Switch Plastics: A Memo

-ThereminGoat, 3/21/2020

To put a little bit of context to this writeup prior to getting into it, this is both a document that I've been wanting to write for quite a long time as well as one that I feel is well overdue given light of recent circumstances in which people are beginning to question more and more frequently the plastics being used in switch housings. (These circumstances being completely non-related to the Coronavirus which currently has us locked inside messing with keyboards all day rather than socializing, as if that were done on a normal day anyhow.)

While I have sincerely enjoyed switch collecting over the last year and a half, it does have its fair share of issues with respect to the practice of transparency and some of the information surrounding some switches. If I were Daniel Beardsmore of Deskthority fame, this would devolve into a long-winded discussion on how absolutely trash companies were back in the day at keeping proper documentation of the stuff that they were manufacturing – and he's not wrong in the slightest. However, since I am a goat and not Beardsmore, one of the biggest issues I've had is a lack of scientific objectivity surrounding the switches that are coming onto market. Being that I am rather vocal about my opinions, this shouldn't be a shock to any of you who share a server with me.

That being said, switches remain, in my opinion, the least understood component of mechanical keyboards. Keyboard kits, keycaps, artisans, and even PCBs are all components that many people in the hobby have a deep working knowledge on and can explain the intricacies of with little effort. Switches, on the other hand, are often left to subjective comparisons simply because things like force curves, switch material, and factory lubing processes aren't actively discussed openly and are only known by a few manufacturers in China. In fact, even at my level of connections and knowledge, the explanations of these things are sparse at best. As well, this isn't to say that things like typing tests or the force curves that Haata has completed aren't appreciated – and they absolutely are – but these things are not done consistently for new switches being produced and thus fail at the constantly updated objective metrics that all other components in this hobby have.

Even though I can sit and write pages on the practices surrounding switch manufacturing that should be changed for the better, this writeup was written with the intent to help clarify the thermoplastics that are commonly used in switches for objective purposes. In a mildly self-serving role, the reason I chose to do this is because I often get confused on all of these materials, myself, and wanted a way to clarify them in my head. However, on a more objective level, the reason I am doing this is because there has been much debate recently in the community on what materials new switches are made out of. Due to the nature of certain vendors, we simply cannot trust that what they are producing is what they say it is and thus should aim to educate ourselves and use multiple lines of objectivity to come to conclusions about the switches we choose to use.

Thermoplastics

Pretty much all plastics used in the mechanical keyboard hobby - and especially switches - fall under a class of polymers (or plastics) known as 'Thermoplastics'. Unlike biologically based polymers or other classes of polymers, these are a type of plastic polymers that become flexible and bendable at higher temperatures. These polymers tend to have higher molecular weights and 'chains' of molecules that are held together by medium strength intramolecular forces.

Now before your eyes start glossing over at the realization that this is going to be more chemistry than you wanted to learn today, I'm going to aim to make this understandable to anyone, regardless of their comfort with chemistry. Polymers are often referred to in terms of ‘chains’ as they are made up of ‘n’ number of polymer units all linked end on end, as you can see below in Figure 1. Much like very long chains that have thousands of links in them, thermoplastics often have a very large number of polymer units strung together and thus have higher weights per molecule chain.

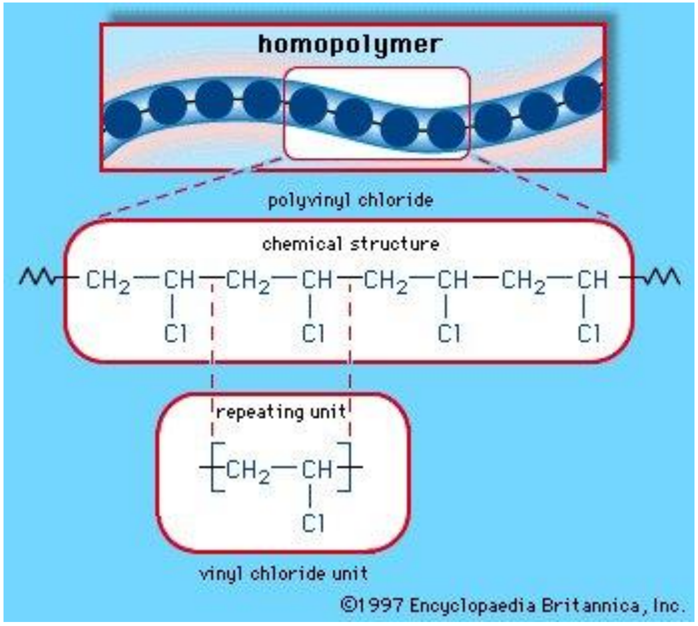

Figure 1: Picture of the structure of Polyvinyl Chloride (PVC), which is another common industrial thermoplastic. [1]

While the aforementioned description applies to *all* thermoplastics, where one gets differences in properties of differing types of thermoplastics is in the structures of the polymer unit making up the chain. For example, I’m sure you could understand that a hypothetical chain that was made up of links in the shape of four-leaf clovers rather than ovals would make a difference in how it moved and performed. Rather than changing the shape of the polymer links, though, different chemical structures are used in the polymer unit. For example, Acrylic (Poly(methyl methacrylate)) is made up of repeating units containing a functional group known as esters whereas ABS (Acrylonitrile butadiene styrene) plastic is made of a mix of polymers that contain nitriles and benzenes as can be seen below.

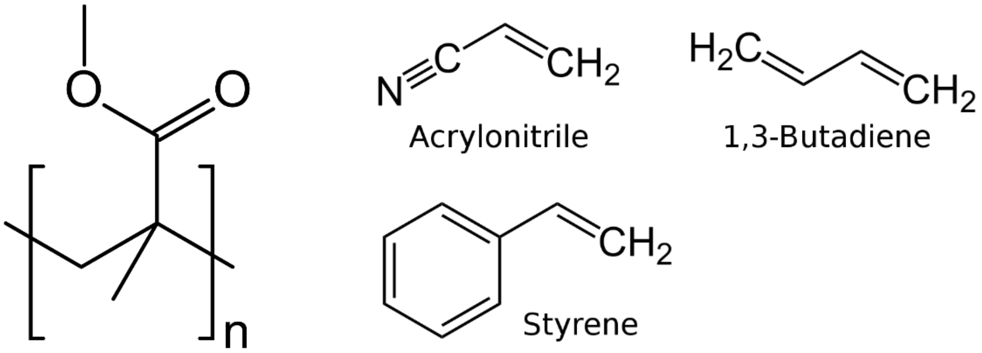

Figure 2: Structure of the polymer unit of Acrylic (Left) and various polymers in the thermoplastic mixture known as ABS (Right). [2,3]

Needless to say, since the study of polymers and plastics is its own discipline – known as rheology – there are a large amount of metrics by which polymers can be compared. Common testing methods focus on the strength of the plastics to scratching, deformation by pulling or smashing, and even resilience to certain chemicals. In addition to these metrics, thermoplastics are often analyzed by determining the high temperature at which they transform from a hard plastic into a rubbery-like state. Known as 'glass transition temperature', this is often determined using an instrument called a DSC or Differential Scanning Calorimeter. In addition to DSCs, and in my limited experience as an intern in a rheological lab, other instruments commonly used to identify polymers include TGA (Thermogravimetric Analysis), GPC (Gel Phase Chromatography), TEM (Tunneling Electron Microscope), and several others not listed here. (While I could go into a lengthy description on the usage and importance of each of these instruments, I feel that it may be a bit out of the interests of most of you here.)

Figure 3: Pictures of a Shimadzu GPC (Left) and TA Instruments DSC (Right). These two are, in fact, the models that I worked on during my time in a rheology lab. [4,5]

Even though it probably doesn't need saying, the alphabet soup of acronyms above are all rather expensive, research-grade laboratory pieces of equipment that the general public does not have access to. While there are means of testing polymer composition to home, such as through chemical resistance tests or burn tests, none are able to provide the same level of depth and intricacy that reports from these instruments provide. Thus, when using homemade tests in order to try and determine the composition of a switch housing – know that your results are at best estimations of majority composition and not a complex analysis. For example, if two switch housings A (85% Nylon / 15% PC) and B (95% Nylon / 5% PC) were burned at home, there likely wouldn't be a noticeable difference in their burning characteristics as they are majority Nylon in composition and the manufacturing techniques likely evenly distribute the PC throughout the mixture of plastics prior to molding. In fact, vendors can (and do often in other fields) 'cut' polymers with cheaper fillers in order to get more volume for less cost and a higher profit margin. The only way to know for certainty the material in a switch housing is using the aforementioned, laboratory grade results and *not* what the vendor tells you. The entirety of my time spent in a rheology lab was actually focused on this aspect, in which I was tasked with determining if the incoming polymer samples from our vendors were up to the specifications that they were touting in sales meetings.

Switch Plastic Types

As mentioned prior, while there are many metrics that are able to be compared between thermoplastics in order to compare their strengths and properties, I'm only going to choose to share a select few of these properties for each of the plastic types I talk about. The metrics being used as well as a brief description of their importance can be found below. While not all of them have a direct, one-to-one correlation with switch performance, they may be useful in helping separate characteristics about certain polymers.

Metrics:

-Young's Modulus – A mechanical property that defines a thermoplastics stiffness or a relationship between the stress that is applied to a material and how much it strains under that load. Not to be confused with strength or toughness, it should be thought of as a way to determine the change in shape of a piece of plastic under stretching or compressing loads.

-Hardness (Rockwell Scale) – While there are different types of hardness scales (such as Mohs, which is the most commonly used), the Rockwell scale is used to determine the force required for an indentation in a thermoplastic.

-Coefficient of Friction – A unitless value commonly used to describe how smooth a material is with respect to a standard. Typically running on a scale of 0 to 1, a value of 0 corresponds to an ideal 'frictionless' material.

-Glass Transition Temp – As described above, this is the temperature at which a thermoplastic goes from a rough and rigid form to a rubbery consistency. While this isn't so much a measure of performance, unless you're typing at some world record speeds, it is useful in helping differentiate polymers when determined via a DSC.

POM (Polyoxymethylene):

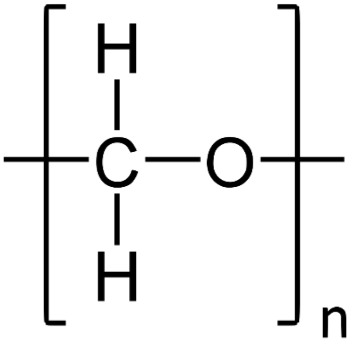

Figure 4: Picture of the polymer unit that comprises POM plastic. [6]

List of Properties:
Young's Modulus: 2.8 GPa [7]
Hardness (Rockwell): M120 [8]
Coefficient of Friction: 0.25 [8]
Glass Transition Temperature: 207-226 C [9]

POM, or Polyoxymethylene if you have no friends, is certainly among the most common thermoplastic used in switches but often forgotten by many people. Rather than seeing listed use in housings, a majority of stems are made out of POM. That is not to say, though, that POM hasn't been used in housings – as POM was featured most notably in the housing materials of Novelkeys' Cream Switches and supposedly in the new Invyr V3 Pandas from Drop.

It is likely that this is the commonly chosen material for the stems as it has a relatively lower coefficient of friction compared to Polycarbonate and Nylon, which are often the materials that the slider rails in switches would be made out of. In the same vein of thought, this is actually the reason that stock Novelkeys Creams have reportedly had issues with slippage in the past. When two materials of similar coefficients of friction rub against each other, such as POM on POM, it can occasionally cause slippage during the keystroke. However, the addition of lubricants like is commonly done with linear switches reduces the issue and allows for a greater reduction in the coefficient of friction of the slider rails.

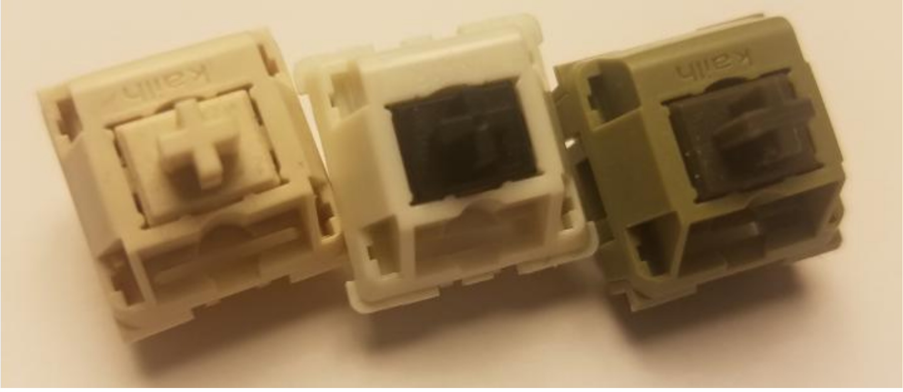

Figure 5: Notable switches featuring POM including Novelkeys Creams, Invyr Panda V3s, and Nolives (Left to Right).

Polycarbonate:

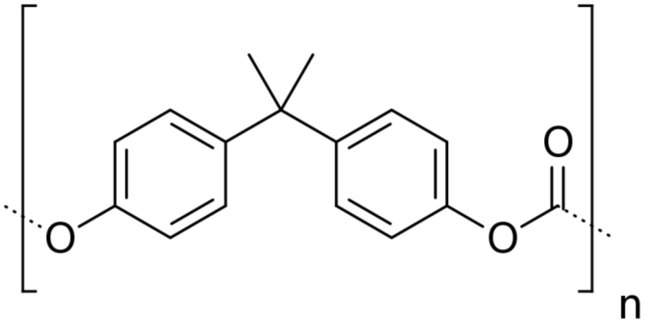

Figure 6: Picture of the polymer unit that comprises Polycarbonate plastics. [10]

List of Properties [11]:
Young’s Modulus: 2.2 GPa
Hardness (Rockwell): M70
Coefficient of Friction: 0.31
Glass Transition Temperature: 147 C

Polycarbonate, or PC for short, is one of the most commonly used thermoplastics in mechanical keyboards at large. With respect to switches, though, this material is used in a *lot* of the clear housings that are seen in switches such as Gateron and Zeal products. Additionally, this material is also used by JWK/Durock in the top housings of Silent Alpacas and Alpacas. While the usage in Alpacas does not necessarily support that PC is only used in translucent switch housings, it used in a large majority of them.

While I typically don’t like giving out ‘rules of thumb’ simply due to the fact that they can get misconstrued and taken as a fact over time – in my experience, the more transparent a switch housing is, the higher pitched and clearer the sound tends to sound. More opaque housings, thus, tend to have deeper and ‘thockier’ sounds. Even though there are multiple compounding factors as to how sound is affected when traveling through different media, an interesting thing to note is that the Young’s Modulus for PC is lesser than that of Nylon, shown below. Being a measure of stiffness, this may explain why the sound in

PC switch housings are clearer than in Nylon housings, as higher stiffness in plastic materials has been correlated to a reduction in sound travel through that material. [12,13]

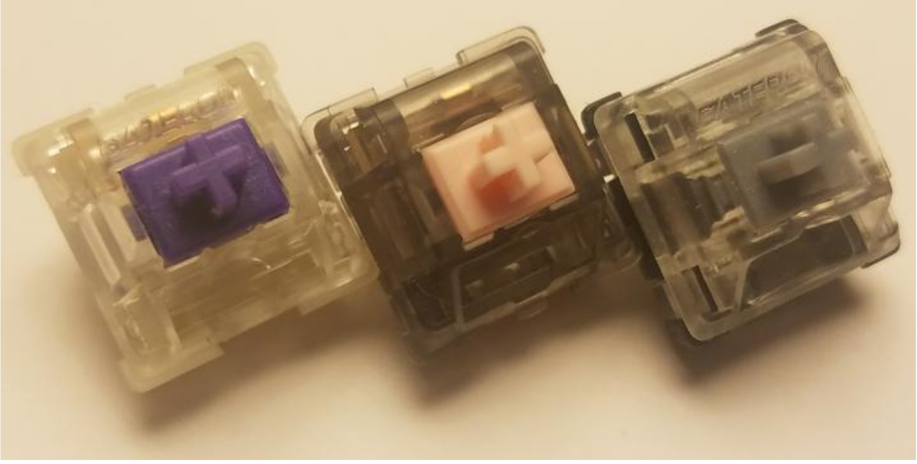

Figure 7: Some of many switches featuring Polycarbonate housings including Zealios, Silent Alpacas, and Gateron switches. (Left to Right: Milky Bottom Zealio, Silent Alpaca, Gateron Silver Optical)

<u>Nylon:</u>

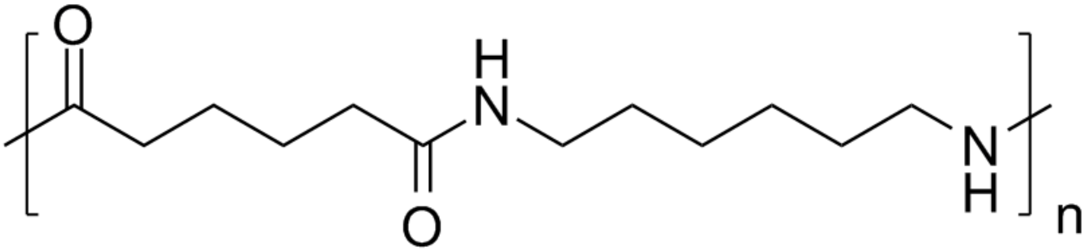

Figure 8: Picture of the polymer unit that comprises Nylon 66 plastics. [14]

List of Properties:
Young's Modulus: 2.31 GPa [15]
Hardness (Rockwell): M90 [16]
Coefficient of Friction: 0.26 [16]
Glass Transition Temperature: 70 C [17]

Unbeknownst to most people, including myself, Nylon actually has several different forms, with the most commonly used for thermoplastic applications being known as Nylon 66. Due to its high strength, heat resistance, and easy moldability, it is not surprising that this is among the most commonly used material for switch housings next to Polycarbonate and liked by many manufacturers.

Nylon tends to be the material used for the more opaque housings as its classically been featured as the standard for Cherry Housings and for the black bottoms of certain Gateron switches. In more recent switch releases, Nylon is the primary component for a lot of JWK/Durock releases including Lilacs, Mauves, Okomochis, Pinokos, and the bottom housings for Alpacas and Silent Alpacas.

Figure 9: Some of the many switches containing Nylon housings including Lilacs, Cherry MX Blacks, and Alpacas (Bottom Only). (Left to Right)

Polyethylene:

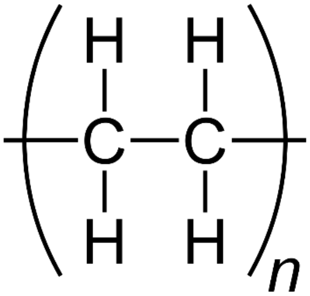

Figure 10: Picture of the polymer unit that comprises Polyethylene plastics. [18]

List of Properties (UHMWPE):
Young's Modulus: 2.4 GPa [19]
Hardness (Rockwell): R64 [20]
Coefficient of Friction: 0.1 [21]
Glass Transition Temperature: 120 C [21]

Polyethylene, or PE, is actually by far the most commonly used plastic on this list of materials, but not necessarily in keyboards. Having a range of functionalities and uses based primarily on the density of the polymer chains in the polyethylene application, there are several different types of commercially available polyethylenes. The one that has been used in mechanical keyboard switches, though, is of the "ultra-high molecular weight" (UHMW) variety, containing chains with hundreds of thousands or millions of polymer units within them. The high strength application of UHMWPE is actually what allows for its use in joint replacements and bullet-proof vests.

Being the newest material to be used in switch manufacturing, UHMWPE has seen usage in both Invyr's UHMWPE aftermarket stems and through JWK in the housings of the C^3 Equalz Tangerine V2 switches. While both of these have received a decent amount of claim for their quality and performance, only time will tell if this grows in popularity in usage to the levels of Nylon and/or Polycarbonate.

Figure 11: Picture of the only two switch pieces containing UHMWPE to date: C^3 Equalz Tangerine V2s and Invyr UHMWPE stems.

Polyamide:

List of Properties:
Young’s Modulus: 6.8 GPa [22]
Hardness (Rockwell): M106 – M119 [23]
Coefficient of Friction: 0.20-0.30 [23]
Glass Transition Temperature: 260 C [24]

Polyamides are a class of polymers, both synthetic and natural, which have polymer units connected via amide-type bonds. While there are several types of Polyamides (and hence the lack of picture), the most commonly used for thermoplastics are Aliphatic Polyamides and Polyamide-imides. Nylon 66, for example, is a type of Aliphatic Polyamide polymer.

To date, only one example of Polyamides being used in switches explicitly separate from the listing of ‘Nylon’. This unique standout is with the new bottom housings for the H1s from JWK. While further specification was not made past ‘polyamide’, my best guess is that the material is a polyamide-imide commonly known as ‘Torlon’ as it easily accessible on the current market and is used as a thermoplastic for wire coatings. [25]

Figure 12: The bottom housings of H1s are currently the only switch to date to have 'Polyamide' plastic rather than Nylon.

ABS (Acrylonitrile Butadiene Styrene):

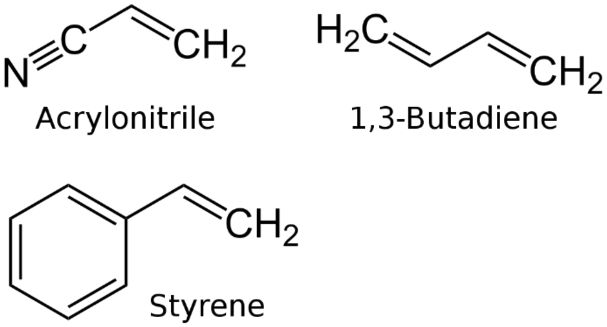

Figure 13: Picture of the chemicals that comprise the thermoplastic mixture known as ABS. [3]

List of Properties:
Young's Modulus: 1.4 – 3.1 GPa [26]
Hardness (Rockwell): R68 – R118 [27]
Coefficient of Friction: 0.11 – 0.45 [28]
Glass Transition Temperature: 108-109 C [27]

ABS is a common thermoplastic polymer that is actually a mixture of Acrylonitrile, 1,3-Butadiene, and Styrene. With properties varying largely based on the ratio of each of these components within the polymer, they can be used in everything from Lego bricks to a car tire. As well, according to Drop's sales page – this is the primary material in Everglide Crystal Violet switches. While I am including it on this list solely for the fact that it is listed in the sales page as the material, I would not be surprised if this is poor marketing on the part of Drop. (As if that takes any convincing.) This should also be used relatively easily as support that we can't always trust what a vendor states their plastics are made out of, as no other Everglide switch has ever been reported to have ABS housings by any other vendor.

Figure 14: Everglide Crystal Purples being the only switch to date to *supposedly* be made of ABS plastic.

Final Conclusions

After having sat down and actually wrote this document, I feel as if I came away with much less understanding of *why* switches behave and sound the way that they do as a choice of their plastic compositions. While I initially sent out to try and determine what metrics could objectively be used to explain the sound and smoothness of certain switches, I discovered that the massive amount of compounding factors when it comes to how sound and feeling are affected makes it nearly impossible to narrow this down into a handful of necessary metrics.

That being said, I think it is important that people try and not make inferences about the material a switch is made out of purely on subjective metrics or even broad, high-level scientific ones such as burn tests, as quality and sound are clearly affected by several, convoluted factors. However, if you or someone you know does come across the ability to use some of the tests I talked about towards the beginning of this document, hopefully you can help better determine what the material it is you test out of each switch using some of the sources and such I have linked.

At the extreme least, I hope you all can take away a little bit more knowledge about some of the materials going into switches as well as understand the few objective scientific points I was able to connect with certain switch performances and why they occur as such.

Sources

[1] PVC Chemical Structure
https://www.britannica.com/science/polymer

[2] Acrylic Chemical Structure
https://en.wikipedia.org/wiki/Poly(methyl_methacrylate)#/media/File:PMMA_repeating_unit.svg

[3] ABS Chemical Structure
https://en.wikipedia.org/wiki/Acrylonitrile_butadiene_styrene#/media/File:ABS_Monomers_V3.svg

[4] Shimadzu GPC Unit Picture
https://www.shimadzu.com/an/hplc/aplsys/gpcclean.html

[5] TA Instruments DSC Unit Picture
https://www.tainstruments.com/products/thermal-analysis/differential-scanning-calorimeters/

[6] POM Chemical Structure
https://en.wikipedia.org/wiki/Polyoxymethylene#/media/File:Polyoxymethylene.svg

[7] Young’s Modulus for POM
https://www.engineeringtoolbox.com/young-modulus-d_417.html

[8] Hardness and Coefficient of Friction for POM
https://www.polytechindustrial.com/products/plastic-stock-shapes/acetal-copolymer

[9] Glass Transition Temperature for POM
https://polymerdatabase.com/polymers/polyacetal.html

[10] Polycarbonate Chemical Structure
https://en.wikipedia.org/wiki/Polycarbonate#/media/File:Lexan.svg

[11] Properties for Polycarbonate
https://en.wikipedia.org/wiki/Polycarbonate

[12] Correlation Between Stiffness and Sound from MachineDesign.com
https://www.machinedesign.com/archive/article/21818584/a-sound-approach-to-designing-plastic-components

[13] Kim, B. J., et al. *Sound transmission properties of mineral-filled high-density polyethylene (HDPE) and wood-HDPE composites*, BioRes. 10(1), 510-526. 2015
https://bioresources.cnr.ncsu.edu/resources/sound-transmission-properties-of-mineral-filled-high-density-polyethylene-hdpe-and-wood-hdpe-composites/

[14] Nylon 66 Chemical Structure
https://en.wikipedia.org/wiki/Nylon_66#/media/File:Nylon_6,6.png

[15] Young’s Modulus of Nylon 66
http://www.matweb.com/search/datasheet_print.aspx?matguid=26386631ec1b49eeba62c80a49730dc4

[16] Hardness and Coefficient of Friction of Nylon 66
http://www.matweb.com/search/datasheet.aspx?matguid=e95795afec4f46539c51269e453cba2b&ckck=1

[17] Glass Transition Temperature of Nylon 66
https://en.wikipedia.org/wiki/Glass_transition#:~:text=

[18] Polyethylene Chemical Structure
https://en.wikipedia.org/wiki/Polyethylene#/media/File:Polyethylene_repeat_unit.svg

[19] Young’s Modulus of Polyethylene
https://en.wikipedia.org/wiki/Ultra-high-molecular-weight_polyethylene#cite_note-5

[20] Hardness of Polyethylene
http://www.matweb.com/search/datasheet.aspx?matguid=dc4013a8f95b49018080ce9683501d6f

[21] Coefficient of Friction and Glass Transition Temperature of Polyethylene
http://www.tribology.fink.rs/journals/2014/2014-3/6.pdf

[22] Young’s Modulus of Polyamide-Imide
https://www.wshampshire.com/wp-content/uploads/torlon.pdf

[23] Hardness and Coefficient of Friction of Polyamide-Imide
http://www.matweb.com/search/datasheet.aspx?matguid=1ca9588da84640d199959da7c00a6083

[24] Glass Transition Temperature of Polyamide-Imide
https://www.wshampshire.com/wp-content/uploads/torlon.pdf

[25] Torlon Brand Polyamide-Imide
https://www.solvay.com/en/brands/torlon-pai

[26] Young’s Modulus of ABS
https://www.engineeringtoolbox.com/young-modulus-d_417.html

[27] Hardness and Glass Transition Temperature of ABS
http://www.matweb.com/search/DataSheet.aspx?MatGUID=3a8afcddac864d4b8f58d40570d2e5aa

[28] Coefficient of Friction of ABS
https://plastics.ulprospector.com/generics/1/c/t/acrylonitrile-butadiene-styrene-abs-properties-processing