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Team 9:

Friction & Wear Analysis of 3D-Printed TPU: A Comparison of Commonly used Filaments

Tribology Final Report

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I. Introduction:

1. Tribology

Tribology is defined as the study of friction, wear, and lubrication of materials in contact with each other [1]. Each material has its own unique tribological characteristics that can be referenced when determining its function in a mechanical system. Friction is the resistance of motion between two surfaces. A key component to friction is the coefficient of friction (COF) that describes the ratio between the frictional force (Fs) and the normal force (Fn) pressing the surfaces together.

$$F_s = \mu \times F_n$$

where μ, coefficient of friction (COF). There are two types of COFs, static and dynamic. This paper will focus on the dynamic aspects of friction therefore the COF will represent the force in motion.

Wear is the removal or loss of material at the solids surface as a result of friction or impact. The wear behavior can be classified in three types: sliding, impact, and rolling. From the sliding wear, there are 4 main subtypes known as abrasive, adhesive, fretting, and surface fatigue. The parameters experienced during wear are known as wear rate, wear factor, and wear volume. Wear rate relates to the amount of material removed due variables such as time, cycles, and distance [1]. Wear factor can be used to determine the material resistance to wear and is derived from the volume of material removed, known as the wear volume.

$$W = K \times F \times V \times T$$

where W = wear volume, K = wear factor, F = Load, V = velocity, T = time.

Lubrication is an eternal substance applied between two surfaces in order to reduce friction. How it improves the materials resistance to friction is by filling in the gaps between any high peaks in the surface, known as asperties. This allows smoother motion between the materials. There are three lubrication regimes: boundary, hydrodynamic, and mixed lubrication. These regimes describe what type of lubricate is presented under certain operating conditions. Commonly used lubricants in an industrial or automotive setting are grease and oil. This paper will focus on water-based lubricants such as salt water and how it affects the friction and wear on the TPU material.

2. 3D Printing

3D printing is a rapid prototyping process used for creating parts for mechanical systems using polymers [2]. How 3D printers work is by replicating a 3D designs' digital file using an additive process. This process describes adding heated then fan cooled material layer-by-layer until the object is created. Various polymer materials known as filaments can be utilized depending on the desired use. The most commonly used filaments are thermoplastic polyurethane (TPU), polylactic acid (PLA), polyethylene terephthalate glycol (PETG), acrylonitrile butadiene styrene (ABS), and polyamide (PA or Nylon). This paper will focus on TPU and how its tribological characteristics compare and differ from that of PLA and PETG.

Due to the nature of 3D printing being a layer-by-layer additive manufacturing technique, the orientation and parameters set can greatly affect the yielding results of a tested specimen. For the best results the samples will be printed flat, with the settings listed below in table 1:

	TPU	PETG	PLA
Extruder (F)	250	235	215
Bed (F)	75	70	70
Speed (m/s)	35	55	50

Table 1: 3D Printing Settings

3. Thermoplastic polyurethane (TPU)

Thermoplastic polyurethane (TPU) is a commonly used polymer that can be manufactured for a multitude of uses. Utilization examples include, but are not limited to, automotive, military and sport equipment. With the technology advancement of 3D printing, a detailed analysis of the tribological characteristics, such as friction and wear, on the TPU filament would be beneficial for its production and consumers. Variations such as applied load and lubrication can further demonstrate the 3D printed material properties and its ability to withstand said conditions. These variations and analysis will be further explored in our literature review.

TPU is considered a composite consisting of amorphous and semi-crystalline segments in the molecules. This blend provides elasticity similar to rubber that exhibits high flexibility as well as high mechanical performances such as the excellent tensile strength of a plastic material [5]. The material is known to be abrasion resistant, UV resistant, with a high percent elongation.

4. What is PLA/PETG

Made from the fermentation of corn starch and sugar, PLA is a fully bio-based polymer [13]. Despite the difference between PLA and petroleum-based plastics, they can be produced using the same equipment, rendering the manufacturing processes relatively cost efficient. It is most commonly used via 3-D printing, with its biodegradability allowing it to be used as medical implants that gradually transfer load onto the body. One of the downsides of PLA is its low melting temperature, standing at around 175°C. This prohibits PLA from being used in automotive or aerospace industries, although it is well suited for food and medical applications. PLA is generally highly brittle, suffering from low impact strength [14].

PETG, a thermoplastic, is widely utilized for electronic insulators, medical braces, and graphic displays. Most applications are suited for the medical and retail industries. Good adhesion between layers, minimal printing deformation, and chemical resistance to bases and acids make this thermoplastic sought after for 3D printing, as well. Like PLA, PETG can easily be recycled with the right chemical decomposition and is also cost-effective. Unlike PLA, however, PETG has high impact strength.

II. Methods:

Search Engine	Search Terms
Google Scholar	FDM, TPU, Tribotesting, 3D Print, Wear, Tribotesting Wear, Pin and Disk, Polymers, TPU/Steel Contact, Additive Manufacturing, ASTM G99.
UTRGV Library Database	Pin and Disk filaments, 3D Printer, PLA

Table 2: Methods used to conduct Literature search

In this project, the team decided to focus on searching for research papers and articles pertaining to the use of ASTM Tribotesting standards. In our search we utilized two search engines, google scholar and the UTRGV Library database to find and filter terminology related to our project. Related terminology used for our research involved Tribotesting, 3D Printing, Wear, TPU/Steel Contact, ASTM G99 and Polymers. In table 2, as shown above illustrates the search engine and key terms used to research articles relevant to our prompt.

Process Parameters	Unit	Sample 1	Sample 2	Sample 3
Load	N	10	20	30
Temp	C	21	21	21
Sliding Velocity	m/s	1	1.5	2
Sliding Distance	m	800	1200	1600
Lubrication	Salt Water			

Table 3: Experiment Parameters

As shown above in table 3, after researching related experiments, our team has compiled a table representing the desired parameters for our experiment which will be implemented towards a ASTM G99, Pin on Disk, test in which we would use to acquire the wear rate in mm^3/Nm. The chosen parameters are to determine the wear rate of three separate material samples, TPU, PLA and PETG, each undergoing three separate trials in which they will be placed under room temperature with an added lubrication of collected salt water.

III. Results:

1. Related Data

The resulting data collected from separate studies showed a consistency in the parameters used, such as, Load (N), Temperature (C), Velocity (m/s) and etc. In the studies, the material contacts described were 3D printed polymers contacting against steel. As shown below, in table 4, the experimental data provided by these studies showed an average wear rate of the polymer TPU to be approximately 8*10^4 mm^3/Nm.

Study	ASTM	Materials	Load (N)	Temp (C)	Pressure (MPa)	Lubrication	Velocity (m/s)	Sliding Distance (m)	Friction Coefficient	Wear Volume (mm^3)	Wear Rate (x10^-4 mm^3 N-1m-1)	Ra (micro m)
[12]	G99	PLA/ Steel	5.49	-	-	-	0.34	-	.492	-	15.2	-
[6]	G133-05	TPU/ SS	166-401.3	21	.44-1.07	Air (1 bar)	.32	500	.61	47.4-175.2	5.7-8.7	-
			330	37.5-75	.88	None	.32	500	.7-.8	130-40	7.9-2.4	.9-1.15
[5]	G137	TPU/ Steel	.5, 2, 5	-	0.5	-	50	-	.5, .53, .53	-	-	-

[4]	-	TPU/ Steel	75	35-40	-	Air		1000	-	34.31	-	-
[3]	D4065	TPU/ Steel	166,215,248, 330,401	21	-	None	0.32	500	.61	-	8.4	.6, 5.4

Table 4: ASTM Tribotestings of TPU/Steel Contact

2. TPU results/Comparison of PLA/PETG

Research carried out by Santos, F.A., et al [15], points out that PETG typically exhibits impact protection ability over PLA. The research was composed of impact testing 3D-printed samples, resulting in evidence that PETG exhibits higher energy dissipation and lower restitution coefficients. They concluded that PETG is better suited for impact protection gear.

Study	Mixture	Shore A Hardness	Shore D Hardness	Density (g/cm^)	Tensile resistance (N/mm^2	Module at 100% (N/mm^2)	Modlue at 300% (N/mm^2)	Elongation at break	Chemical Identification
[6]	-	95	46*	1.23	>45	>20	>42	>440%	FTIR
[2]	95% PMMA	-	88	-	69.4	-	-	11.3%	Mettler Toledo
	90% PMMA		85		66.7			29.2%	
	85% PMMA		83		63.9			34.7%	
	80% PMMA		82		50.9			36.3%	

Table 5: Physical Properties of TPU

3. Team 9 Collected Data

Section for our future data

IV. Conclusion:

In conclusion, 3D-Printed Materials can yield independent tribological results from one another, such as the focus of our study, TPU and its counterparts PETG and PLA. Each material has its own unique tribological characteristics that can be referenced when determining its function in a mechanical system. In comparison to PLA, from the studies our team researched, TPU is shown to have a lesser wear rate of approximately 8*10^4 mm^3/Nm. TPU being a composite consisting of amorphous and semi-crystalline segments provides more elasticity similar to rubber that exhibits high flexibility as well as high mechanical performances such as the excellent tensile strength of the material which greatly reflects its results in comparison to that of PLA.

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