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PLA and 3D printing

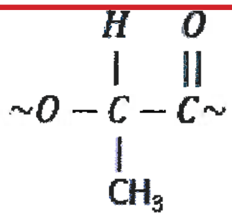


Figure 1 - PLA monomer molecular structure

PLA (PolyLactic Acid) is made up of repeating lactic acid monomers, as shown in the diagram. The basic formula ($(C_3H_4O_2)_n$) has a similar makeup to glucose ($C_6H_{12}O_6$), but because PLA is a polymer its long chain gives it rigidity and reasonably strength. In its basic form PLA is colourless but translucent, so generally colour is added to give the desired appearance to the finished product. This is generally what makes up the small amount of non-toxic waste when PLA breaks down. It has a number of properties that make it suitable for 3D printing: it is cheap, hard, and can be melted at a relatively low temperature (generally 200 to 225 degrees C). It's rather brittle, though, so while it can stand a fair bit of wear it fatigues and breaks. As well as a reasonably low melting point, its 'glass transition point' is about 60 degrees C, any higher than this and it will begin to soften. These last points are especially important for 3D printing, as they allow smaller and cheaper printers since less power is required to heat and melt the filament, and also because the layers are still soft when the next layer is applied, reasonably strong bonds are formed between layers.

PLA is made from corn or sugar beet and was developed in the 1930's, although it is only more recently as oil prices have risen and growing concerns towards the environment that PLA has become a more favourable material to use for making plastic parts. PLA is now one of the most used bioplastics, its main applications are fresh food packaging (e.g. salads and tomatoes). It breaks down naturally over time in the presence of water, oxygen and a number of naturally occurring organisms to leave carbon dioxide, water and a small amount of nontoxic waste. Exposure to sunlight seems (in my experience, anyway) to have a degrading effect on the PLA, making it brittle as most plastics do upon extended exposure to UV light. http://www.iopp.org/files/public/KingslandCaseyMohawk.pdf

3D printing is an additive process; it binds layers of material to make the final part rather than starting with a billet stock and machining material away. In this report, I will focus on the FDM (Fused Deposition Modelling) type of 3D printer, also known as the RepRap type. This type of printer melts a plastic filament and forces it through a nozzle that moves about over the print bed, thus building up layer by layer the final model. Such machines have changed with the advent of PLA, allowing them to be smaller and lighter, thus making them cheaper to obtain and more accurate. Also known as rapid prototyping, 3D printed parts can be used to simulate injection moulded parts, which would otherwise have to be CNC machined (often in a number of operations, depending on the part and the machine) from a billet stock. 3D printing has this greatly reduced the time taken for a part to be developed, and less waste is produced during the process.

3D printed parts can have a number of characteristics that machined or injection moulded equivalents cannot have; they can be hollow (or have an internal lattice structure), have square internal corners (milling cutters leave the radius of the cutter on internal corners) and (with printers using dual extruders) parts can be made up from two or more different materials or different colours.

3D printing has been being developed since the 1980s, and the main type of plastic used for printing was ABS. ABS is an oil-based plastic that tends to be printed at 240-260 degrees C and requires a heated bed at ~110 degrees in order to be able to print reliably and without much warping in the first few layers. ABS was developed for injection moulding, and for this application the shrinkage rate of approx. 1% helps the part to pull free and release from the mould. In 3D printing, however, this creates stresses between printed layers and tends to make the part warp as it cools. ABS also produces toxic fumes as it is printed, however, it is well suited to industrial applications as it is tough and lasts reasonably well.

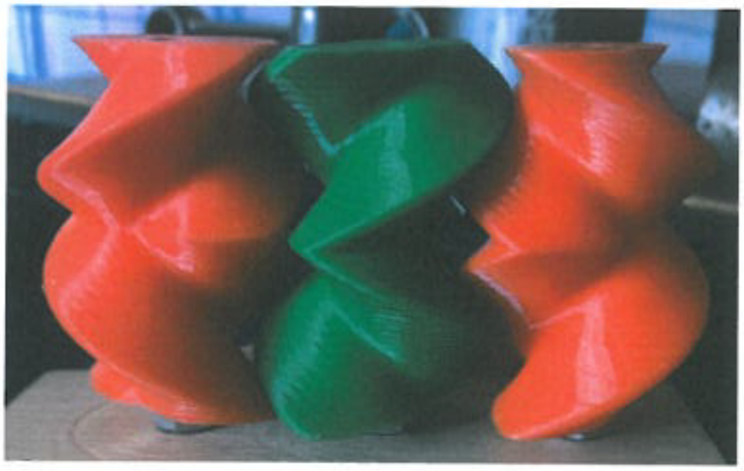
Both PLA and FDM-type 3D printers have been developed to be more suitable for 3d printing parts for practical and decorative purposes and more accessible to the hobbyist as well as professional engineers. A number of advances, both technological and economical, have lowered the cost of both the machines themselves and the associated consumables that go with them. Because of this, the 3D printing industry has grown and more effort is being made to develop the technology further.

PLA Enhancements and how it affects 3D printing/3D printed parts

Because PLA is one of the cheapest and most used 3d printing materials, a number of companies have made efforts to improve its properties by adding fibres such as wood, carbon fibre and brass, each of which give it a slightly improved property. The addition of wood allows the part to be sanded and varnished as wood does, while a brass part can be easily polished, and a carbon fibre part has a superior surface finish, although it doesn't seem to inherit many other properties from the carbon fibre.

I find it interesting watching the videos that Thomas Sanladerer is putting up on his website (http://toms3d.org/2016/10/16/filaween/)at the moment, as he has devised a set of standards and is performing ongoing 'torturing' of filaments, then rating them based upon a number of factors regarding print quality, fine details, overhangs, strength etc. He made a video on Proto-pasta's carbon fibre filament, which showed a fantastic part surface finish but reasonably poor strength and bridging characters when compared to standard PLA. I recently modelled and printed a set of 'paradoxical gears' (worth investigating, shown below), which are an ideal shape for my printer, as they have only one body, so the printer does not need to retract the filament to move between parts.

On the All3dp website I found an interesting page detailing 32 different types of PLA filament, which I believe is about as many as there currently are. Enhancements included colour changing (based upon temperature or UV light), metallic (fine metal powder throughout filament to give colour), glow in the dark, fluorescent, conductive, scented, flexible, highly sustainable and magnetic filament, which used iron powder. Many of these enhancements require a specialised nozzle for the extruder, as the additions to the filament can make it more abrasive. These specialised nozzles tend to be made from stainless steel, rather than copper or brass (I believe the printer I use has a brass nozzle).



https://all3dp.com/best-pla-filament-types-3d-printer/

Figure 2 - 'Paradoxical gears' - I believe this is the best surface finish I can achieve with the hardware and material I have at the moment. Note how the mesh (the digital model was made up of triangles) can be seen on the surface of the part, thus showing that an excellent resolution has been achieved. A smoother part finish would require a digital model with a finer mesh, but I'm not worried for these gears.

Manufacture and recycling of PLA

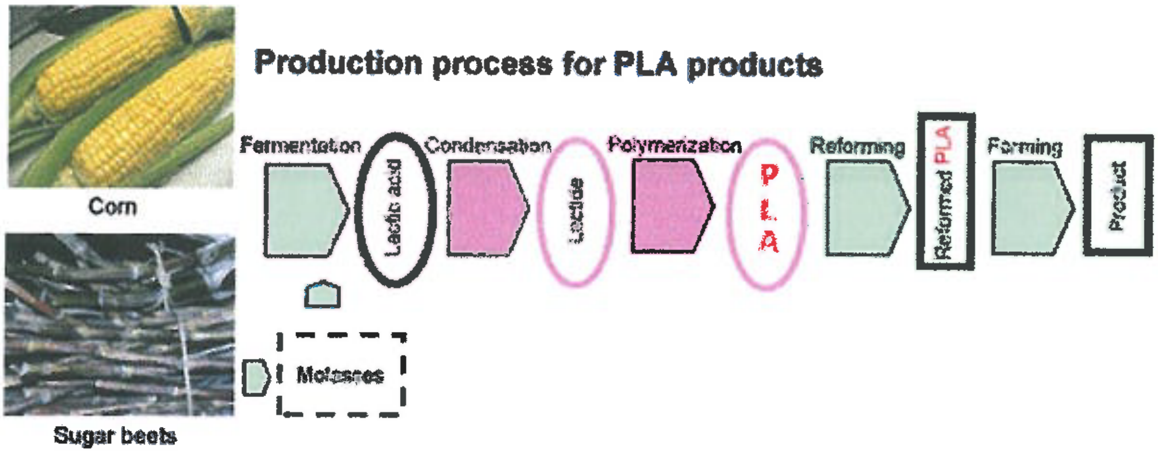


Figure 3 - http://www.hitachi.com/businesses/infrastructure/product_site/ip/process/pla.html

I've put the manufacture and recycling of PLA together as PLA can be part of an endless cycle of recycling. Starting as sugar beet, sugar cane, or corn it is fermented into lactic acid by chemical means. It is then polymerised (polymerisation usually occurs under high temperature and pressure, and is the process by which small carbon compounds are converted into long carbon chains), to form raw PLA.

I found this rather neat diagram showing the basic steps of PLA production from the raw materials on the Hitachi website, which sums up most of what I have found about PLA manufacture. The Loopla system, illustrated below, shows how once produced PLA can be converted back into the raw lactic acid by chemical means, then purified to remove any impurities such as colour pigments that may have been added (especially relevant in the case of 3D printing). It is then ready to be re-polymerised back into raw PLA and reused.

Attempts have been made by a number of companies to make machines that grind up old 3d printed parts and re-extrude them, but from my experiences, this would prove ineffective for two reasons. Different colours are often used, which would make the 'new' filament come out a very different colour, and different filaments have slightly different properties, even if they are supposedly the same. Secondly, in the process of re-extruding could well introduce imperfections and impurities in the filament, which will affect the quality of parts printed with the filament.

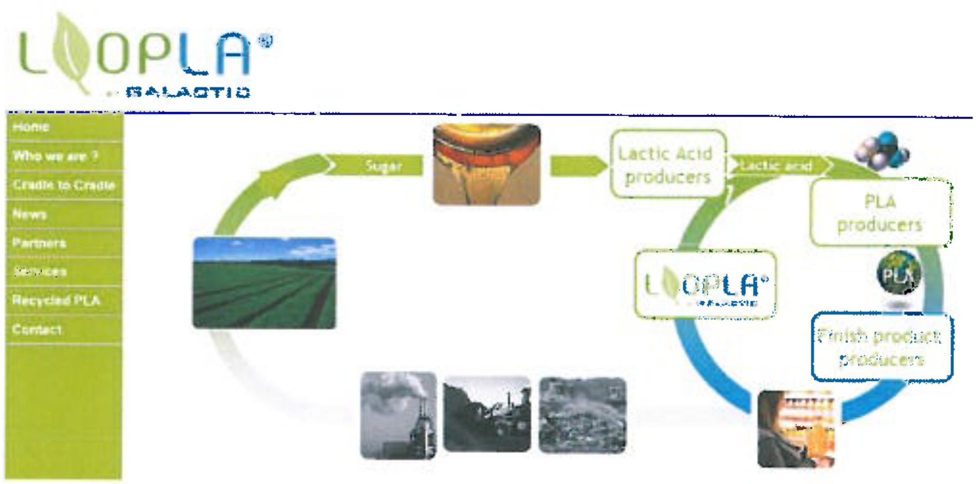


Figure 4 - This quite nicely shows where the Loopla system fits into the PLA recycling process.
http://www.loopla.org/cradle/cradle.htm

Storage and maintenance

PLA filament manufacturers now package filament airtight bags, in order to keep out moisture whilst in storage. This is because PLA tends to absorb moisture while in storage which makes it brittle and can have a number of effects on the finished print, such as discolouration, warping, or completely failed parts. I found an interesting video a long time ago detailing how someone had suffered from a reasonably old roll of PLA breaking up as it was unspooled from the reel, so the heated it up in a pot of water on the stove, which reportedly fixed the issue. I believe the heat will have been responsible here, as the article I found on the 3d printing geek page suggests that the filament is 'hygroscopic', and thus naturally absorbs moisture. http://www.3dprintinggeeks.com/3d-printer-filament-storage/

The 3d printed parts themselves seem to last well, as I still have a few parts I made when I first started experimenting with 3D printing about 3 years that have retained much of their strength and colour. There is certainly a tendency for it to go brittle after a while, though.

How has 3D printing been changed by PLA?

PLA has allowed 3D printers to become simpler, as PLA can be effectively printed without a heated bed or an enclosed build chamber as PLA doesn't warp as much as many other plastics (e.g. ABS) do when the cool. A lighter and less powerful extruder can be used to melt the filament, meaning that that with the same motors the print head can move faster without losing print quality. Perhaps one of the biggest advantages of using PLA over ABS is its low odour when it's melted, which according to the M3D website is 'a faint honey-like odour, if any'. This is in accordance to what I have found in my experiences, and since PLA is a non-toxic bioplastic, these fumes are non-toxic. ABS releases a strong melted plastic type of smell, which due to its oil base is toxic.

Conclusion – Where to next?

3D printing is still rapidly developing as more applications are discovered and new methods and materials are found. I believe PLA will continue to be the most popular choice of 3D printing filaments for a while yet, however many new filaments such as PET, PVA, and nylon offer far better properties and performance, without having to make any changes to the printer.

Grade A	Material PLA
Context 3D printing	Enhancement cost and various other mentioned
	Product generic printed components

Assessment Schedule. AS91613

VERSION 3 annotated 2016

Demonstrate understanding of material development

Commentary

The candidate specified the material to be PLA and the product(s) to be printed components. The report is clear and concise with appropriate in line referencing. There is some confusion when describing the printing as the candidate moves between describing the material of PLA and the components of the printer. Candidates must be clear that they are focussed on the material, its development, which this report clearly shows, and the impact of the material and how it enhances a product and the design, development implementation, maintenance and disposal of the products (in this case the printed pieces such as the gears).

The PLA is defined and the development and historical context is described. Also included are the impacts of changes in PLA over time and the development of 3D printers both considered in relation to printed components. Maintenance and disposal of PLA is included to ensure the criteria for achieved are all covered. The report could be strengthened by explanations of the enhancements to the product through the use of PLA and explaining the impacts on the design, development, implementation, maintenance and disposal on the product,

Issues from the Specifications

- Where a candidate has provided a brief answer, the answer should not be penalised because of length.
- Candidate work in excess of 10 pages must not be marked.
- Where a candidate has used a small font markers should make a judgement about where to stop marking. This judgement should be made relative to 10 pages at Arial font
- Where work is illegible, it cannot be marked.
- Digital submissions that cannot be read cannot be marked.
- Material must be referenced to acknowledge original sources, texts, URLs and websites

Achievement	**Achievement with Merit**	**Achievement with Excellence**
Demonstrating understanding of material development involves.	Demonstrating in-depth understanding of material development involves.	Demonstrating comprehensive understanding of material development involves.
describing the **development of a material designed to enhance** a product's performance describing the **implications of the material** on the design, development, implementation, maintenance, and disposal of products. **MEP** A **Material** must be specified and its **development** must be evident- considering such things as historical and or technical aspects and properties; manipulation, transformation, formulation of the material(s) The **enhancement** must be identified in relation to a specified product (product specified) for example washability, durability, strength, speed enhancement, viscosity The Material must be described in its relationship to and impact on the design, development, production , on-going maintenance and disposal of the **product**	explaining how the **material enhanced the performance of a product** explaining how the **material impacts** on the design, development, implementation, maintenance, and disposal of **products.** As for achievement plus Explain (give detail , example and reason) how Material interacts with the product to enhance the performance of the product Explain how the material impacts on (influences the choices relating to) design production maintenance and disposal of product(s)	explaining the **concepts and processes** employed in the **development of a material.** As for achieved and merit plus Explaining (detail of description with example and reasoning) the concepts and processes used in the development of the material Development, processes such as raw material to refined material and its development and enhancements

Technology AS91613 Schedule Appendix 1

<table>
<tr><td colspan="2">Markers must exercise professional judgement to decide if a report demonstrates understanding. The following appendix provides guidance for markers making this judgement.
A report must use information to demonstrate understanding.
Reports described wholly or substantially by one or more of the statements in the left column demonstrate understanding.
Reports described wholly, or substantially, by one or more of the statements in the right column do not demonstrate understanding.</td></tr>
<tr><td colspan="2">Where the report is made up of both used and reproduced information the marker must decide if the report is successful against the standard when the reproduced information is ignored.</td></tr>
<tr><td>Evidence of use of information(understanding)</td><td>Evidence of reproduction of information (copy and paste/plagiarism)</td></tr>
<tr><td>Candidate’s report describes and explains the Material development related to their context practice, or information relating to the standard</td><td rowspan="2">Information is unrelated to the context, unreferenced and is not relative to the understandings expected at NZC Level 8
Downloaded material that is not mediated, interpreted or synthesised is not acceptable as this does not show understanding of the concepts related to the development of a material or the material’s relationship with product design, development, implementation, maintenance, and disposal

• Comparing various materials for their use in a product or comparison of various products is not part of this standard</td></tr>
<tr><td>Information from the candidate’s practice, research, the practice of others, and teaching is related to the development of a material and then in relation to products..
The report describes understandings you would expect to come from a course of instruction derived from the Technology Learning area of the NZC at Level 8.
These could include but are not limited to

• The context of the products’ development links to the material development and the implications of the material on the design, development, implementation, maintenance, and disposal of products.

• Describe/ explain the material, the product and the enhancement
• Candidates begin with the development and processing of a material and then moved to link to the product development and implications of the material on the design, development, implementation, maintenance, and disposal of products
• Explanations should have detailed description plus how and/or why statements to give reasons

• Information is presented in alignment to context of study and is referenced appropriately and is relevant to the context at level 8 of the New Zealand curriculum

• the design, development, implementation, maintenance, and disposal of products the product in relation to the ,material under review must be part of the candidate description/explanation (some products may not have all parts of this due to the nature of the product but this should be addressed in the report)

• Products may include existing or feasible future products. In the case of feasible future products, the candidate must have covered the range of implications of the material within the context of the future focused product.</td></tr>
<tr><td>Information from research, the practice of others, visiting experts or teaching is reported in the candidate’s own voice to enhance their understandings. Information synthesised from a range of credible evidence and sources is synthesised in a coherent report</td><td>Information is not in the candidate’s voice. The word choice, sentence structure, sentence length, punctuation and so on are not what a candidate could be expected to produce.
However, care must be taken where students have synthesised material to a high degree and presented an articulate report</td></tr>
<tr><td>Referenced, complex research information unchanged by paraphrase (ie use of quotations) is related to other information in a manner that constructs meaning within the context.
Use of credible evidence (not reliant on Wikipedia or wise geek as a sole reference)</td><td>Unreferenced, complex, research information is presented as though it is the candidate’s own work. Plagiarism evident</td></tr>
<tr><td colspan="2">Where the marker suspects a report is a deliberate attempt to deceive the report should be referred to the panel leader using the Irregular Booklet process.</td></tr>
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