Northeastern University

Mechanical Properties of Keyboard Switch Materials

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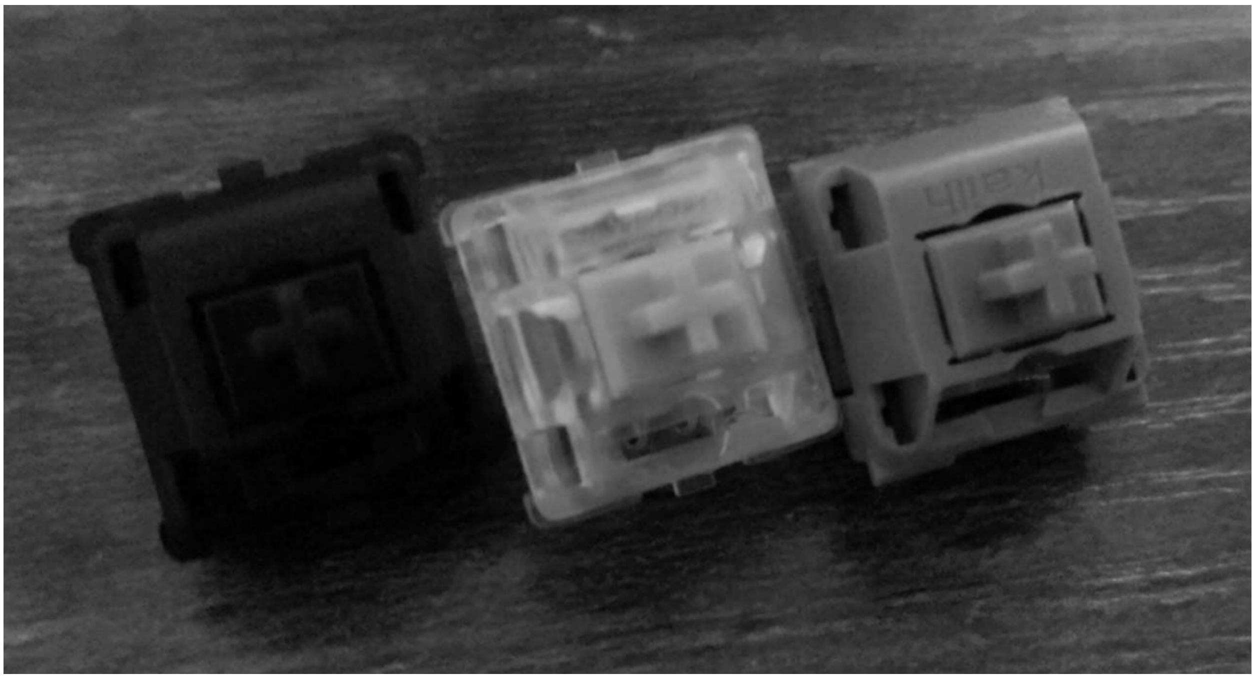


Abstract:

Keyboards are an essential and omnipresent technology in the current world of computers. The function of a keyboard is carried out by the actuation of a switch. Throughout the 2010s and early 2020s, demand for mechanical keyboard switches has dramatically increased for their improvements in typing experience, strength, sustainability, and modularity compared to traditional membrane switches. This experiment tests the mechanical properties of three of the most common thermoplastics used in manufacturing of these switches: nylon, polyoxymethylene, and polycarbonate. Through axial compressive loading, a force can be simulated on a switch as if it were a human input. The subsequent measurements of the yield strength and elastic modulus glean insight into both the strength of the thermoplastics themselves as well as the strength of the switches before they are no longer able to actuate. Ultimately, these switches were found to have ultimate strengths of, at minimum, 17% over their silicone membrane predecessors, easily able to resist human typing forces. All three thermoplastics were proved to be suitable for use in mechanical keyswitch housings. However, the polyoxymethylene switches proved to be the strongest and most stiff with an ultimate strength of 2249.01 psi and an elastic modulus of 2868.79 psi, making it 280% stronger than the membrane switch and an order of magnitude stronger than the average human typing force.

Table of Contents

Table of Figures

Table of Tables

Introduction

Within the last century, computers have become ubiquitous throughout the world to assist in facilitating human needs and productivity. However, extracting utility out of a computer necessitates human-computer interaction, and the vast majority of computers accept human input through the use of buttons on a keyboard. The outward appearance of a keyboard is little more than a collection of buttons engraved with symbols. These buttons on a keyboard, called keys, when pressed, express those symbols in some way that the user can interpret, like on a screen (1). These keys are an integral component of any keyboard, and they function by one mechanism alone: keyboard switches.

The keys on a keyboard are powered by electrical switches. Keyboard switches, often abbreviated as “keyswitches”, are little more than a simple circuit housed in a material casing. When a certain key is pressed, its circuit is closed, sending an electrical signal that the key has been pressed. Usually, switches are encased in rubber or silicone in the case of a membrane keyswitch; or thermoplastic material, such as nylon, polyoxymethylene, or polycarbonate for a mechanical keyswitch.

Due to their widespread use, keyboards are mass-produced, often cheaply. The most common type of keyswitches are membrane keyswitches: where the press of the buttons compresses a malleable dome called the membrane, activating a capacitive plate underneath the keys. Membrane keyboards are ubiquitous on laptops and cheaper external hardware. Silicone rubber is inexpensive, but thin rubber membranes have a proclivity to tear with daily use (2). Since one key breaking can be the end of a keyboard’s useful lifespan, the delicateness of a membrane switch can result in entire keyboards, or even entire laptops, becoming e-waste. Thus, as demand rose for sustainable and long-lasting products throughout the 2010s, an alternative rose to popularity among consumers: mechanical switches.

Conversely to how membrane switches send current from every switch through a single capacitive plate, mechanical keyswitches are activated by a discrete mechanism under each individual key. Each switch has its own housing, usually made of a thermoplastic such as nylon, polycarbonate, or polyoxymethylene. The thermoplastics used in mechanical keyswitches are much stronger than silicone and rubber, and won’t tear or break from human typing forces alone (3)(4). This gives mechanical keyswitches the ability to better withstand the daily strain set upon them. Mechanical switches not only are sturdier, but their design as discrete switches within each unit instead of one entire capacitive plate covered in membrane allows consumers to replace switches individually as they break, so a mechanical keyboard isn’t relegated to e-waste if one switch breaks.

The hypothesis to be tested was that polymerized thermoplastic keyswitch housings should be sturdier than their silicone counterparts. Within the scope of thermoplastics, materials that are known to deform less under stress, such as polyoxymethylene, likely proved stronger than others such as nylon or polycarbonate. However, due to their hollow structure, switches should be measurably weaker than an average thermoplastic specimen. This hypothesis can be evaluated via axial compression testing.

Ultimately, by testing the yield strength and deformation capacity of keyboard switches. Given that the force-displacement data for human typing force has already been studied, measuring the yield stress and stiffness of common keyswitch housing materials can render the keys to calculating the optimal materials to use for some of the most frequently used devices in the modern household.

Literature Review

As keyboards are only a century-old invention with their specific properties being a concern of only the past few decades, relevant research is scarce. However, the materials used in a keyboard switch are not exclusive to that use case. Thermoplastics are used in sports equipment, shampoo bottles, food storage containers, and many more everyday items which have been studied previously. Extrapolating revelations about more conventional uses of thermoplastics to the budding fields of typing, stenography, and keyboard manufacturing can provide insight into how thermoplastics can improve the experience of using and maintaining a keyboard for everybody.

Since membrane keyboards have existed since around the early 1970s, some research has been done on the rubber and silicone used in the membrane domes. One type of such silicone was studied in L. Guo et al (2016) to have an elastic limit of around 5.5 MPa, meaning it experiences permanent deformation after experiencing 5.5 MPa of stress. Ultimately, this study proved that as silicone samples experienced wear, they had successively less resistance to breaking upon being strained (3). This is an unfortunate property for a material that is repetitively placed under stress. Meanwhile, alternative studies show that the thermoplastics used in mechanical keyswitches are much stronger. Nylon has a yield strength of around 50 MPa (4). Polyoxymethylene has a yield strength of around 65.5 MPa (5). Polycarbonate has a yield strength of 60 MPa (6). All of these thermoplastics nearly an order of magnitude stronger than their silicone predecessor (Table 1).

Due to the ubiquity of keyboards in daily life in the 21st century, much of the modern scientific interest in keyboards has taken place in the medical field. The repetitive motion and force applied by a user onto a keyswitch has implications in the fields of biomechanics and ergonomics, which have been studied extensively. For the purpose of material testing, these studies are useful because they establish information about the average applied force by users on switches in a controlled environment. Applied force on a material is directly related to the stress and strain it experiences, two properties which are of paramount importance in the experiment at hand. In both D. Rempet et al (1997) and J.H. Kim et al (2014), a study which cites D. Rempet et al, researchers generated force-displacement curves for keyswitches of varying rated actuation forces (1)(7). Ultimately, this experiment is interested in the peak force, which is the applied force at the end of the measured key press. An applied force on a key doesn't apply a stress on the switch's housing until the key actually makes contact with the thermoplastic housing material. This contact occurs at the end of a press at the peak force. J. H. Kim et al measured various key switches on modern laptop and desktop keyboards and found that, for a desktop key switch with a travel distance of 4.0 mm, the average peak force for a typing session was 1.98 N (1).

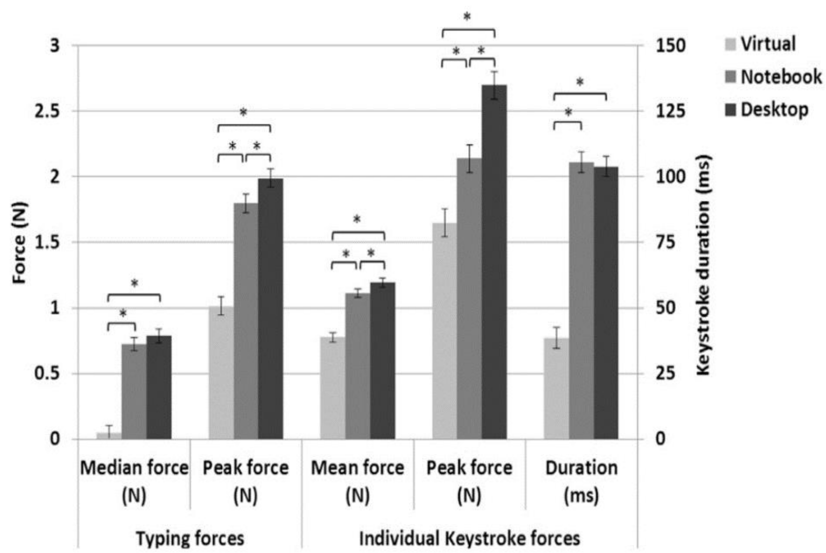


Figure 1: The averaged force-displacement curve for a 2.0 mm key press and a 4.0 mm key press, as measured by J.H. Kim et al (1).

Data is also plentiful about the physical properties of the thermoplastics used in switch housings. Previous studies of material behavior can serve as a point of comparison for the results obtained within this study. PA66, the housing material used in the switches tested in this experiment and the most ubiquitous nylon used in mechanical keyswitches generally, was studied in Q. Duan et al (2017). The study found that, among shear-compression specimens, unreinforced PA66 maintains a modulus of elasticity, a measurement of material stiffness, of around 2,000 MPa (4)(8). Rémond et al (2004) came to similar results, although with specimens under 1 mm in thickness reaching a modulus of elasticity of up to around 3,000 MPa (5). POM, which was also tested by Rémond et al, was found to have a modulus of elasticity of 2,000 MPa up to 3,200 MPa for specimens with a thickness below 1 mm (5). Polycarbonate, which was tested in Krausz et al (2021), in the context of automotive parts, was found to have an elastic modulus of 2,457 MPa to 2,551 MPa depending on the specimen's thickness (5)(9)(Table 1).

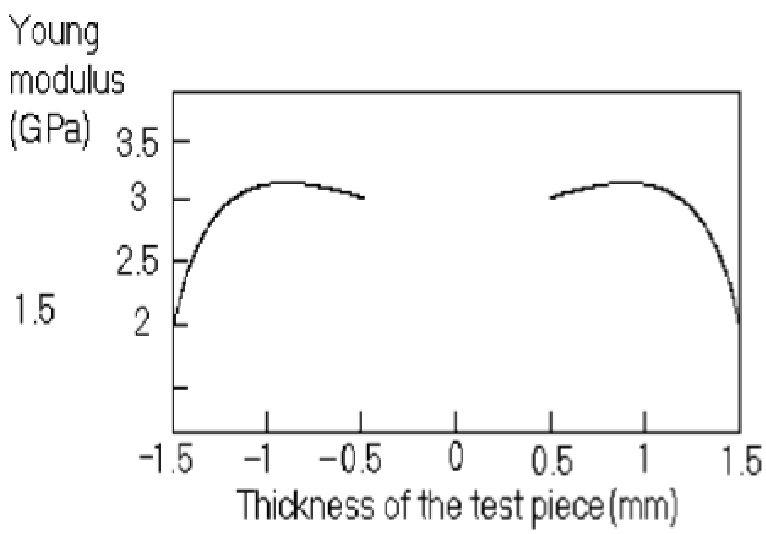


Figure 2: The measured modulus of elasticity for polyoxymethylene by Rémond et al (5)

Material	Yield strength (psi)	Modulus of elasticity (psi)
Nylon/PA66	7250	290000 - 435000
Polyoxymethylene (POM)	8700	290000 - 464000
Polycarbonate (PC)	9500	356000 - 370000

Table 1: Approximate experimental mechanical properties of thermoplastics from literature, converted to psi.

Ultimately, this literature only covers non-composite, non-mechanical thermoplastic specimens. Thus, such experiments can provide insight into which specimen may be strongest or stiffest, but results aren't expected to be equal to those of the specimens tested in this experiment. Although previous literature on thermoplastics doesn't cover the context of keyboard switches, the available studies can be extrapolated to provide experimental reference and expectations for measurements for the purposes of this study.

Experimental Design

This experiment consists of a simple compression test performed with repeatability to study the strength of the switch thermoplastics in both a theoretical perspective and in a real-world use case.

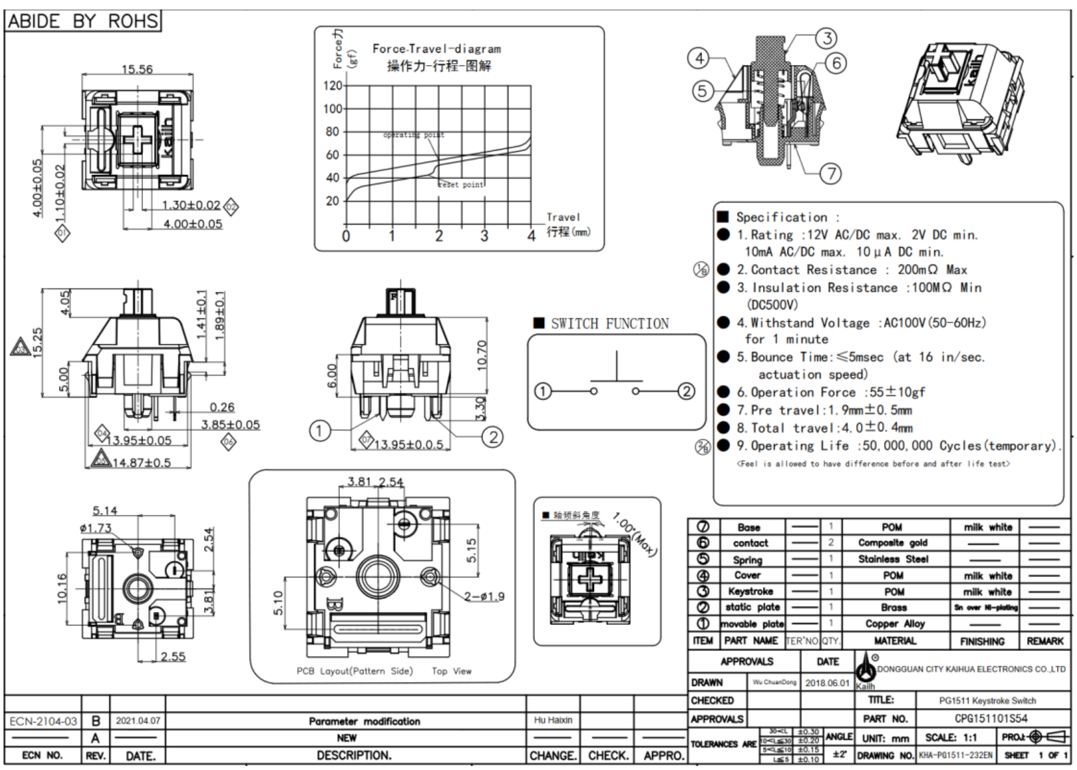


Figure 3: An orthographic drawing of the NovelKeys Cream switch from the manufacturer. Dimensions are in inches.

Six keyswitches total are required to conduct this experiment: two switches with housing composed of 100% non-reinforced polyamide 66 (nylon), two switches with housing composed of 100% non-reinforced polyoxymethylene, and two switches with housing composed of 100%

non-reinforced polycarbonate. The specific models used in this experiment are as follows: two with Cherry® Hyperglide Black switches with nylon housings, two NovelKeys® Cream switches with POM housings, and two Zeal® Tealio V2 switches with polycarbonate housings.

Additional materials and equipment are also required. For starters, a distance measuring tool is necessary, be it digital calipers or a ruler, as long as it can measure the dimensions of each specimen. An ADMET compression machine will also be necessary. For this test, a vertical axial compression machine provided by the Northeastern University Civil and Environmental Engineering department's Materials lab was used with flat compression plates above and below the specimen.

First, the materials need to be prepared: one of each switch should be disassembled and stripped of its non-housing components. Each switch is composed of a bottom housing, a top housing, a spring, a stem, and an actuator mechanism (Figure 4). The top and bottom housings are connected by a series of four latches: two on either side. By using angled tweezers to lift two of the latches on one side, and pulling upwards, the two housings can be disconnected (Figure 5). From there, the actuator, stem, and spring can be extracted from inside the specimen with the same tweezers. From there, the hollowed top and bottom housings can be reattached and the latches should click back together (Figure 4).

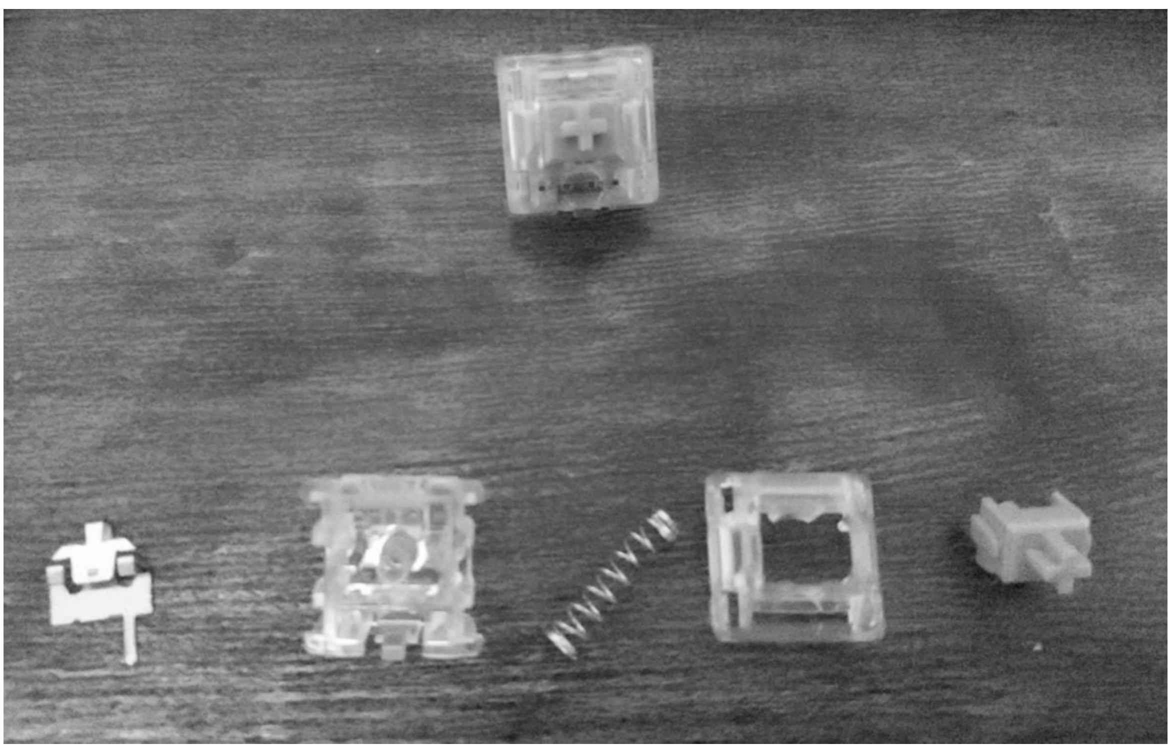


Figure 4: The anatomy of a keyboard switch. On the bottom left, the components are arranged from left to right as follows: the actuator, bottom housing, spring, upper housing, and stem.

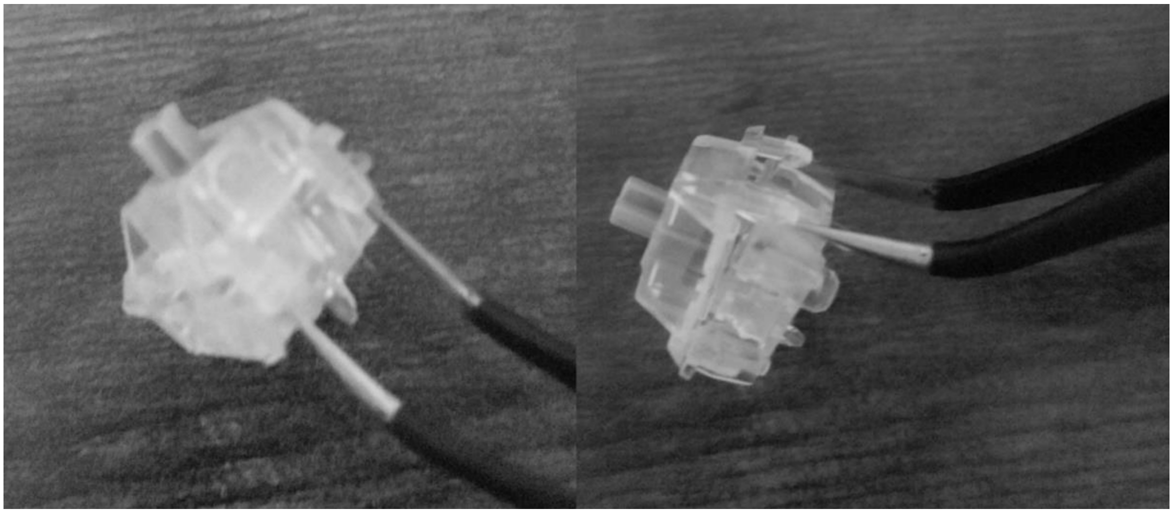
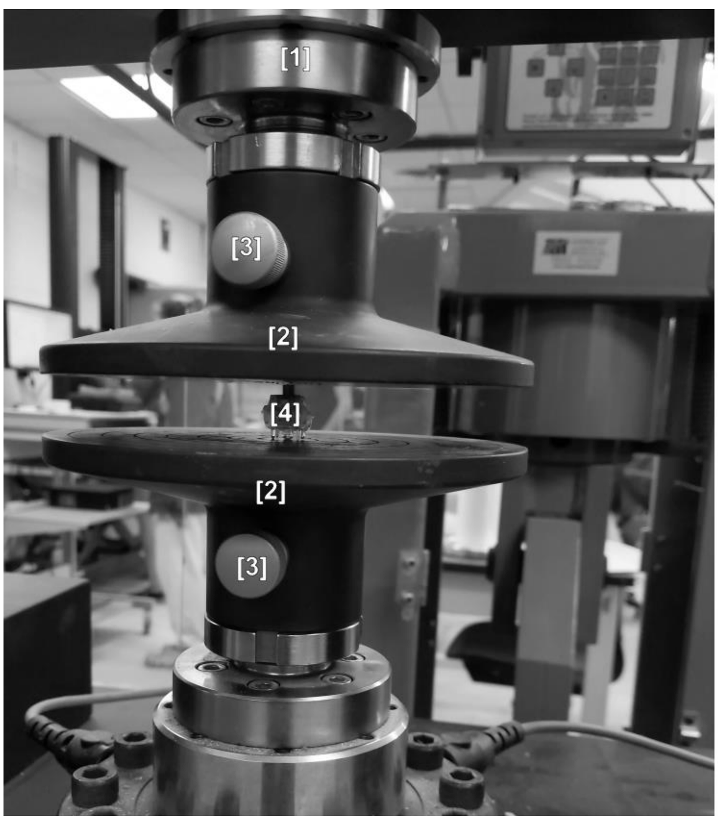


Figure 5: An example of using angled tweezers to lift the latches on the top switch housing.

From there, the compression machine can be set up. Turn on the machine and open the LabView software. The order of switches to be tested is irrelevant, so any switch can be chosen. The switch's dimensions should be measured, and the results, along with the material name being inputted into a new entry in the software. The plate movement should be set to 0.1 inches per second. The upper plate can be lifted, and the switch positioned such that it stands upright under the bottom plate.



[1] The hydraulic piston of the ADMET machine. It can apply up to 10,000 lb of force, so handle it with care.
[2] The circular compressive plates can apply the force from the hydraulic piston by evenly distributing it across the entire surface area of the switches.
[3] These bolts can be tightened/untightened to replace the plates. Make sure they are fully tightened.
[4] The area in between the plates is where the switches will be situated. The switches should sit upright, supported by the plastic bumps on the bottom housing.
[5] This knob can be turned to raise or lower the upper compressive plate prior to testing. Exercise extreme care around this and make sure to remove fingers from the compression area before using it.

Figure 6: An annotated picture of an intact switch before undergoing the compression test.

The hollow switches should be positioned such that the hole for the stems is upright, and the intact keyboard apparatuses should be facing such that the switch will be pressed down by the load. The compression machine's load should also be zeroed before running the test. When everything else is ready, the upper plate can be lowered to just above the top of the switch, to save time during the test and, the apparatus and software should be ready to run (Figure 6). Once the machine is running, a force-displacement curve will be generated. The resulting LabView data can be saved as a spreadsheet, and the same procedure may be repeated for the five remaining configurations of switch material and level of disassembly.

Methods and Theory

Ultimately, the goal of this experiment is to find the ultimate strength of each keyswitch housing material before the mechanism is no longer able to actuate. The raw data collected in this experiment is force-displacement data. To find the stress applied axially along the direction of a press of the switch, the following equation can be used:

$$\sigma = \frac{F}{A_0}$$

In this equation, σ is the stress, F is the axially applied force, and A_0 is the surface area of the switch. In this case, the switches can be effectively treated as rectangular prisms, so the area can be found by multiplying the length and width of the specimen. The axial strain is the change in length of the dimension of the stress divided by that dimension's original length. In this case strain is applied along the direction of a key press, which is the switch's height:

$$\varepsilon = \frac{\delta h}{h}$$

Plotting the stress on the y-axis vs. the axial strain on the x-axis provides stress-strain curves for the switches. The yield strength of the switches can demonstrate how much stress it will take for a switch to be irreparably damaged. A specimen is yielding after its stress-strain curve takes a visible dip in stress while still increasing in strain. However, keyboard switches experience little elastic behavior and start yielding almost instantly. During a specimen's elastic behavior, it is possible to calculate the stiffness, given by Young's modulus, E, of each thermoplastic by taking the slope of any linear portion of the stress:

$$E = \frac{\delta\sigma}{\delta\varepsilon}$$

Since a keyboard switch has multiple points of failure, switches will yield briefly as one piece of the housing fails but will then resist further stress until the next component fails. Generally, a switch's first point of failure is going to be the latches holding the top and bottom housings together. However, a switch is only considered to no longer work when the housing itself yields, since the stem and spring are no longer free to move up and down. This is the second yield in the switch.

Finally, the type of failure can tell be indicative of how the material will respond to stresses in other environments. A ductile material will resist yield before breaking, whereas brittle materials don't have much capacity to yield. In the context of this experiment, a switch that compresses fully before breaking will be ductile, whereas a material that fractures instead of compressing is considered brittle.

Analysis and Results

First, the dimensions of each switch type were measured (Table 2).

Table 2: Dimensions (length x width x height) of the three types of switches.

Switch Name	Material	Length (in)	Width (in)	Height (in)	A_0 (in^2)
Cherry MX Hyperglide Black	PA-66 Nylon	0.569	0.444	0.486	0.253
Novelkeys Cream Linear	Polyoxymethylene	0.576	0.450	0.480	0.260
Zealios V2	Polycarbonate	0.576	0.462	0.480	0.267

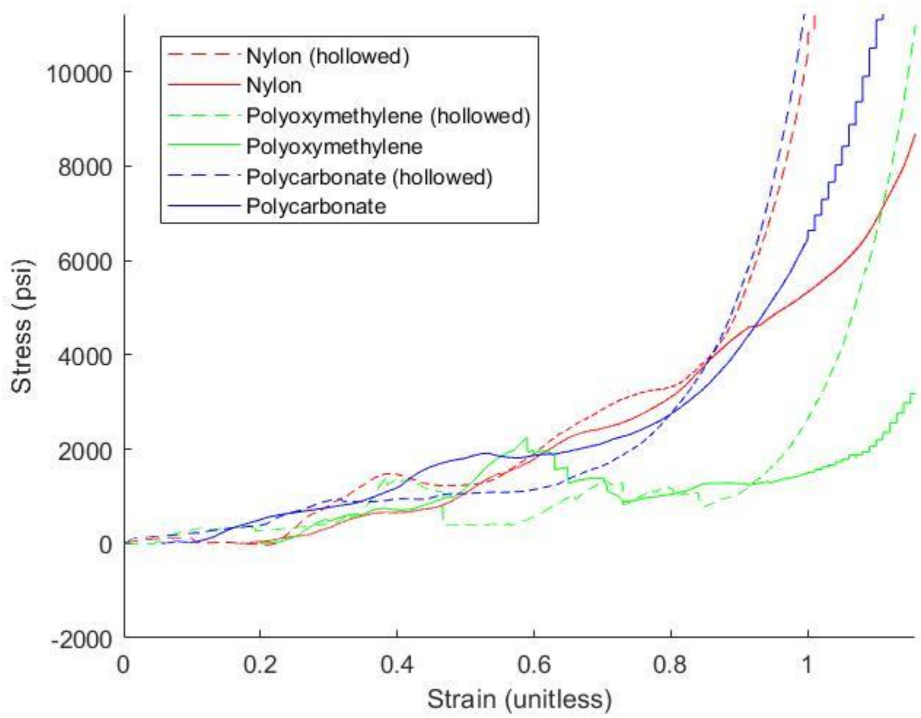
The cross-sectional area of each switch was calculated simply as the length times the width of each switch. The measured dimensions of each specimen remained within manufacturing tolerances of 0.570 in x 0.450 in x 0.480 in ± 0.02 in for each dimension, as expected.

Stress-strain curves were calculated from the raw force-displacement data (Appendix X). By dividing each measured force value by A_0, the resulting values are plotted on the y-axis for stress. By dividing the displacement data by the measured initial height, the resulting values are plotted on the x-axis, for strain. These calculations were done with all six specimens, and the resulting graphs were plotted and analyzed in MATLAB (Figure 7). Said data was plotted for all six specimen: all three types of switches, each having both a hollowed (the stem & spring mechanisms of the switch removed, leaving only the thermoplastic material) and unhollowed (fully intact and assembled, right out of the box) specimen.

On these plots, visible points can be located at which the strain continues increasing but the specimen doesn't experience increased stress. For the latch yield, the first point of failure of each switch, the failure occurred very early on into compression, so the plots were zoomed in to about 0.1 strain (Figure 8). This analysis was performed on all six specimens, with the stress of the yield points noted as "latch yield" in pounds per square inch (Table 2). Here, the young's modulus was also calculated, by dividing the measured stress by the measured strain (assuming that the deformation would be linear given a uniform specimen of the same thermoplastic).

The same analysis was done for the second visible yield: the yielding of the switch body. Graphs were plotted at a large scale for each material, since the switch body yield represents an "ultimate yield" (Appendix A, Figures A1-3). This yield represents not necessarily the most stress that the specimen resisted, but the most stress a switch could resist before no longer being able to function as a keyboard switch.

Figure 7: *Full stress vs. strain curves for keyboard switches of the three thermoplastics.*



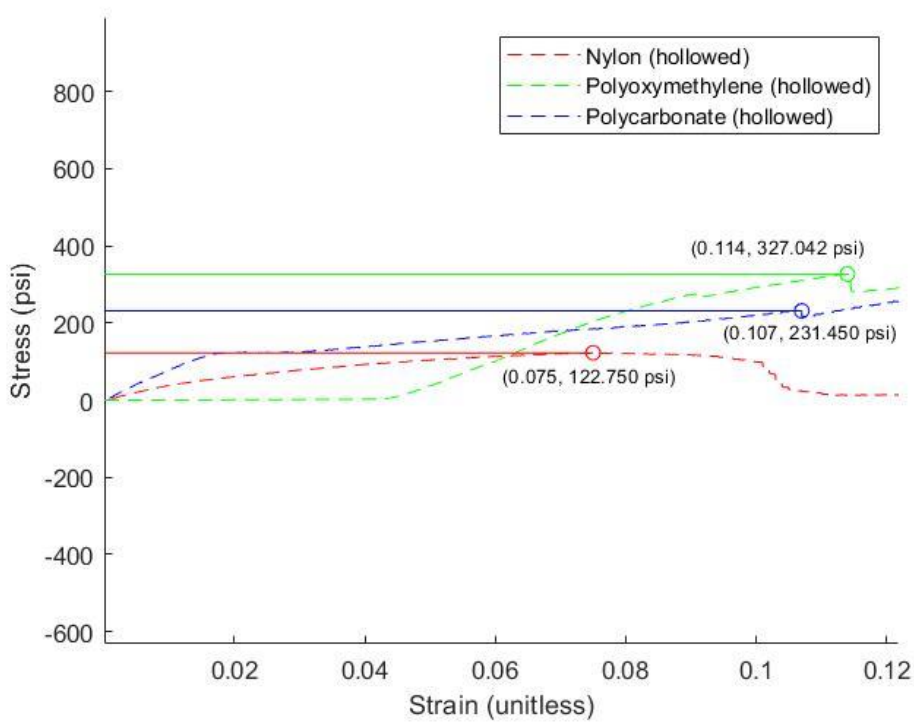


Figure 8: Stress-strain behavior for hollowed switches, zoomed in to highlight initial yields and the elastic limit of the latches of the switch (yield strength).

Ultimately the empty nylon switch's latch yielded after 122.750 psi of stress and the switch body yielded after 1476.37 psi, and the Young's modulus was measured at 1636.67 psi. With the stem and mechanism intact, the latch yielded after 660.640 psi, and the switch's body yielded after 1483.40 psi. The empty polyoxymethylene switch's latch yielded after 327.042 psi of stress and the switch body yielded after 687.83 psi, and the Young's modulus was measured at 2868.79 psi. With the stem and mechanism intact, the latch yielded after 511.657 psi, and the switch's body yielded after 2249.01 psi. The empty polycarbonate switch's latch yielded after 231.450 psi of stress and the switch body yielded after 937.55 psi, and the Young's modulus was measured at 2163.08 psi. With the stem and mechanism intact, the latch yielded after 601.607 psi, and the switch's body yielded after 1907.43 psi (Table 3).

Table 3: Notable calculated and measured values from the stress-strain curves.

Switch material	Latch yield (psi)	Switch body yield (psi)	Young's modulus (psi)	Failure Type
PA66 (hollowed)	122.750	1476.37	1636.67	Ductile
PA66 (intact)	660.640	1483.40	--	Ductile
POM (hollowed)	327.042	1427.18	2868.79	Brittle
POM (intact)	511.657	2249.01	--	Brittle
PC (hollowed)	231.450	937.55	2163.08	Ductile
PC (intact)	601.607	1907.43	--	Ductile

Additionally, both the nylon and polycarbonate switches had a ductile failure, resisting additional stress after yielding on each step. Both materials, whether the switches were hollowed and intact, were effectively fully compressed into soft and flat discs. However, the polyoxymethylene was brittle, and was unable to resist much stress after yielding (Figure A-2). The housings audibly cracked and popped during compression, and ended up fragmented into multiple small pieces unlike the other two materials (Figure 9).

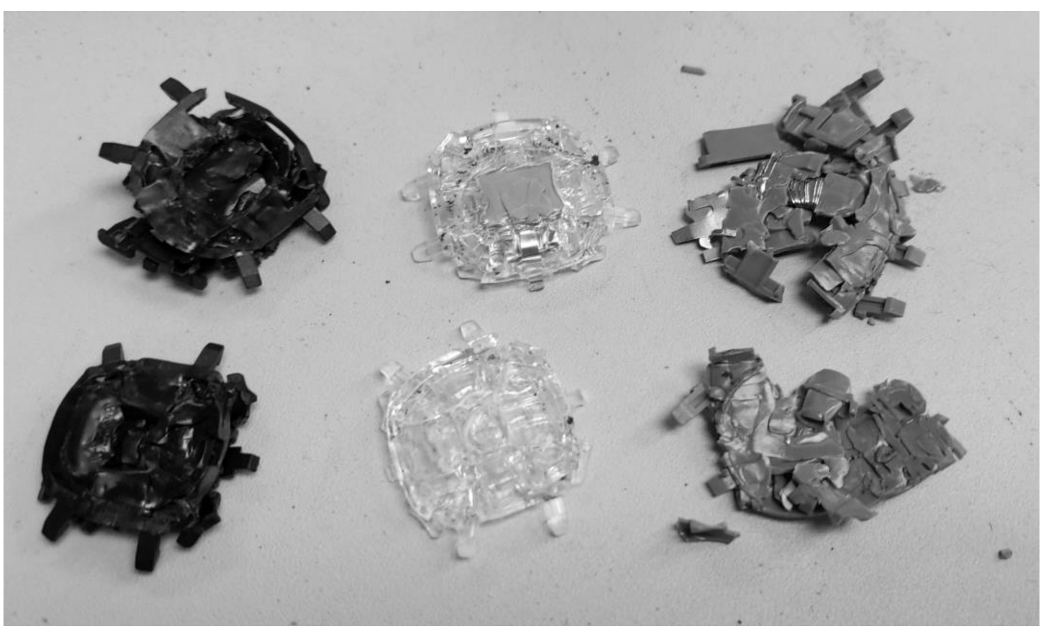


Figure 9: From left to right: Nylon, polycarbonate, and polyoxymethylene switches after full compression, with the fully intact housings on top and the hollowed housings on the bottom.

To measure how the addition of the stem changed the strength of each switch, the strength difference can be calculated by subtracting the yield strength of the hollowed switches from the yield strength of the intact switches of each material. The margin of error was also calculated as 1% of the largest yield strength value.

Table 4: Strength differences (deltas) between hollowed and fully intact yields for the three switches.

Switch material	Latch yield delta (psi)	Body yield delta (psi)	Margin of error (psi)
PA66	537.890	7.03	14.83
POM	184.615	821.83	22.49
PC	370.157	969.88	19.07

With these results, several conclusions can be drawn about the efficacy of the various switch materials.

Conclusions and Recommendations

The results of this experiment give ample insight about the properties of keyboard switches and their materials. Through compressive testing, multiple differences were illuminated between various keyboard switch housing materials. These differences manifested themselves as variances in yield strength at different failure points of the switches. Additionally, compressive testing illuminated differences between a hollowed and assembled switch made from the same material.

Nylon proved to be the strongest material on its own, but the polyoxymethylene switch housing became the strongest when assembled. Additionally, polyoxymethylene switches were found to be stiffest, although brittle, as predicted in the hypothesis. Ultimately, all three thermoplastics can easily resist the average human typing force of 1.98 N. There is a reason why all three thermoplastics are used commonly in manufacturing of switches. In practice, the main differences between the three thermoplastics are their acoustic properties, price, availability, and their workability for manufacturing purposes.

Unfortunately, the Young's modulus measurements were far lower than expected. This is most likely due to the specimens yielding almost immediately, with very little usable linear data. Usually in material testing a specimen would experience more linear elastic deformation than these switches.

It was expected for the latch of a switch, which takes the brunt of the initial stress as the weakest part of the switch housing, to gain strength with the stem present. The stem spans the entire height of the housing body and should act as a reinforcing member. This expectation held true for all three switches, with their latch yield strength deltas being large and positive. It was also expected for the switch body to gain strength with the stem present. This was observed with the polyoxymethylene and polycarbonate switches, gaining a substantial difference in strength with the stem present (Table 4).

However, the nylon switch body's yield strength only increased to 1483.40 psi, an increase of only 7.03 psi which lies within the margin of error (Table 4). The intact switch still experienced more strain before reaching this yield strength than the hollowed one, which means the stem still adds resistance to deformation. This discrepancy is likely explained by the area of compression where the switch body yields. Since the stem has already compressed because of the latch breaking, the upper housing body remains exposed and could be forced to yield at the same strength.

This experiment sought to look at the properties of the materials used in keyboard switches. While successfully testing for yield and ultimate strength, this experiment could not utilize the volume of switches or the time necessary to conduct repetitive testing to determine fracture strength. A human keypress emulates a cycle of applied stress and strain. It would be useful to use Miner's rule by measuring the number of cycles of stress it would take for switches to fail. Also, while the thermoplastic housings are surely worn out as keys are pressed, the springs and actuator are more fragile. Research within the fields of electrical and mechanical engineering can assist in finding out more robust switch mechanisms than those of today.

As mechanical keyboard switches rise in popularity for their sturdiness and modularity, the thermoplastics used in their housings may differ to strike a balance between strength, cost, or even cosmetic properties. As sustainability grows in the public consciousness and enthusiast communities surrounding keyboards grow, the quality of keyswitch manufacturing has grown in tandem. This experiment indicates that all three thermoplastics tested: nylon, polyoxymethylene, and polycarbonate, are equally suitable for continued use in keyboard switches, with the goal of creating long-lasting keyboards that put customizability and repairability in the hands of their users.

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Appendices

Appendix A – Individual switch body yield plots per material

Figure A-1: Isolated switch body yield data for the nylon switches.

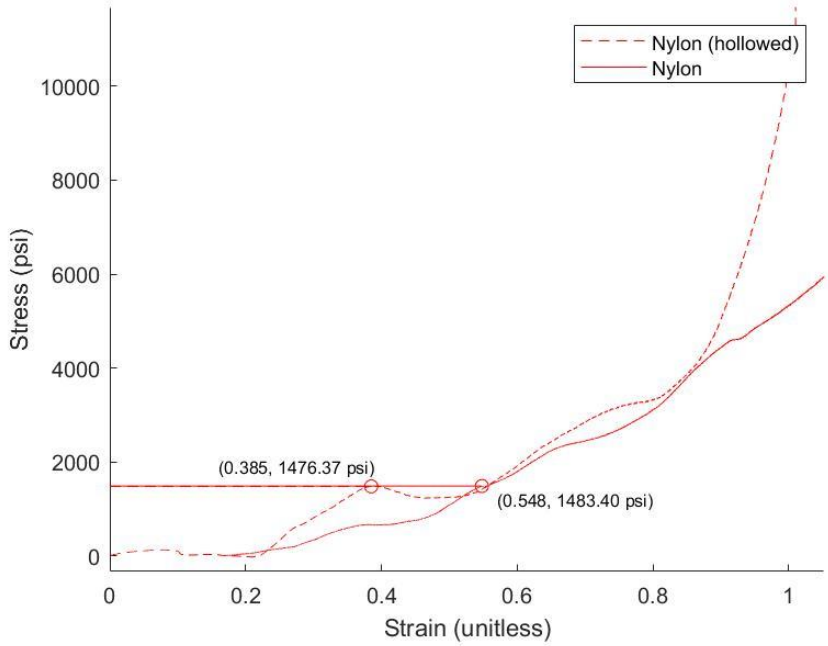

Figure A-2: Isolated switch body yield data for the polyoxymethylene switches.

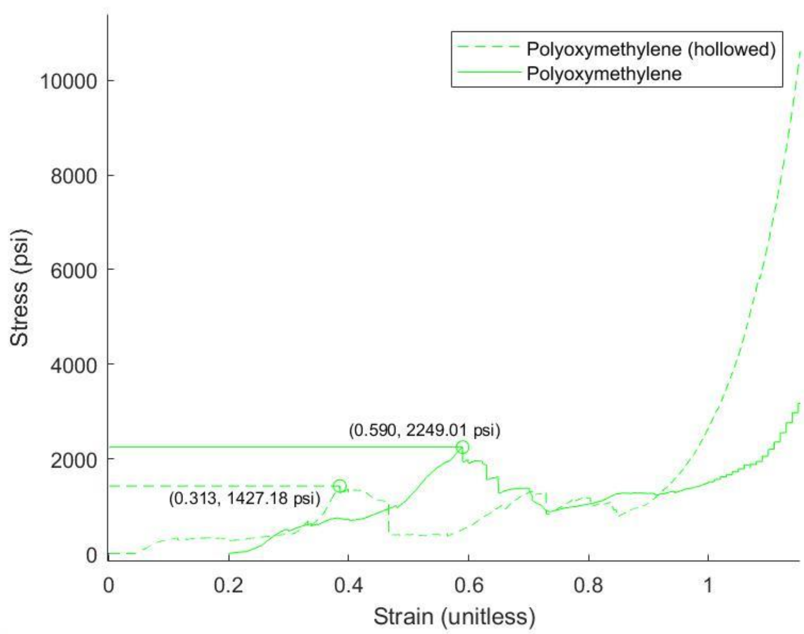

Figure A-3: Isolated switch body yield data for the polycarbonate switches