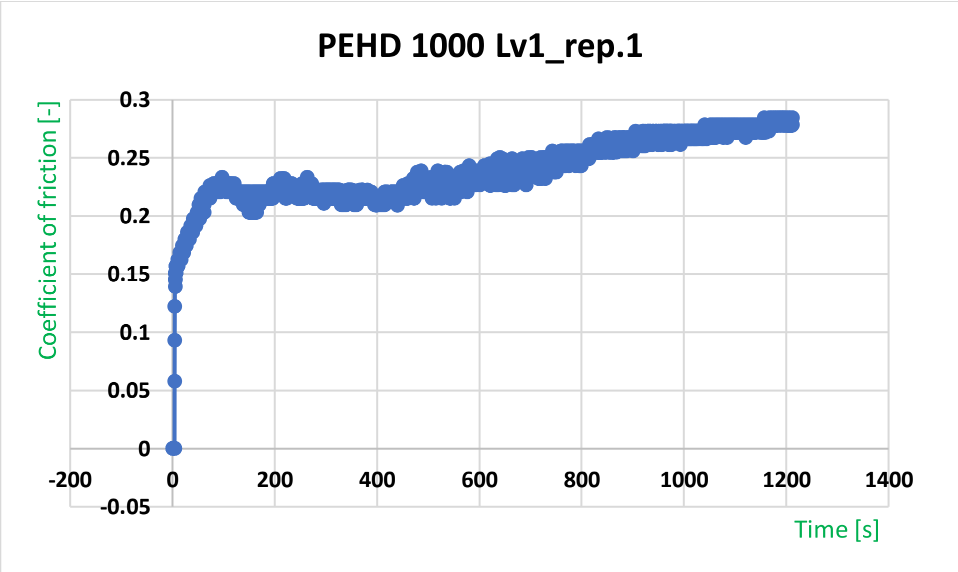
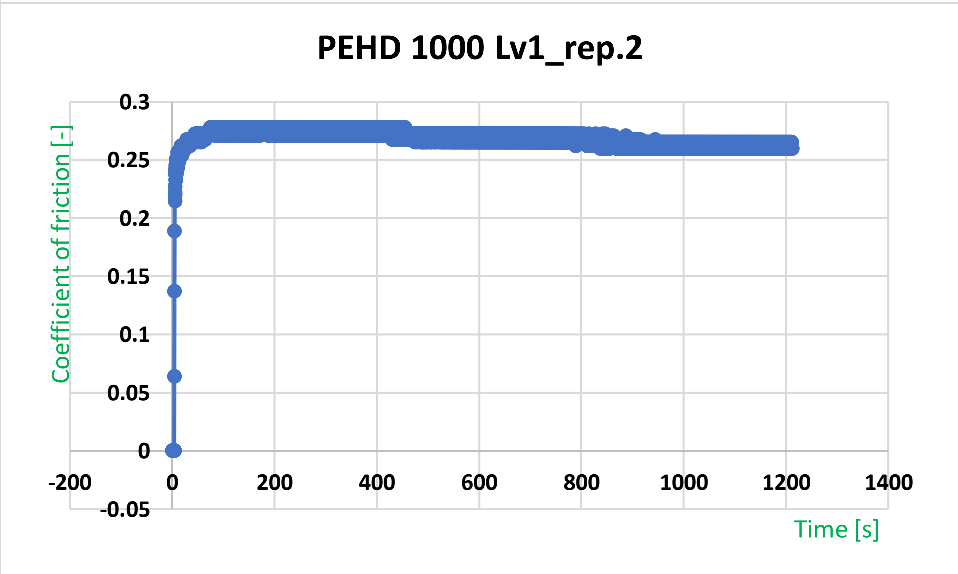
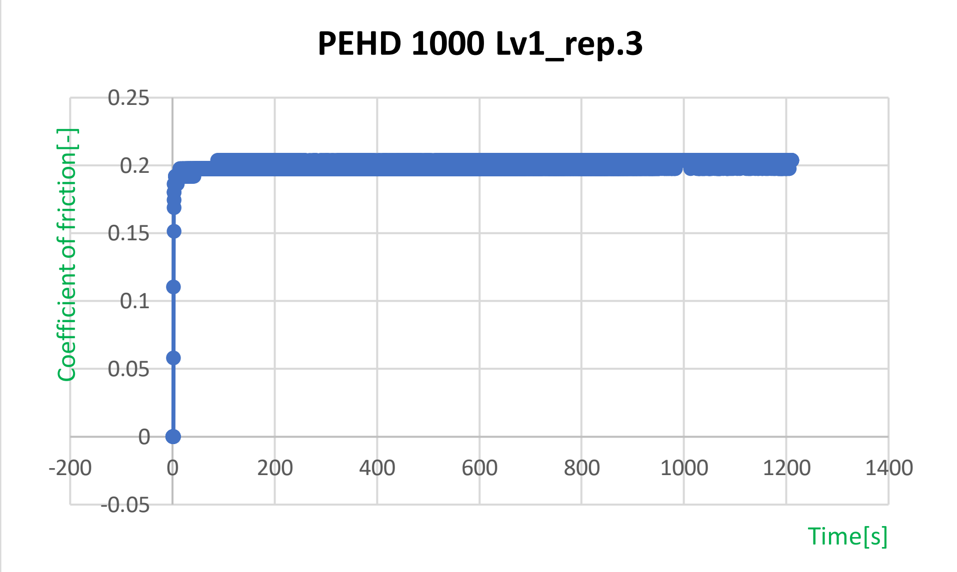
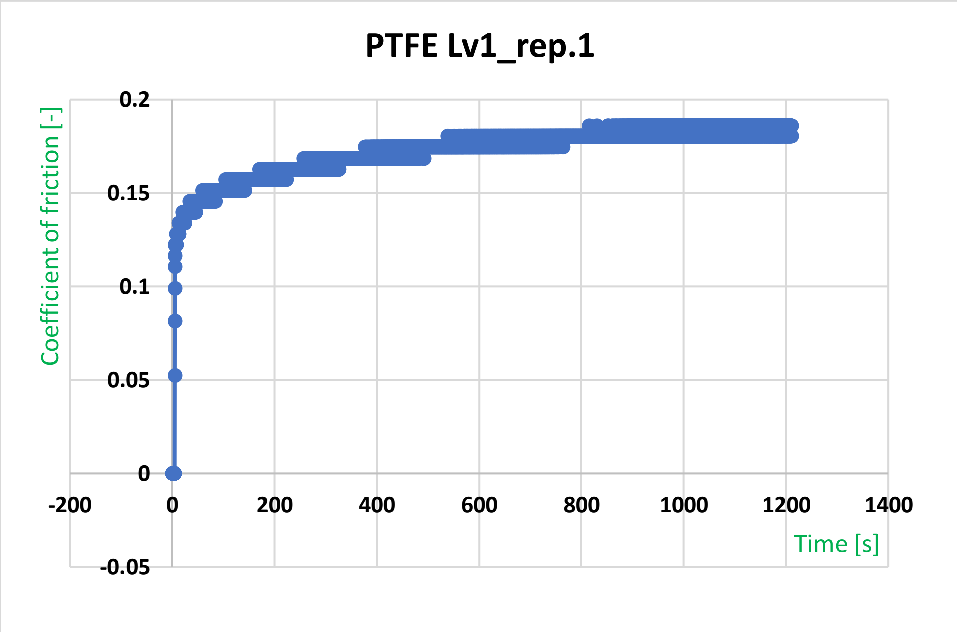
9. APPENDIX A

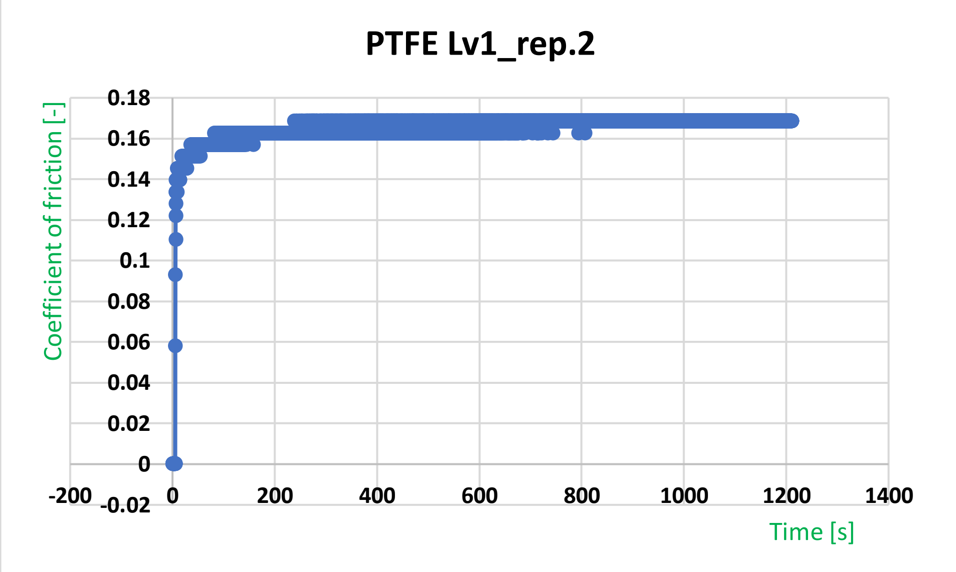
Coefficient of friction

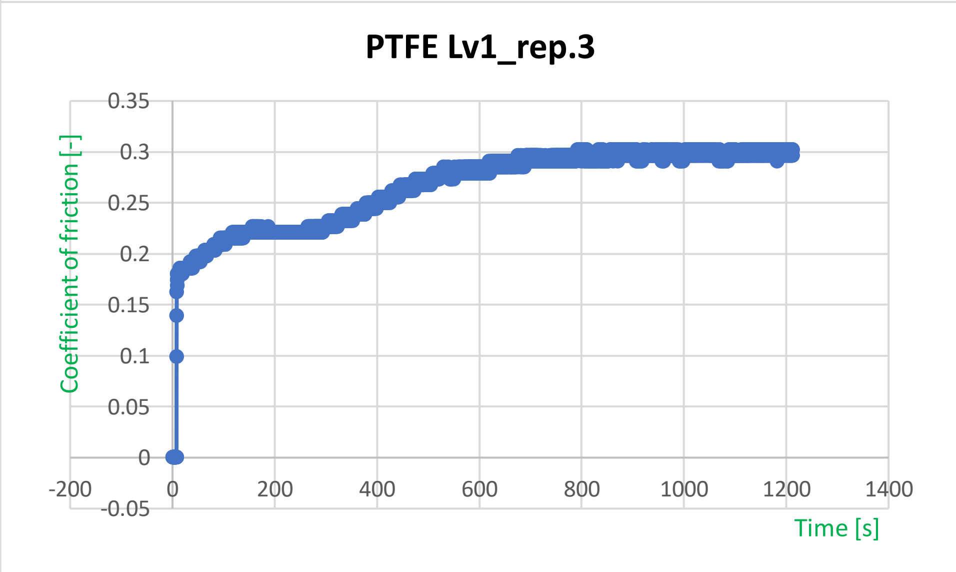


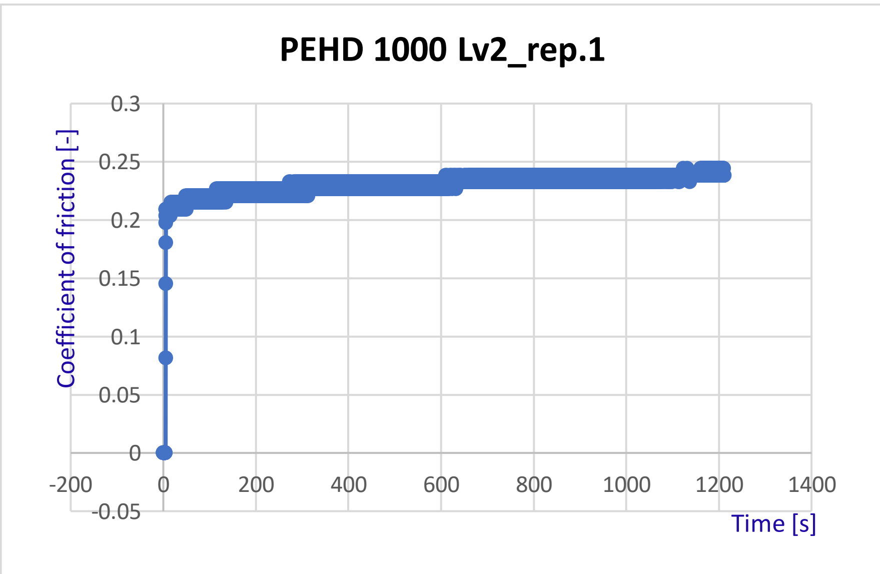


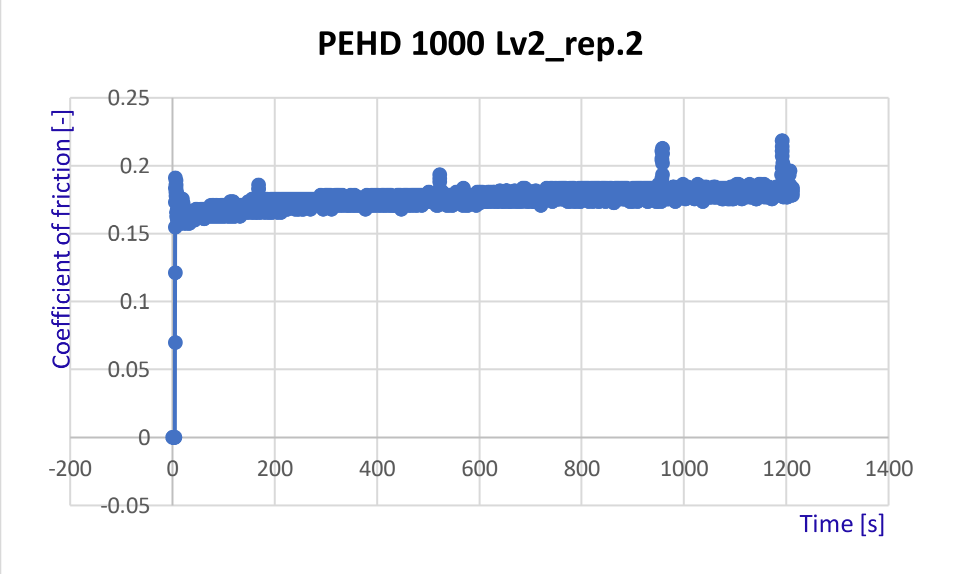

PEHD 1000 Lv1_rep.3
Coefficient of friction[-]
0.25
0.2
0.15
0.1
0.05
0
-0.05
-200
0
200
400
600
800
1000
1200
1400
Time[s]

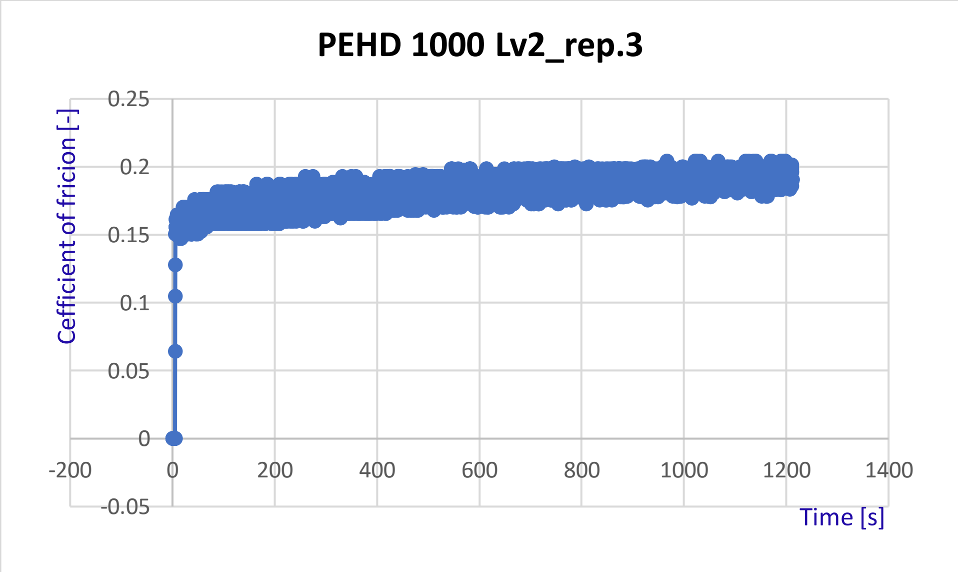

PTFE Lv1_rep.1
Coefficient of friction [-]
0.2
0.15
0.1
0.05
0
-0.05
-200
0
200
400
600
800
1000
1200
1400
Time [s]

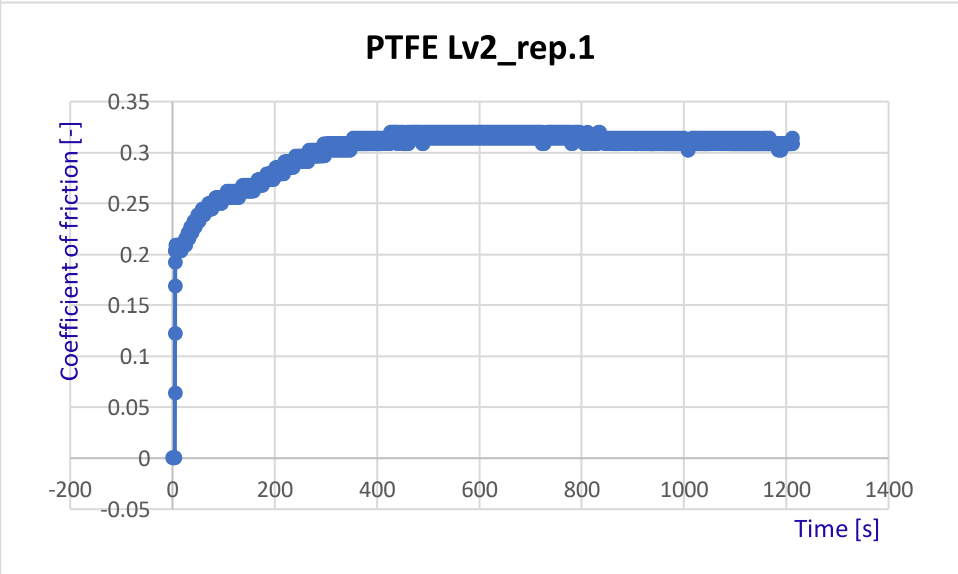

PTFE Lv1_rep.2
Coefficient of friction [-]
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-200
0
200
400
600
800
1000
1200
1400
Time [s]

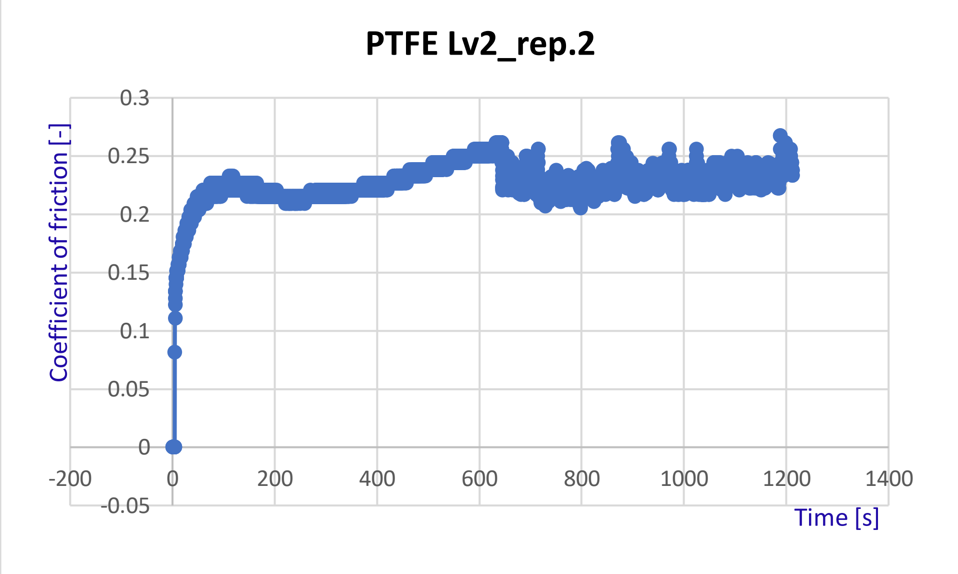

PTFE Lv1_rep.3
Coefficient of friction [-]
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-200
0
200
400
600
800
1000
1200
1400
Time [s]

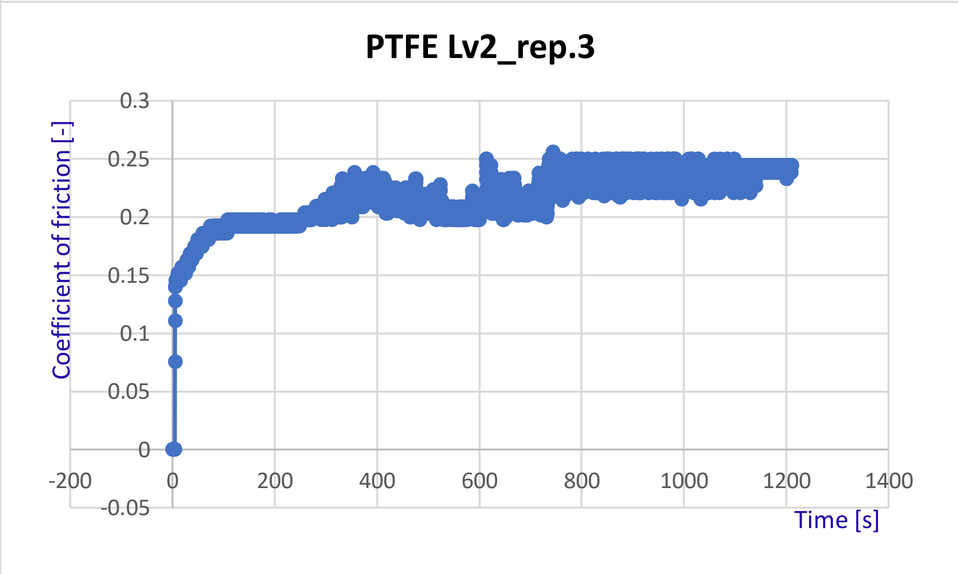

PEHD 1000 Lv2_rep.1
Coefficient of friction [-]
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-200
0
200
400
600
800
1000
1200
1400
Time [s]

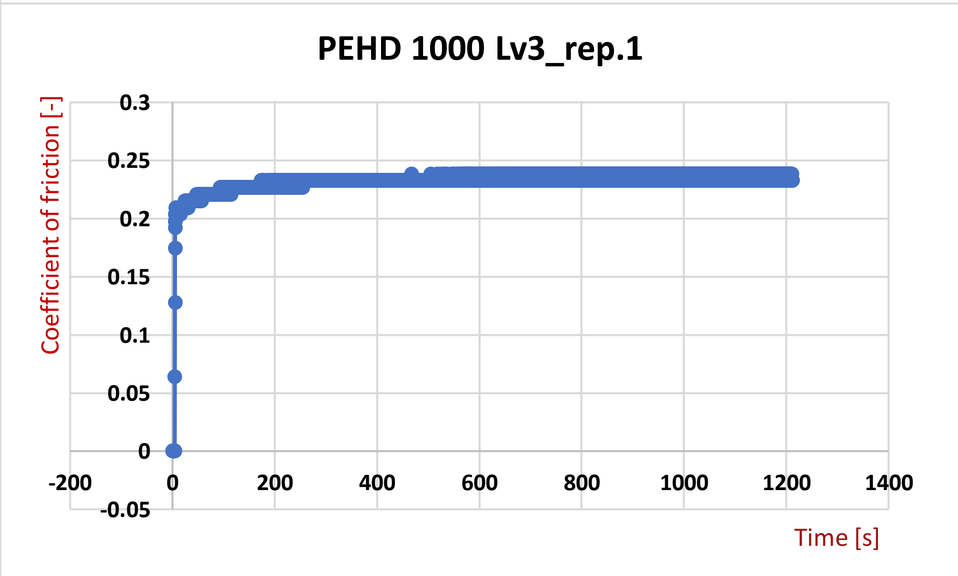

PEHD 1000 Lv2_rep.2
Coefficient of friction [-]
0.25
0.2
0.15
0.1
0.05
0
-0.05
-200
0
200
400
600
800
1000
1200
1400
Time [s]

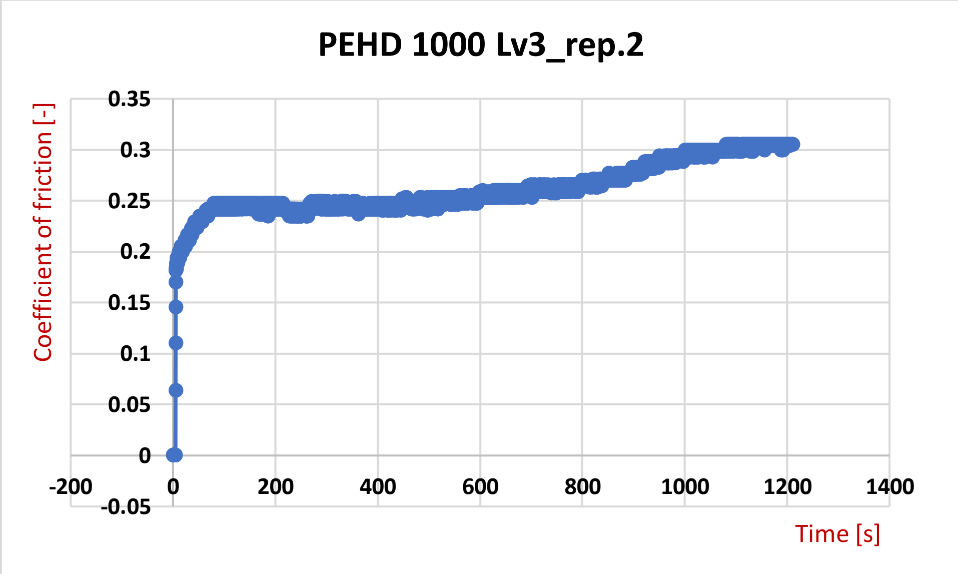

PEHD 1000 Lv2_rep.3
Cefficient of fricion [-]
0.25
0.2
0.15
0.1
0.05
0
-0.05
-200
0
200
400
600
800
1000
1200
1400
Time [s]

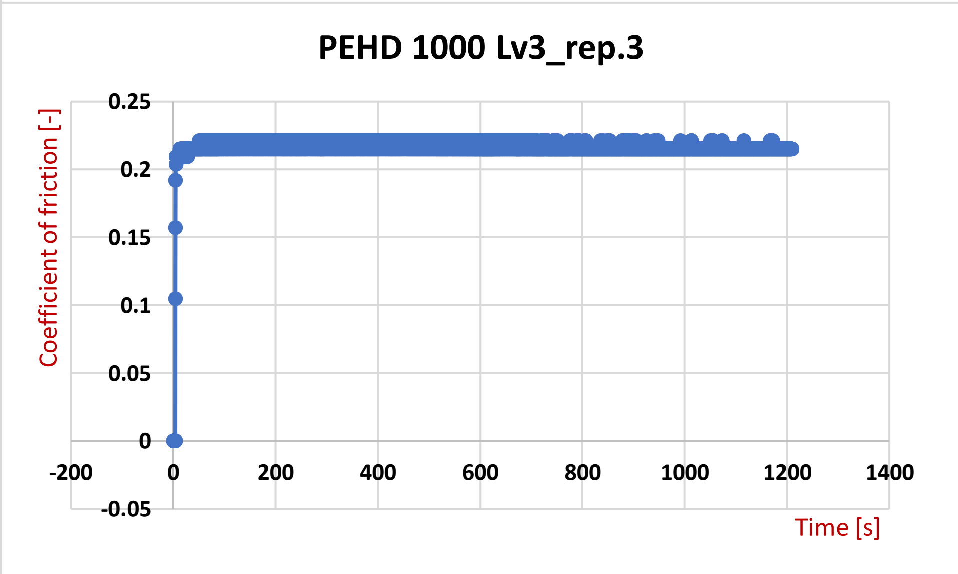

PTFE Lv2_rep.1
Coefficient of friction [-]
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-200
0
200
400
600
800
1000
1200
1400
Time [s]

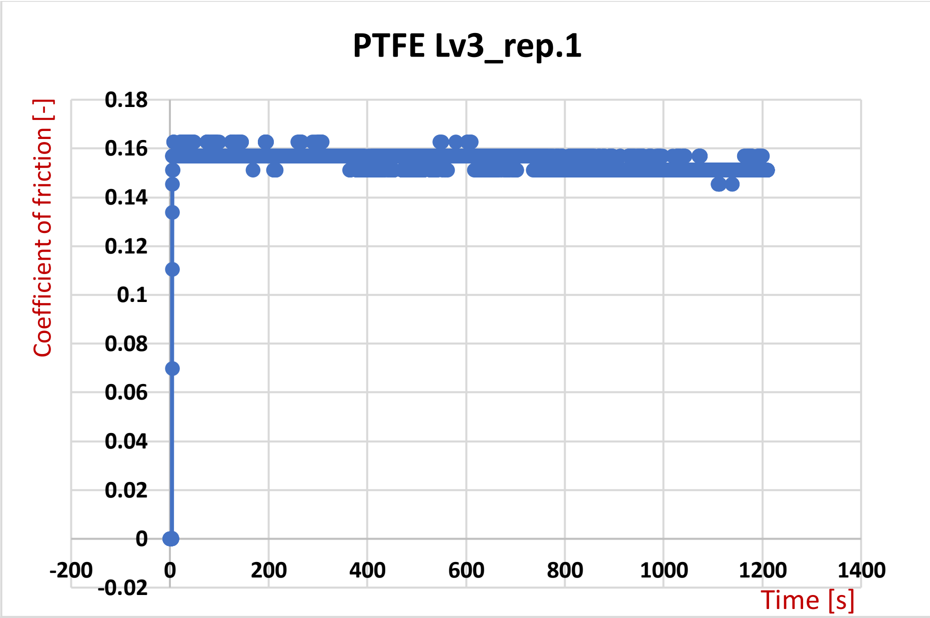

PTFE Lv2_rep.2
Coefficient of friction [-]
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-200
0
200
400
600
800
1000
1200
1400
Time [s]

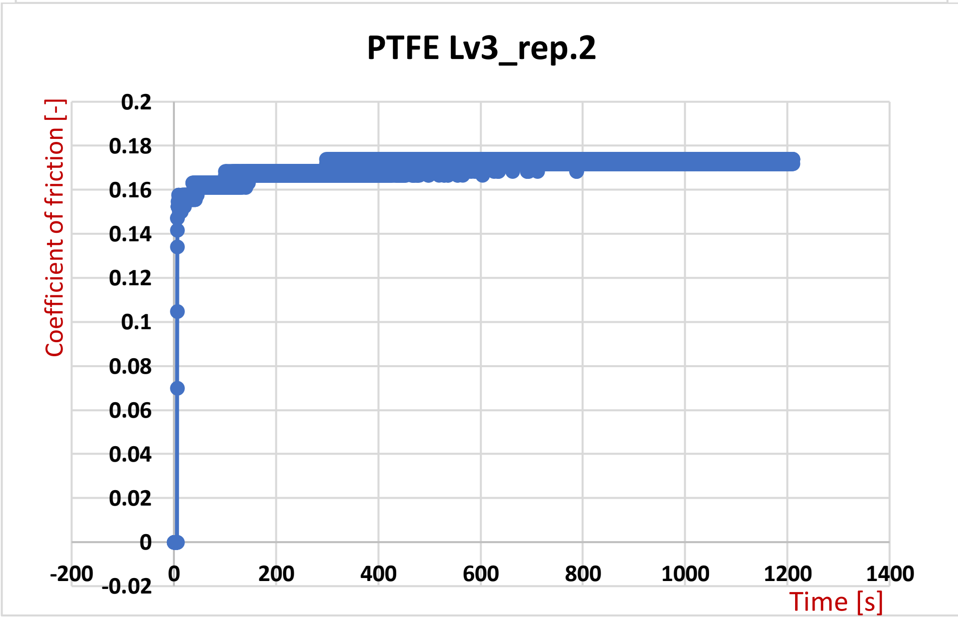

PTFE Lv2_rep.3
Coefficient of friction [-]
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-200
0
200
400
600
800
1000
1200
1400
Time [s]

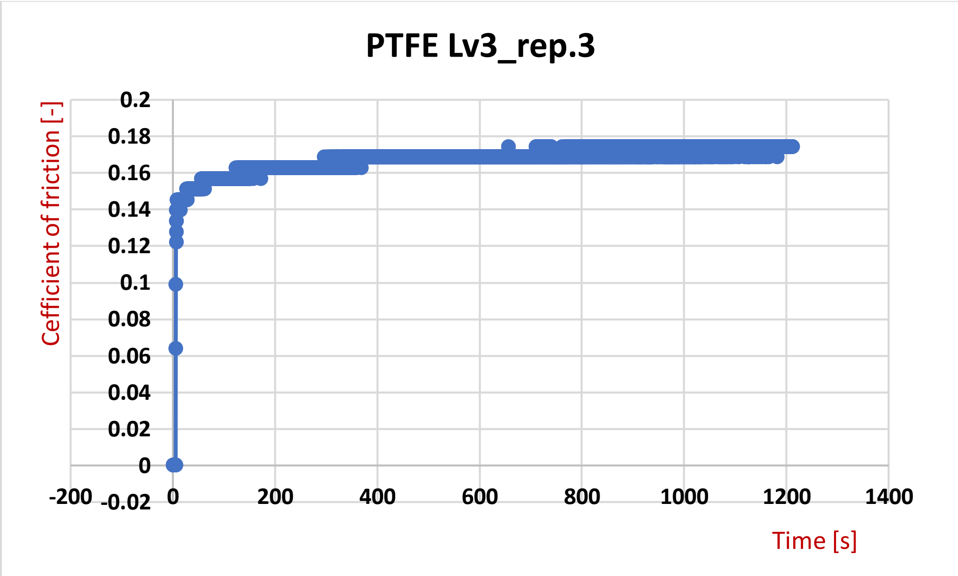

PEHD 1000 Lv3_rep.1
Coefficient of friction [-]
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-200
0
200
400
600
800
1000
1200
1400
Time [s]


PEHD 1000 Lv3_rep.2
Coefficient of friction [-]
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-200
0
200
400
600
800
1000
1200
1400
Time [s]


PEHD 1000 Lv3_rep.3
Coefficient of friction [-]
0.25
0.2
0.15
0.1
0.05
0
-0.05
-200
0
200
400
600
800
1000
1200
1400
Time [s]


PTFE Lv3_rep.1
Coefficient of friction [-]
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-200
0
200
400
600
800
1000
1200
1400
Time [s]


PTFE Lv3_rep.2
Coefficient of friction [-]
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-200
0
200
400
600
800
1000
1200
1400
Time [s]


PTFE Lv3_rep.3
Cefficient of friction [-]
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-200
0
200
400
600
800
1000
1200
1400
Time [s]