PROJECT SUMMARY

Recycled Plastics in 3D printing - Laboratory for Development

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Introduction to the project

Utilization of 3D printing is believed to have as significant impact to societal changing as urbanization and internet. Using recycled plastics in 3D printing is a part of the developing concepts included in the circular economy model. In Finland, recycled plastic waste has not been commercially utilized for 3D printing so far. At the moment, the use of recycled plastics is restricted by significant factors such as the diversity of plastic material, the small amounts in the raw material batches and the traditional plastic processing methods being too sensitive for the changes between the raw material batches. The greatest barrier for the utilization of recycled plastic is pure plastic and manufacturing techniques developed for them especially.

In order to achieve the authoritative objectives related to recycling, new and affordable processing techniques must be invented. This way, 3D printing has potential to rise as one of the most remarkable processing techniques of the future. It is important that recycled plastics are along the development of 3D printing from the start as one of the potential raw materials.

The aim of the project is to renew industries with creating common and new ways for utilizing recycled raw material. The advantages are affecting a wide value chain: from raw materials, to consumer products and B2B-services through industries. The project is based on the needs of small and medium-sized companies, and the researches published related to plastic recycling which claim plastic recycling to develop not only straightening recycling objectives of waste management but also to decrease energy consumption and the need for fossil raw material and this way to help forward the aims of circular economy.

The development laboratory of 3D printing is a project involving the following research partner's; Turku University of Applied Sciences, Arcada University of Applied Sciences and the Finnish Environment Institute, and the project is executed in a close co-operation with the participating companies. In the project, the utilization possibilities of recycled plastics are being researched as a 3D printing material. In addition, related business possibilities are also researched starting from the needs of the companies.

TURKU AMK TURKU UNIVERSITY OF APPLIED SCIENCES ARCADA SYKE Suomen ympäristökeskus Tekes Leverage from the EU 2014–2020 European Union European Regional Development Fund

Research organisations

Turku University of Applied Sciences

Turku University of Applied Sciences (TUAS) is an inspiring community of 10,000 members – an innovative and multidisciplinary higher education institution, which creates international competitiveness and well-being for Southwest Finland. Our graduates are practice-oriented professionals with top competencies.
In the field of applied research, Turku University of Applied Sciences represents the top tier in the country. TUAS coordinates or acts as a partner in over 200 RDI projects annually.
(https://www.tuas.fi/en/)

TUAS was coordinating the whole project and three research groups were involved: the Resource-efficient business research group, the Material efficiency and renewable energy research group and the Future product processes research group. Their role was in researching and developing new business models, in researching and processing of plastic materials and in 3D printing.
(https://www.tuas.fi/en/research-and-development/research-groups/Resource_efficient_business/;
https://www.tuas.fi/en/research-and-development/research-groups/material-efficiency-and-renewable-energy/;
https://www.tuas.fi/en/research-and-development/research-groups/future-product-processes/
)

Arcada University of Applied Sciences / Department of Energy and Materials Technology

Arcada is a multi-professional university of applied sciences (UAS) with campus located in Arabianranta, Helsinki. Arcada arranges degree education in Swedish and English within: Business Administration, Sports, Media, Culture, Social- and Health Care and Technology.
(https://www.arcada.fi/en/about-arcada)

The Department of Energy and Materials Technology is responsible for the education in the fields of sustainable materials processing technology and energy and environmental technology. The degree education is utilising the material processing and testing laboratories at Arcada, as well as the modern engineering softwares (3D modelling/design/printing). The students of Arcada have been active in publishing thesis reports in the field of 3D printing and plastics recycling. During the past few years Arcada has invested to develop the 3D printing laboratory. The Department has also participated in a national strategic research program in the field of circular economy and material recycling, specialising in plastics recycling (http://arvifinalreport.fi/; http://arvifinalreport.fi/content/plastic-recycling/full).

SYKE - Finnish Environment Institute

The Finnish Environment Institute (SYKE) promotes the development of a carbon neutral circular economy and a sustainable bioeconomy by assessing the environmental aspects of products and services throughout their entire lifecycles. Other major issues that the expert and research work at SYKE focuses on include the prevention of waste production, effluents and polluted soil, waste management, risks associated with hazardous substances, and industrial emissions. In this project SYKE studied the sustainability of 3D printing by applying life cycle assessment (LCA).
(http://www.syke.fi/en-US/Research__Development/Consumption_and_production)

Companies

Oili Jalonen Oy

Oili Jalonen is a car recycling company operating in Southern Finland. In addition, the company sells new and used automotive spare parts to consumers and businesses all over Finland. Oili Jalonen has an unswerving desire to serve its customers reliably, quickly and with the highest quality. Oili Jalonen gives full consideration to sustainable development and the environment in every aspect of its operations. (http://www.oilijalonen.fi/)

3DTech Oy

3DTech is one of the 3D printing pioneers in Finland providing customers with comprehensive 3D solutions and services including 3D printing, scanning, design, reverse engineering, consultation and contract manufacturing as well as own 3D printing technology development for global markets.

The company's vision is to allow everyone world-wide an easy access to the world of Direct Digital Manufacturing with user-friendly devices. 3DTech also aims to allow everyone an access to locally produced recyclable materials and biomaterials. (http://3dtech.fi/en/)

Fortum Oyj, Fortum Recycling and Waste Solutions

Fortum is a leading clean-energy company that provides its customers with electricity, heating and cooling as well as smart solutions to improve resource efficiency. Fortum wants to engage its customers and society to join the change for a cleaner world. The company's role is to accelerate the change by reshaping the energy system, improving resource efficiency and providing smart solutions. The company employs some 9,000 professionals in the Nordic and Baltic countries, Russia, Poland and India, and 62% of its electricity generation is CO_2 free. In 2016, Fortum's sales were EUR 3.6 billion. Fortum's share is listed on Nasdaq Helsinki. (www.fortum.com)

Fortum Recycling and Waste Solutions provides environmental management and material efficiency services in the Nordics. The company improves its customers' material and energy efficiency by providing them with recycling, reutilization, and final disposal solutions, as well as soil remediation and environmental construction services.

LapMek Oy

LapMek manufactures wooden pallets for both businesses and private clientele. LapMek uses Solid Edge -modeling software, 3D printing and a six axis industrial robot in their production. With the 3D printer, the company produces all plastic parts that its production requires, for example tool fixings for the industrial robot. (http://www.lapmek.fi/en/frontpage/)

Prenta Oy

Prenta is the biggest 3D printer company in Finland. Prenta offers 3D printers, services and maintenance for industry, companies, schools and private persons. The company has specialized in 3D printing in plastics and it brings 3D printing closer to everyday life. (http://www.prenta.fi/en/)

Methods of Research

THEME 1: Material Research

The materials research included testing the currently most used materials in fused deposition modeling (FDM) 3D printing and studying the manufacturing process of the plastic filament used as feedstock in such 3D printers, as well as attempting to produce filaments using recycled plastics. The filaments produced were then analysed visually and dimensionally and tested further for their properties and usability, in form of 3D printing with the filaments as well as performing tensile tests on the successfully printed objects. The plastic materials studied were ABS, PLA and PP, some of which were studied in pristine form, some as commercial filaments, some as recovered (waste) resources, some as all of the above in various grades. The results of the experiments were as varied as the materials, some showed great potential, a real case for good recycling prospects, while others were verified as nonoptimal choices for 3D printing as such altogether. All the materials were also tested using the following methods: The mechanical properties were tested by tensile testing, the rheological properties by MFR and some of the unconventional materials were further attempted to be characterized by the use of FTIR, DSC and microscopy. Detailed information on the mentioned methods are found via the document's in electronic report at kumu (access using the www address given in References).

THEME 2: 3D Printing

As 3D printing is a relatively new manufacturing method, not a lot of research has been published on the topic of experimental 3D printing. The standards involved and all methodology is relatively fresh. For this project the majority of 3D printing experiments were performed using FDM method, by testing various material filaments, both commercial and experimental, unconventional ones. The materials used in 3D printing include: PLA, rPLA, ABS, rPP. The prints were evaluated and assessed for their properties and the methodology of testing a 3D printed product was assessed as well as the effect print parameters have on the result.

THEME 3: Business Models

3D printing brings new opportunities for business. It enables products to be manufactured close to the customer and to be easily personalised to meet the customer's needs. Complicated components can be manufactured even more inexpensively. Furthermore, the company will be able to enter the market faster, as travel from the designer to the finished product becomes shorter. In this project, it was examined what kind of industrial scale products and models can be created around recycled plastic and 3D printing, for instance by assessing the effects of circular economy on product development processes in various industries.

THEME 4: Environmental Impacts

3D printing can support circular economy e.g. by helping to lengthen the use time of products by stimulating repair of products if spare parts can be supplied on demand. Additionally, 3D printing can improve material and energy efficiency and yield logistic benefits by enabling the decentralization of product manufacturing from large-scale industries to households or office factories. It can lead to reductions in material consumption due to being less wasteful than subtractive technologies. Recyclability can increase when 3D printed products are made from a single material. However, multi-material 3D printed products can impact recyclability negatively.

In this project, life cycle assessment (LCA) was used to evaluate the possibilities to support circular economy with 3D printing in a case example of repair business and spare parts production focusing on the reparation of cars. More specifically, we compared the current way of repairing a broken car handle to a potential 3D printing assisted way. LCA was applied for assessing the global warming of three alternative scenarios for repairing a broken car handle. Scenario 1 represented the current, centralized production, in which the breaking of the metallic handgrip of the car handle causes the entire car handle being replaced with a new one. At the same time all the unbroken parts of the old handle were discarded and replaced with a whole new car handle manufactured from virgin materials. The contemplated car handle was made up of eleven different parts made of plastic and metal. Scenario 2 represented a decentralized production system utilizing 3D printing. In scenario 2 only the broken metallic handgrip was replaced with a 3D printed spare part made from virgin polyamide (PA) printing powder. In Scenario 3 recycled plastics was assumed to be used in the 3D printing to produce the spare part needed to compensate the broken metallic handgrip. For Scenario 2 experimental data for 3D printing was received from project partners, but for Scenario 3 this data was gathered from expert estimates.

Project communication and networking in events

The project has been active in several networking events for communication. The presentation materials are public and can be accessed via the electronic project report at kumu (see the References for e-access) as well as via the links given below.

3DStep, Tampere, 5.10.2016

- Maiju Holm: "Recycling in 3D printing – The use of recycled plastics in 3D printing filament" (https://storage.googleapis.com/turku-amk/2017/05/3dstep-holm.pdf)

Muovijätteenkierrätyksen kevätpäivät, Oulu, 18.5.2017

- Maiju Holm: "Kierrätysmuovien 3D tulostuksen sovelluslaboratorio" (https://storage.googleapis.com/turku-amk/2017/05/muovijatteenkierratyksen-kevatpaivat-holm.pdf)
- Hanna Eskelinen: "3D-tulostuksen ympäristövaikutukset" (https://storage.googleapis.com/turku-amk/2017/05/muovijatteenkierratyksen-kevatpaivat-eskelinen.pdf)
- Liisa Lehtinen: "Kierrätysmuovien 3D-tulostuksen sovelluslaboratorio" https://storage.googleapis.com/turku-amk/2017/05/muovijatteenkierratyksen-kevatpaivat-lehtinen.pdf

The closing seminar of the project, Alihankintamessut, Tampere, 27.9.2017

- Jenni Suominen: "Kierrätysmuovin käyttö 3D-tulostuksessa – mahdollista vai mahdotonta?"

(https://storage.googleapis.com/turku-amk/2017/05/loppuseminaari-alihankintamessut-suominen.pdf)

- Riitta Noponen: ”Kierrätys-ja biomateriaalien mahdollisuudet tulevaisuuden valmistavassa teollisuudessa” (https://storage.googleapis.com/turku-amk/2017/05/loppuseminaari-alihankintamessut-noponen.pdf)
- Juha Nurmio: ”Kierrätysmuovin käyttö 3D-tulostuksen raaka-aineena (https://storage.googleapis.com/turku-amk/2017/05/loppuseminaari-alihankintamessut-nurmio.pdf)
- Maiju Holm: ”3D-tulostusjätteen uusiokäyttö 3D-tulostuksessa” (https://storage.googleapis.com/turku-amk/2017/05/loppuseminaari-alihankintamessut-holm.pdf)
- Hanna Eskelinen: ”3D-tulostettu vai perinteisesti valmistettu varaosa? – Ympäristöhyötyjen tarkastelua case-esimerkin kautta” (https://storage.googleapis.com/turku-amk/2017/05/loppuseminaari-alihankintamessut-eskelinen.pdf)

Summary of the key results

In the following sections links to all data currently accessible for the public is disclosed per theme. The reports and publications lists include internal documents as well as some public articles that are unaccessible online. More information regarding their contents can be asked from the contact person of the organisation involved.

THEME 1: Material Research

In this project batches of recycled plastics with different origin were utilized as feedstock in preparation of 3D printing filaments for FDM printing. The results of the laboratory tests indicate, that it is feasible to recycle the discarded FDM printed objects in manufacturing of 3D printing filament as such, even without blending with a portion of pristine material. However, controlling of the quality of filaments requires more attention, when the recycled plastic is a mixture from several product applications or it is containing contamination (dirt/ other chemically deviating plastics). The recycled material for straight-forward manufacturing of a 3D printing filament, with such such low dimensional tolerances, is required to be as homogeneous (chemical + product type) as possible.

Recycled polypropylene (PP) from car industry was also used as a raw material. Technologies to process it included crushing, extrusion and 3D printing. In these preliminary tests it was discovered that it is possible to manufacture PP filament with 50 % reused raw material.

PUBLICATIONS AND REPORTS

- Katja Talvensaari, Degree Thesis (Bachelor of Engireering): "Car Plastics Recycling" (http://www.theseus.fi/bitstream/handle/10024/132516/Talvensaari_Katja.pdf?sequence=1&isAllowed=y)
- Elina Iunolainen, Degree Thesis (Bachelor of Engineering): “Suitability of recycled PP for 3D printing filament”, 2017 (To be published online in www.theseus.fi open access database)
- A research article: Maiju Holm, Liubov Nikiforova, Kateryna Angatkina and Mirja Andersson, “working title; rPLA in 3D printing” (to be published later in a journal)
- Mari-Liis Kotsar, Degree Project (at Arcada) for graduation (Tallinn University of Applied Sciences): “Filament Extrusion of Recycled PLA and Its Suitability for 3D Printing”, 2017. (Not published by Arcada/internal project report)
- Liubov Nikiforova, Project Report: “Suitability of recycled PLA filament for 3D printing”, 2017 (not published by Arcada/internal project report)
- Liubov Nikiforova, User’s guide: “Extruder purging recommendations”, 2017. (Not published by Arcada/internal document)

- Maiju Holm, Equipment Specific Guide for Students: “MFI testing According to the ISO 1133:2005 standard”, 2016. (Not published by Arcada/ internal document)
- Pietari Shalah, Project Report: “Making Round Filament”, 2016. (Not published by Arcada/internal project report)
- Dennis Biström, Pietari Shalah, Project Report: “New Die and Nozzle”, 2016. (Not published by Arcada/ internal project report)
- Kateryna Angatkina, Project Notes: “The Separation of PLA”, 2016. (Not published by Arcada/ internal document)
- Kateryna Angatkina, Technical Notes: “Filament extrusion of pristine PLA”, 2016. (Not published by Arcada/ internal document)
- Kateryna Angatkina, Maiju Holm, Technical Notes: “Filament extrusion of pristine ABS”, 2017 (pdf). Accessible via the e-report at kumu (see the References)
- Kateryna Angatkina, Maiju Holm Technical Notes: “Filament extrusion of pristine PP”, 2017 (pdf) Accessible via the e-report at kumu (see the References)
- Kateryna Angatkina, Project Notes: “ Filament Extrusion of Recycled PLA and Its Suitability for 3D Printing”, 2017. (Not published by Arcada/ internal notes)
- Maiju Holm, Project Activity Summary: “Process optimisation and equipment upgrades for extrusion of 3D printer filament”, 2017 (pdf) Accessible via electronic project report at kumu (see the References)
- Juha Nurmio: "Polypropylene filament for 3D printing manufactured with recycled raw material", 2017 (pdf) Accessible via electronic project report at kumu (see the References)

THEME 2: 3D Printing

The 3D printing settings for printing of tensile test dumbbell samples was studied and some optimisation was reached. PP was one of the more unconventional 3D printing materials used in the project. In the ELV waste research it was found out that PP is hard to print without a heated build platform and anti-slip tape.

PUBLICATIONS AND REPORTS

- 3DTech, Oili Jalonen: https://www.y-lehti.fi/uutiset/nayta/14109?uutiset/nayta/14109
- Sara Gallardo Nieto, Degree Project (at Arcada) for graduation (the Universidad Politécnica de Madrid): “Comparative analysis of 3 D printers at Arcada UAS: Fused deposition modelling (FDM) and Stereolithography (SLA)”, 2016. (Not published by Arcada/internal project report)
- Adolfo Olea Gutiérrez, Degree Project (at Arcada) for graduation (the Universidad Politécnica de Madrid): “Tensile Behaviour of layered polylactide (PLA), 2017. (Not published by Arcada/internal project report)

THEME 3: Business Models

Based on the research on the novel business models in 3D printing it was identified that the concept of circular economy is somewhat familiar among industries and companies. However, the benefits of the economic model and ways to achieve these should be emphasized. In addition, it was discovered that the intellectual property rights regarding 3D printing are still in transition. Therefore, at the moment it is difficult to estimate how they will change in the future. To ease the transition, it would be essential for companies to develop new business models. For further study it would be beneficial to study the transition of intellectual property rights regarding 3D printing in the automotive industry.

PUBLICATIONS AND REPORTS

- Nina Aarras, Jenni Suominen: "3D-tulostus avaa uusia ovia kiertotaloudelle" (https://bastuturku.wordpress.com/2017/02/08/3d-tulostus/)
- Laura Laitinen: "Kiertotalouden vaikutukset tuotekehitykseen", opinnäytetyö (http://urn.fi/URN:NBN:fi:amk-201705168434)
- Laura Laitinen: "Kuinka kiertotalous vaikuttaa tuotekehitykseen?" (http://www.uusiouutiset.fi/kuinka-kiertotalous-vaikuttaa-tuotekehitykseen/)
- Jenni Suominen: "Tulevaisuuden muoviosat valmistetaan kierrättäen ja paikallisesti" (http://www.uusiouutiset.fi/tulevaisuuden-muoviosat-valmistetaan-kierrattaen-ja-paikallisesti/)´
- Laura Laitinen: "Kierrätysmuovit tulevat mukaan 3D-tulostukseen" (https://storage.googleapis.com/turku-amk/2017/05/muoviplast-3d-laitinen.pdf)
- AMK:n opiskelijat kiertotaloutta edistämässä (https://www.turku.fi/uutinen/2016-07-06_amkn-opiskelijat-kiertotaloutta-edistamassa)

THEME 4: Environmental Impacts

The preliminary LCA results of the case study on repairing a broken car handle indicate that 3D printing could help mitigating climate change impacts in spare part business operation. Largest environmental benefits can be obtained from the potential reduction of natural resources use and recycling of the broken spare part. Nevertheless, the results are very case specific and when developing business models based on 3D printing, the environmental impacts should be studied for each case.

Uncertainties in the results of this case study originate due to e.g. the following:

- Modelling the use of recycled materials in the 3D printing instead of virgin material suffered from lack of data. Recycled powder material for 3D printing could not be obtained and printing could not be experimented. The use of recycled material in 3D-printing requires further research.
- Data on 3D printing materials and their manufacturing was not found in databases or from operators.
- Results were very much affected by the energy consumption of 3D printing, which varies a lot. Only two printing methods were modelled in the case study.

PUBLICATIONS AND REPORTS

- Eskelinen, Laine, Dahlbo, Soukka: Environmental competence of centralized versus decentralized spare part supply chains - case recycled thermoplastics (estimated to be published in 2018)
- Eskelinen 2017. Tarjoaako 3D-tulostus ympäristöhyötyjä varaosabisnekseen? Loimu 5/2017.
- Eskelinen & Dahlbo 2017. Tarjoaako 3D-tulostus ympäristöhyötyjä varaosabisnekseen? Ympäristö ja terveys 7/2017.
- Eskelinen & Dahlbo 2017. Tuoko 3D-tulostus ympäristöhyötyjä autokorjaamotoimintaan? Purkamo Uutiset 4/2017.

Discussion

During writing this summary, two scientific articles based on the results are still in preparation. SYKE is publishing the environmental competence of supply chains of centralized versus decentralized spare parts, and Arcada is publishing the experimental results on utilisation of rPLA in the manufacturing of 3D printing filaments. In addition to this some thesis publications are also in preparation.

The interest towards the project, as well as the number of companies starting in the field of 3D printing indicate that there is a need to develop the technology further. Currently the use of recycled plastics in 3D printing is very limited. In order to develop the growing 3D printing industry into a more sustainable path, the use of recycled materials as well as assessing the recyclability of the printed objects is essential.

Material research in this project focused mostly on FDM 3D printing technology. The results indicate that failed FDM 3D printed objects can in principle be used in making a new filament for the same process. However the feasibility of this should be assessed. It appears to be more worthwhile to use significant waste fractions for industrial scale solutions. Also different usage of failed FDM printed objects could be considered altogether. The very strictly defined tolerances for a FDM filament create challenges for production with 100% recycled materials. Also the fine lumen of the nozzle of the FDM 3D printers require that there are no immiscible contaminations in the filament, making the material requirements for the feedstock regarding the purity high. This kind of waste plastic is more likely found on an industrial level (chemically homogenic reject from production), yet contaminations are possible there as well.

While the 3D printing industry is expected to grow, it might be meaningful to focus on the sustainability of other 3D printing technologies than FDM 3D printing. As a manufacturing method FDM printing already involves such a high number of processes, from making the filament, to using the 3D printer to remelt it, then to repeat the two if looking to recycle the plastic. Using pellets or flakes of recycled plastic as feedstock for a 3D printer could be an option for deleting the production of the filament in between. This, however, would require a different kind of a 3D printer altogether.

In addition to the studies regarding the plastic materials, FDM 3D printing as a manufacturing method was also briefly investigated. The printing patterns were assessed to see how they affect the strength of the printed product, and tensile tests were performed on various kinds of test specimens. As 3D printing is a developing field of manufacturing methods, a single standard that applies for example to mechanical testing of FDM 3 printed objects is yet not established. In general, the standardisation process for 3D printing technologies is gradually ongoing and all new research data would greatly benefit it.

Considering the new business models in 3D printing, the intellectual property right questions arise. The intellectual property rights encourage creativity and inventiveness but in circular economy they act somewhat as a limiting factor, for example, for 3D printing of car spare parts. The solution is to find new business models. A similar struggle has once occurred in music industry, which eventually developed functional business models (e.g. streaming services). Currently, the intellectual property rights regarding 3D printing are still in transition. Changing business models to match 3D time as early as possible saves resource-intensive fighting in this regard.

The results of the environmental impact assessment help focusing the development of the studied process chain to minimize the environmental impacts generated. The results support the application of waste hierarchy where reuse of parts and products is on the highest level followed by recycling. Further research is required on the sustainability of using recycled materials in 3D printing and on the different 3D printing methods. Each new business model should be assessed separately in order to minimize the environmental impacts.

TURKU AMK TURKU UNIVERSITY OF APPLIED SCIENCES ARCADA SYKE Suomen ympäristökeskus Tekes Leverage from the EU 2014–2020 European Union European Regional Development Fund

References

The electronic project report accessible via Kumu at:

https://resurssitehokkuus.turkuamk.fi/uutta-liiketoimintaa/kierratys-3d/

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