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GLOBAL SYSTEMS DESIGN

Implementation of 3D printing technology in flexographic packaging printing

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Preface

The concept for this project, was born during a conversation I had with a good friend of mine who owns a small printing paper factory in Chios island, back in Greece. Many times, in the past we have been discussing about his business and about the hard work in his factory. It is quite challenging for a small company to run its business from the very start with the orders, facilities, labour, machinery, packaging and even delivering the final products with its very own capacity. It doesn't seem easy at all and for sure this small place, has potentials for improving in many areas of its operation.

We really have had interesting talks regarding the actual printing process, which I feel is quite impressive. When I got explained the basic philosophy of how the machine works, something was telling me that I could do something in there, to learn more and perhaps I could come up with some idea for my good friend Kostas. We talked about the printing plates that he uses for his production. One of his main concerns was the cost of it and that there wasn't any possible way of modifying it, without damaging the prototype. He did once try to modify the printing plate (I figured out the name after I started working on this) in order to accommodate a customer's request on adding a Christmas decoration on it. A bakery logo for December only. He kind of ruined the plastic mould with the logo. He did manage to satisfy his customer, but now he had a ruin plastic negative of the logo, into pieces. That part costed approx. 250 euro, and its replacement was expensive.

Something was blinking in my mind, but without giving that much thought until when I discussed the matter with Professor Lazaros Nalpantidis and he proposed to investigate the possibility of using a three-dimensional printer (3DP) for that matter. A master thesis, presented here in Aalborg University, had previously investigated the 3D printed injection mould tools and based on that case study, significant results there were presented. It was very interesting to see how this excellent work, proceeded throughout the pages, experimenting with the 3D printing technology, proving that there are many benefits of its application and a definite need for attention in manufacturing processes, more than in the prototyping phases that it was aimed for, in the early years when this technology was born. I couldn't have had a better opportunity than that, to use what I have learned during the period of the master's programme had started. In fact, I have had courses and projects with the use of the 3D printing technology as a focus item, and I could see now a possibility of combining this experience with other topics that the university offered me throughout the semesters.

That would be an excellent self-test, for applying my knowledge with a real-time business problem. I could apply the MSc tools to, identify the system, its characteristics and problems, redesign it, and evaluate the final results, having gained an overall look of this specific system.

Acknowledgments

Firstly, I would like to thank my supervisor Lazaros Nalpantidis from Aalborg University. This work, wouldn't have come to life without his guidance. I would also like to thank my dear good friend Konstantinos Evgenikos, the owner of Hartopolis paper printing factory, which offered all his knowledge and of course the facilities and equipment for this project. He was always busy with work and family, but he did everything he could to help me fulfil this project. I would also like to thank 3DHub and Kostis, the 3D printing expert who helped me out with the items we have created in his lab, it wouldn't be possible without his help. I shouldn't forget my family back in Chios, which they have had the kid again in house, being spoilt, after many years living abroad. Closing I would really like to thank my very good friends, Allan, Graca, Inga, Jesper, Karsten, Katerina, Maria, Michael and Stefanos, that they were picking up the phone once in a while, to send me good energy and pull me back into the work mode. Their support was what I really needed, and I feel they have had a share of this work.

Abbreviations

AM additive manufacturing

ABS acrylonitrile butadiene styrene

CAD computer aided design

FAB LAB fabrication laboratory

FDM fused deposition modelling

LOM laminated object manufacturing

R2R roll to roll

RP rapid prototyping

SGC solid ground curing

SL stereolithography

SLA stereolithography apparatus

SLS selective laser sintering

SME Small and medium-sized enterprises

STL standard tessellation language

TP thermoplastics

TS thermosets

TPC thermoplastic co-polyester

UV ultraviolet electromagnetic radiation

3DP three-dimensional printing

3DP flexo-plate three-dimensional flexographic printing plate

Introduction

Since the industrial revolution had started for more than 250 years ago, the use of machines has been the major part of this breakaway. The hand labour was replaced by the industrialization while the constant technological development, came side by side along the way, together with terms, such as, time, money, efficiency, effectiveness, quality, customer satisfaction.

One of the most distinguished technologies that became a major part of worlds daily lives was printing. Printing in nowadays is everywhere, from books to magazines, street signs, to food packaging, from a tiny wrapping paper to a large scaled advert sign on top of a building, a truck or an aircraft. Obviously, this industry has created products and services that our societies are using and counting on a constant basis. More particularly, flexography is a printing technique which finds applications mainly in the packaging printing industry, including food packaging, using thin substrates from materials, such as paper, cellophane and many more. The printing press that is used in this industry, is a complex machine which often combines more processes than printing, such us folding, packing etc, to produce the final products.

European commission reports, that the 99% of the European enterprises, labelled as micro, small, or medium sized, are dominating the European market. The SME's that are commonly known, are enterprises having less than 250 persons to work for them [1]. The 1% of the big enterprisers, seems to have more people, money and opportunities to invest to new technologies, without any significant delays or issues in their function. But what about the smaller ones? Even though they dominate the market, the budget usually doesn't give the chance for updating the equipment, hiring more personnel, or introducing their businesses to new technologies, able to boost their performance. On the other hand, there are companies that have even less than 10 employees which directly labelled as micro enterprises. Those companies, also need to find ways to improve their productions, cut costs and improve the technologies they currently use.

This project was accomplished in collaboration with Hartopolis, a paper printing factory with 3 employees. The expensive raw materials comparing with the prices that bigger sized companies can get, the old machines and an increasing order demand, which is positive but challenging, because of the special requests for customization needs. Due to seasonal changes customers, requests on small adjustments on their logos, are increased. Logos modified during Christmas, Easter, winter or summer, would make more attractive and competitive the company's production. This seasonal modification though, is not affordable, since the current plate making is expensive and time consuming due to the external partner's production flow. All those assets together with the external partners, added to the puzzle, the company is trying to survive and think ways for its efficient and as competitive as possible performance. There is not budget for innovative big plans, but still there is knowledge, technologies and will power, that can always make a difference.

There is a main part of the printing presses, called flexographic printing plate, which is responsible for the imprints on packaging. That could be interesting to be re-designed and produced with the use of 3D printing technology, which currently is blooming. Since 3D printing technology is getting more affordable every year, and constantly evolving and there is a customer demand in customizations of their products, it would worth to investigate this matter and try to find out how this idea could come to life, and merge the two technologies together and see what the outcome could have been.

Therefor this project will test the possibility of re-designing and creating with a new manufacturing method the flexographic printing plates, replacing the dominant current plate making technique and examine the advantages and disadvantages from the attempt.

Problem formulation

In this project will be investigated the possibility of replacing the current printing plates manufacturing technology, by using three-dimensional printers (3DP), as well as if there are to be found other materials which can replace the ones that are currently used. That would allow Hartopolis not to rely on external suppliers for the printing plates, to have frequent design changes and to reduce production costs.

Research questions

The main research questions that will be answered are:

- How does the current process flow with the use of the flexographic plate?
- Is the use of a 3D printed printing plate, technically and economically feasible?
- How realistic is the implementation of a new technology?

Limitations delimitations

Firstly, Hartopolis provided access to the factory to observe and understand the processes involved in typical production day. It should be noted, that printing days, are only based on incoming orders. The order's pace, is based on the season. The current time that this project took place was in a low production season. That means that the opportunities of observation of the actual printing day were only few.

That didn't create any negative effect in the current work, since the aim was on the printing plates and their replacement from the new ones. That gave the opportunity to test the 3D printed prototypes when the machines had a "day off".

Secondly, regarding the printing experiment, it should have been taken into consideration that it wasn't economically feasible to run the machines for long time, due to paper, electricity, ink and time costs. The experiment ideally could have run for a certain time of the day but the practicalities, gave the opportunity to run it for each of three-dimensional printed flexographic plate (3DP flexo-plates) for a sort cycle. A longer cycle could have put in a more realistic test the material's strength, durability under pressure and a better understanding in its aging process, during the printing process.

Another fact was that there wasn't a direct access to a 3D printer or any fab lab in the island. The only alternatives, were 3D printing companies which they were found online, located in Athens. That means that more tests, printing attempts, material selection and general experimentation could have been accomplished, but that narrowed down the experiment's options. It was decided for the 3DP part, to be taken care of an external partner, which in this case was a company called 3Dhub. The company choice was made based on its very positive review, large varieties with 3DP materials, different kind of printers and quite good experience, since they are in the market more than two years, having great success. The distance also had to be taken into consideration and the difficulty that was faced regarding ordering, producing and delivering the items needed. Therefor lack of direct access to a lab limited the efforts and results of this work.

It should be also noticed, that processing methods to finishing the products, will not be investigated. Nevertheless, the experienced gained during the Master's program back at the university's fab lab, by having worked closely with 3D printers and CAD programs, redesigning and producing prototypes, as well as a visit to a 3D printing company, provided valuable experience over that matter.

It should be also noticed that topics such as marketing, and the use of other additive manufacturing and not only technologies weren't chosen to focus on. The economic feasibility of this work, was decided to present the direct cost only, (paper, ink, platemaking) and no 3D printer prices and the general cost of running the business, such as electricity, labour, taxation etc., have been considered.

The logo chosen to be the focus for the project, were initially, the Aalborg's university logo which is relatively simple and a logo that Hartopolis uses for one of their active customers. Nevertheless, the prices for printing plates in the actual size (an average plate is 12,5 cm x 40cm) that the company uses for its production, would have been proved costly, even before the experiment had started. The choice of a smaller and simpler logo, was thought as a good way to start, test and evaluate the idea, before moving further on bigger and more complex printing plates. For the same reason, it was decided the use for one colour only, meaning only one printing plate (if an image requires more colours, each colour should have its assigned printing plate).

Another tool used within this work, is the SIPOC (suppliers, inputs, process, output, customers) high level process map. This tool is commonly used in Lean Six sigma, which combines different tools for process improvement. This work will not utilize this technique, but it was decided this specific flow chart to be used, to create an overview of the Hartopolis as a system and by analysing the interconnection in between the different processes.

Method

The method this project followed, commonly is known as the research onion [2]. The philosophy is that while the research starts, the different steps needs to be unfolded and examined. As the research proceeds and every layer is comprehended, the next layer has its turn to be examined. Like an onion that is peeled off, layer by layer, the same way was used to reach the core of this project which were to be answered the research questions formulated after the problem formulation was stated.

More specific the research philosophy is based on the experience that will be gained during this work and that will provide a solid base, commonly accepted for the next step. An inductive approach characterised the current work, which means a lot of information regarding specific technologies were gathered, such us readings, as well as talking to people related to the business. The goal was to learn this subject in a realistic way. Important to notice, that there might be theoretical background for the technologies presented in this report, but the same time it no reported related work or study was found, investigating the potential of using additive manufacturing technology to replace the dominating manufacturing technology, for the so called flexographic printing plates, the focus of this report. Therefore, the knowledge gathered from this specific topic, could be generated and provide with new information this newly touched subject. For that reason, a case study will be able to look closer the issues that will arise, and the experimentation will help, as much as possible, to a concrete conclusion of the work, by analysing the data gathered. The following figure1, depicts the steps explained previously.

12

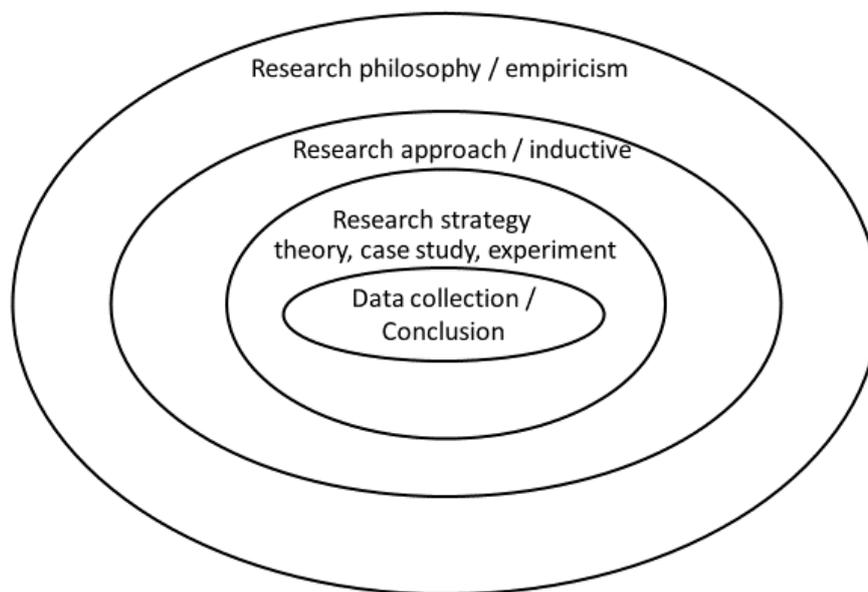


Figure 1 The research onion method, adopted from Institut Numerique

¹ <http://www.institut-numerique.org/chapter-3-research-methodology-4ffbd6e5e3391>

² <https://www.ukessays.com/essays/psychology/explanation-of-the-concept-of-research-onion-psychology-essay.php>

Theoretical background

Printing history

Johannes Gutenberg back in 6th November in Mainz Germany 1445, introduced the world to his breaking through invention, the letter press printing techniques. His innovation, the moving type printing machine, produced the first book ever printed in Europe, the so called "Forty-Two-Line" Bible. Johannes Gutenberg's name was recognized as the father of the letter printing. The next 400 years whole Europe used his invention as a standard printing type process. [3] The letterpress, known also as relief printing, basically uses metallic parts, such as (letters, lines, punctuation, in different fonts etc) that are raised in such a position within the printing surface, while ink supplied to those raised parts. The pressure applied to the specific area of the raised surface, results to the printed paper on demand.

Introduction to flexography

Flexography is an improved letterpress technique with the only difference that the printing plates used on cylinder for that case, are constructed by flexible or soft materials, such us rubber or plastic, instead of the hard metal printing plates that letter press uses. Important to notice, that those printing processes are distinguished as, roll to roll (R2R) manufacturing processes which are allowing high printing speeds in mass production which is an advantage.

The ability to print on any flexible and underlying layer or substrate as it commonly called, such as paper, cellophane, plastics, even microelectronics, makes the flexographic printing very popular, especially for food packaging and product labelling. This kind of printers operates in a highly efficient and cost-effective manner. Depending on the machine, the printing rate can reach up to 400 meter/minute. That is a remarkable speed comparing with digital printing or lithographic presses. The technology finds applications commonly, in food packaging, which demands high levels of health and safety standards. Important to notice that the broad ink diversity (low viscosity), such as Water based, Solvents and Ultraviolet (UV) makes flexography more appealing to different customers. [4]

The general principle of the flexographic printing press, shown in the figure 2, aims to transfer the low viscosity ink from the ink fountain and with the use of the fountain roller. The anilox roll, which is a specially designed cylinder, regulates the ink supply on the printing plate by contact, during rotation. The printable area of flexographic printing plate (texts, images), which is mounded on the plate cylinder, meets the anilox roll. This process supplies the flexo-plate with ink and with the applied pressure from the impression cylinder beneath the image will be transferred on the substrate.

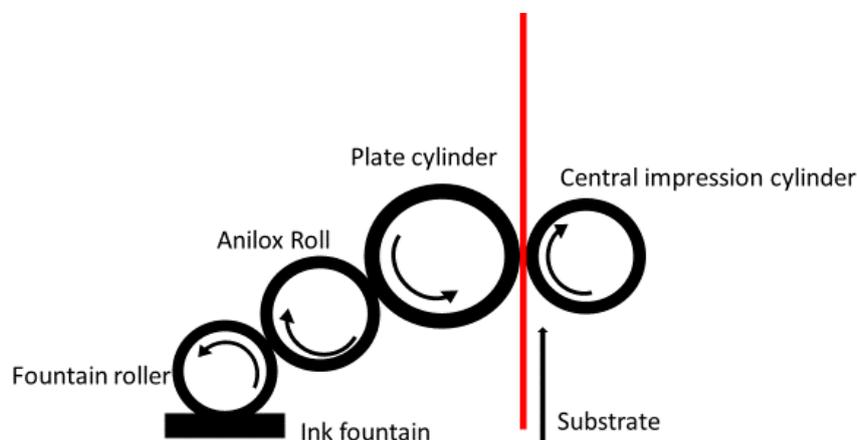


Figure 2 Flexographic printing press, own production

Flexographic printing plates

A large variety of flexographic printers, with Europe and USA leading in this manufacturing production are commonly found in the market. The platemaking process is the most important part. The flexographic printing plate as it is called commonly named as flexo-plate, which is a plain flat flexible base where the text and images are raised off and kept grouped together, resulting on the negative of the imprint to be printed. Depending on the number of colours required for the final image, separate plates needs to be produced, corresponding to the colour number, resulting in a two, or up to five coloured images.

Three main platemaking manufacturing processes can be distinguished, throughout the printing history:

- Metallic plate etching / rubber plates:
Initially, an engraved negative of the print image is created on a plate made of metal zinc or magnesium. The emerged image will be visible on the plate after, a thorough wash in an acid bath. As a following step, a plastic mould is produced, shaping the flexible thermoplastic polymers, to the final printing plates. This method is not used nowadays, because it tends to be rather time-consuming and expensive.
- Photo etching or photo chemical milling / Photopolymer Plates:
UV light projected on a light sensitive polymer plate, where the areas exposed to it, hardens and by the removal of the surroundings, (washing, use of tooling) the plate is ready for use. This producing technique is the most commonly used.
- Digital platemaking/Digital Plates:
In this process, the initial digital image is projected via a computer driven laser equipment on the surface of the photopolymer plate. [5]

It should be noticed that flexographic printing is the only letter press process that is still growing, especially in packaging, label and newspaper printing. As referred to the report earlier, flexographic plates are the main feature of this technology and they are made by softer materials comparing to book printing plates. The following figure 3, presents an example of how a photo-polymeric plate, is exposed to UV light, the hardening of the surface after the UV exposure and the final plate, having removed the unexposed areas.

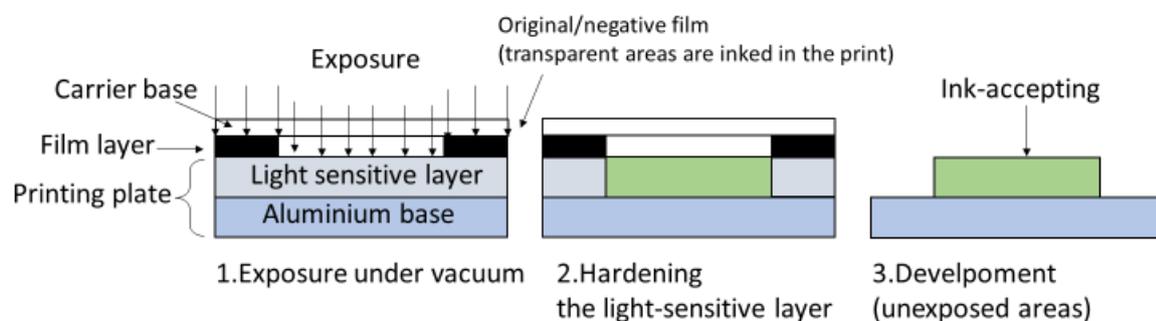


Figure 3 Plate making using a photo polymeric plate, adopted from Handbook of Print Media, H.Kipphan

The following figure 4, presents the printing plate's structure.

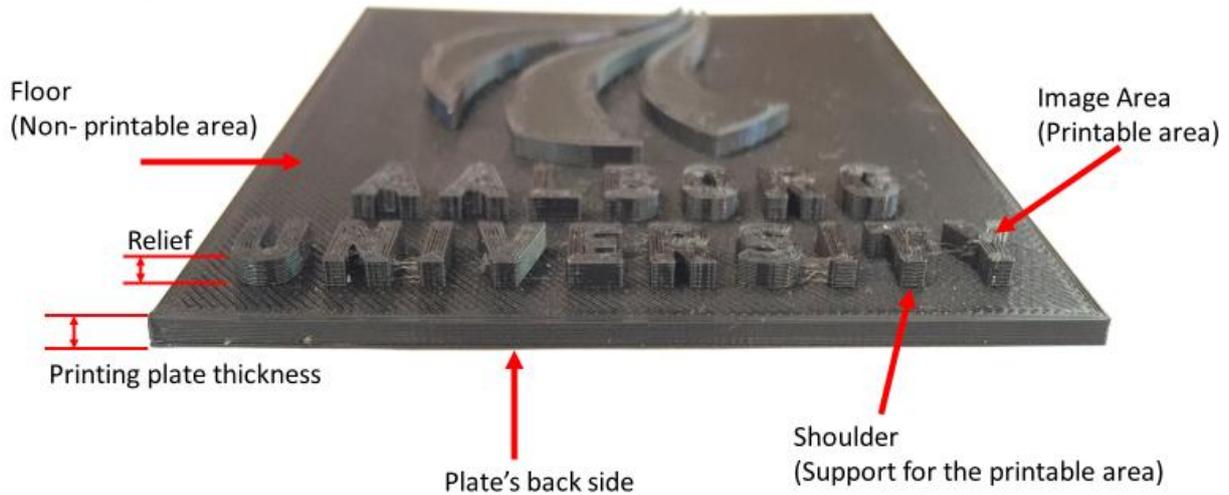


Figure 4 Printing plate description, own production

Polymers

Polymers, are one of the three main engineering materials, together with metals and ceramics, which used in manufacturing. Most polymers that are used today are synthetic. Plastics and rubbers are the two subcategories, which are produced by applied chemical processes.

Thermoplastic polymers or thermoplastics (TP) are solid materials, that when heat is applied, their phase will turn into a liquid form with no much energy intake. That means that can be shaped and formed in an easy manner and produce finished products with less energy consumption comparing with the metal industry. An advantage is they have long life cycle.

Thermosets (TS) are polymers which react differently (in comparison with TP) into temperature changes, meaning after heated up and while cooling down, the chemical molecule changes the material in a permanent state, that cannot be melted if heat is applied again.

Elastomers, common known as (rubbers) have many similarities to TS in a molecular structure, but this material when in solid form can be stretched in extremes ways and still can regain their initial shape [6] Those different polymers categories finds applications in different industries and products. Thermoplastics are commonly used in 3DP technology, and there is a continues effort on creating materials that they could serve this industry.

Acrylonitrile butadiene styrene (ABS) is a plastic which consists of three combined polymers. ABS is having useful mechanical characteristics therefore finds applications in different industries such as, piping, tooling, manufacturing and it has become quite common in 3DP. [6]

The market has quite a few companies producing flexographic plates, with different names each company such as Cyrel from Dupont, Nylonflex from Flintgroup and Flexcel from Kodak, but following the same manufacturing plate making principle. These manufacturers having a large variety of products and equipment related to flexographic printing [7] [8] [9] [10]

Nevertheless, Cyrel is the most popular method in flexography, but that comes as well with a high price. Especially, when it is about small companies that the production, follows a low pace. An option of replacing it with another printing making method, such the 3DP which is examined in the current work, would seem appealing for Hartopolis.

Figure 5, presents, the Cyrel making process, (all brands following similar processes) requiring four different machines for the preparation.

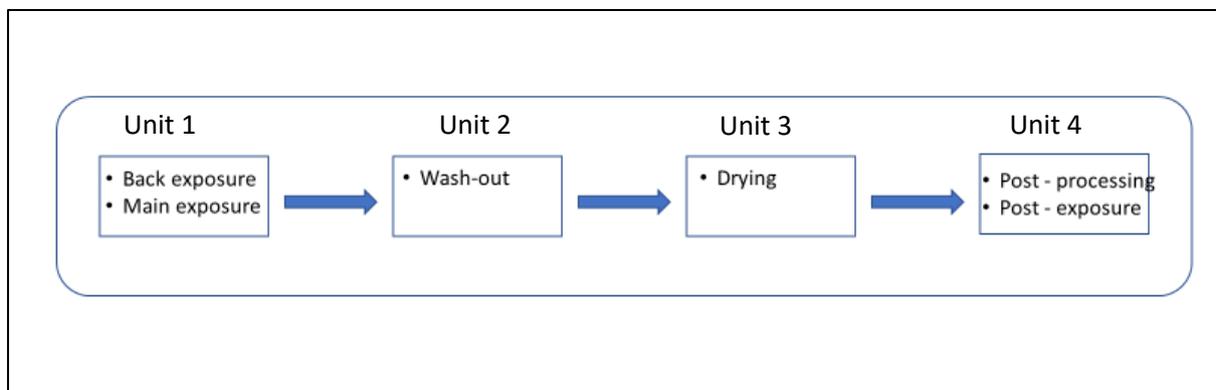


Figure 5 Cyrel printing plate making process, own production

Brief History of Additive Manufacturing and 3D Printing

Additive manufacturing is a group of manufacturing methods with its main goal, to bring to life a digital design to the physical world in a relatively short time. That gives the opportunity, for a product under development, an architect model, or a machine part, to be created and evaluated before its real production. In some cases, it can be used directly, if the material fulfils the criteria that a final product requires for its usage.

There are two main categories of manufacturing processes. The subtractive manufacturing methods, with the most popular the computer numerical control (CNC). This more traditional method, includes steps, that involves machinery methods such as, drilling, cutting, milling and while removing material, resulting to a final product.

On the contrary, the additive manufacturing (AM) processes, can produce a product by building it layer by layer from the start to the end. The last few years, worldwide has been observed an explosion of a promising and remarkable AM method known as 3D printing, which uses one and only machine to create a product. Initially, digital files are required, which are necessary to create the product required.

Since 1960's researchers tried to work on ideas of manufacturing 3D objects out of photosensitive materials with different methods always combining it together with digital computer files. There were many ideas, researches and innovations, with the most of them never commercialized or became known, mainly because of the manufacturing or/and research cost level.

All started back in 1967, when a Danish researcher named Wyn K. Swainson and his partners, had the idea of creating a 3-Dimensional object by using a laser beam that could change after its application, the physical characteristics of a photosensitive material. The patent was granted in 1981 but it didn't go as expected until it died out few years later. [11]

Charles W. Hull the founder of 3Dsystems corporation³, in 1983 invented stereolithography (SL)⁴, which officially, was the first 3D printing technology. Not to forget to mention that 3D Systems was the first 3D printing company in the world. The basic principle of this method uses a laser beam that is projected on a tank which contains a liquid photosensitive material. The laser "dances" on the liquids surface and layer by layer a 3D object gradually is emerging from the tank. [12] [13] [14]

In the beginning of 1990's another method was developed by Scott Crump back in 1988, founder of Stratasys⁵, known as fused deposition modelling (FDM). That became one of the most popular 3D printing methods especially after 1996 when low cost printers made their debut in the market.

The principle of the process, uses different kind of a filaments based on thermoplastic polymers (TPE), polyester, ABS, elastomers, and investment casting wax. The filament needs to be heated up to a point, that it becomes soft enough to be spread out of a nozzle. The object is created, on a glass or metallic surface and it consists of very thin layers, grouped together, resulting to the final product. The affordable prices, gave opportunities from educational institutes to even hobbyists, to own a 3D printing machine.

More 3DP methods were developed through the years such as solid ground curing (SGC), laminated object manufacturing (LOM), selective laser sintering (SLS), and generally many things have happened since then, developing this technology that currently seems to blossom. Internet use and the open character of this technology, is a part of its success, by means, giving access to more and more people all over the world.

It should be noticed, that an initial step for all AM technologies, is the use of a computer aim designed (CAD) which required for designing the product on demand followed by a standard tessellation language file (STL), that converts the digital model, into a group of sliced layers before the 3D printer receives and executes the printing process. [15]

Of course, by referring to all those technological methods it shouldn't be forgotten the term Rapid prototyping (RP) which intentionally kept out from this report. RP, are named all those techniques, which have as a goal to create a prototype rapidly, giving the advantage in many different industries to visualize in sort time a product, study it and re design it, before its production using the necessary manufacturing techniques. 3DP is linked with that term, due to the high speeds to conventional manufacturing, but the effort of this work, having focused on using the 3DP technology only as a manufacturing technique and not a quick way to create the product.

[14] [13] [12] [16] [4] [11] [17]

³ <https://www.3dsystems.com/our-story>

⁴ https://www.youtube.com/watch?v=3uYsviZ8Cuo&index=1&list=PLE0sxfHXc9_fx3PLtACy952RxqoFKwI11

⁵ <http://www.stratasys.com/>

Case study

Company introduction

Hartopolis, is a paper printing factory, located in Chios island in Greece and the only food packaging business in the island. The local market has many bakeries, local fast food restaurants and of course fish boutiques, grocery shops etc. The number of customers exceeds the 300, but their activity differentiates based on their individual workload. Obviously, there is a need for the food packaging market, which Hartopolis, is taking care of. The demand is quite high, since all those shops and businesses are in need for packaging almost daily, depending of course on the size of their orders. It has been noticed that the demand increases during the summer period, which starts as early as May and starts to decrease at the end of September.

The company has 3 employees. The staff, operates the machines and perform the necessary work, involving the overall process, from raw materials (order, storage, usage), the actual printing operation such as, pre-printing, printing, post printing processes, including the final packaging and shipment to the final customer. In some cases, they take care the maintenance of the machines which might get relatively small problems and easy to fix. Finally, the administrative work is performed as well. Obviously, there is a lot of work to be accomplished and therefore with the more improvements in any aspect of the production, the better results will be shown, in the overall operation. More detailed can be seen in the following chapter economic feasibility.

The number of customers it is a vitally important issue for the company which wants to keep a healthy and steady operation with the possibility of a profit increase. Naturally, more customers mean more work and an increased income for the small company. Each customer has individual needs regarding the appearance the requested products. It is very important for Hartopolis, to have a high customer satisfaction. Requests for seasonal additions on the logos, like Christmas or Easter, for example are increasing, but the company can't afford to accommodate those requests, due to the cost of the current plate making technique. An average cost of a printing plate is approx.250€. A replacement just for a short period of time, is not feasible. Opposing a large sized company with more advanced technology, better trained crew and larger budget, there are a lot to be done for optimizing the many different processes within the whole company system.

Paper type	Specific weight	Tons / year	Cost in euro
Grease proof	45gr / 32gr	20 tons	26.000
Butcher's wrapping	90gr / 115gr	62.4 tons	46.800
Fish wrapping	100gr / 130gr / 170gr	3 tons	1.500
Bakery very thin layer	27gr	4 tons	4.200
Total		89.4 tons	78.500

Note: Average size order 185kg / customer

Table 1 Paper costs of Hartopolis

Ink	4.5euro / litre	(7litre/ton) x 3colours ink	94.5 euro / ton
Cyrel printing plate	0.5 euro / cm ²	Av. 12,5cm*40cm	250 euto / plate

Table 2 Ink & Cyrel costs of Hartopolis

From the previous operational direct costs, can be accumulated the paper and ink cost together:

89.948 euro / year

It should also be noticed that 1 ton of paper requires 7 hours of processing. (printing 4hours + folding & cutting 3 hours)

Machines description

There are two flexographic printing presses within the Hartopolis factory. One is a model manufactured in 2003 (machine A) and the other has a manufacturing year in 2006 (machine B). These machines can perform more tasks, than imprinting the logos on demand. Involved processes such as folding and cutting are following the very first step of the main printing process. The finalized item, exits the press and depending on which machine is under operation it is either rolled again to a cylinder or waiting to be collected for further storage.

One basic manufacturing principle, known as roll to roll manufacturing process, is combined with flexography. R2R involves a process, based on a continuous supply of a flexible substrate as it is conveyed between two rotating rolls of material. A following graph depicts the R2R principle.

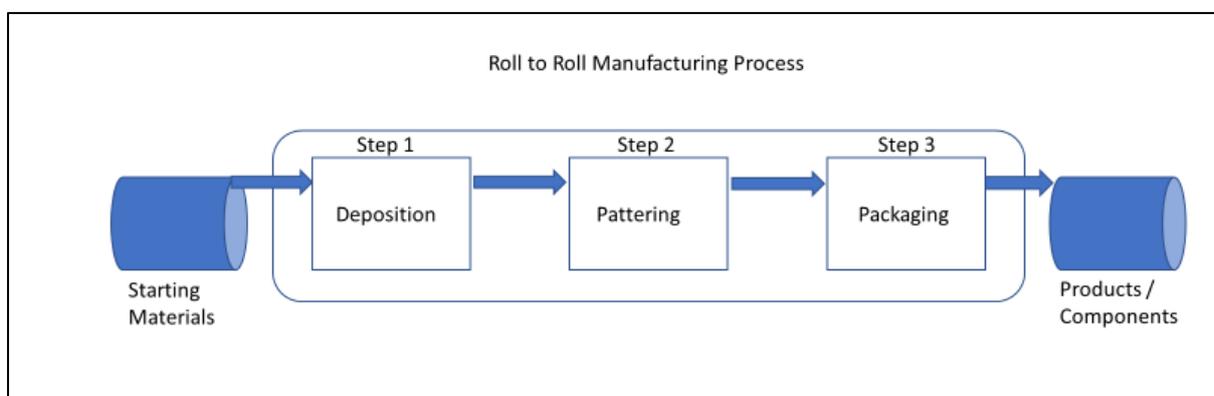


Figure 6 Roll to Roll Manufacturing Process Adapted from US energy review pdf

- The press model from 2003, which will be named "Machine A", is used for printing wide width packaging paper, that is mostly used for businesses that wrap their product before delivering it to their client (fish, meat, pastries, etc. This press involves a step, which a very thin layer of glue is applied on the substrate's one side before a cellophane layer is added to it. Naturally grease and moisture from the food products can ruin the package and therefore should not come into direct contact with it.
- The press model from 2006, "Machine B", is mostly producing smaller sized paper bags, that are used for (sandwiches, fruits, etc). A glue layer can be applied this time to specific areas of the paper before the folding step, so it can be attached together before the last step of exiting the machine as a finished bag.



Figure 7 Machine A flexographic printer



Figure 8 Machine A overall view



Figure 9 Machine B, feeding roll & printing unit



Figure 10 Machine B during folding process



Figure 11 Machine B, overall view

Flexographic printing plates

As it has been referred earlier, Cyrel is the printing plate making technique that Hartopolis uses. Each plate lasting life, depends on its use through time, careful mounding on the printing cylinder and a good cleaning after use. An average Cyrel plate, has an average of three years.

The material selection, is a task that requires a lot of time and testing since the material variety that exists in the market is quite large. There are many companies that producing materials for the 3DP industry, such as Formlabs, Recreus, Polymaker and many more. 3D printing as a constantly improving technology with high speed, surprises even the innovators with what the possibilities are of this promising AM technique.

A thorough search in the market proved to have quite few materials that could get tested in the flexographic printing process. A general observation was that flexographic printing plates required to have a shore hardness type A (soft plastics). There must be also a number which indicates the hardness from 0 to 100. The bigger the number on this scale, the harder the material is. Very important to note is that the shore hardness should be also measured before and after the platemaking process when the material is a photo polymeric, due to the fact that, the hardness might change after the UV treatment.

The focus was on materials that could provide some flexibility, so it would be possible to bend as much as needed, and be able to be mounded on the flexographic cylinder. That was a factor that couldn't be ignored since the philosophy of flexography is based on those cylinders. The shore hardness chosen for the 3DP flexo-plates, were more than shore hardness type A70.

So, all materials required certain degree of elasticity enough to bend and mounded on the cylinder without losing the logos shape. The main two material family's that are on the AM market are the *rigid* and *flexible*. In the first try the flexible materials were the ones to be tested.

Thermoplastics comes in a large variation based on the chemical composition and way of their manufacturing, which results in products with different technical characteristics. Those type of plastics

can be given flexible characteristics that could be seemed useful in flexography. Therefore different industries, uses the materials that suits best in each case. AM and 3D printing has its own categories of those materials that are also chosen based on the 3D printing process. SLA for example uses different materials from FDM.

Nowadays polymers and its composites, are everywhere in a large variety of products that we use in our day life, as well as products in many industries as well. Nevertheless, the application of those materials requires a constant search for developing polymers and create new ones with new properties.

Combining polymers with different kind of other materials, additives, reinforcing agents and fillers, it can be possible to create new materials with mechanical characteristics that would serve certain market needs. Polymer processing improves the technical properties, by adding different chemical and not only fillers, it can be observed the change of the mechanical, electrical and thermal properties as well as UV stability. [18]

By contacting 3DHub it was gained valuable technical information regarding the materials that could be used for the attempt of the 3D printing the 3DP flexographic plates. The best candidates for the experiment were:

- Recreus filaflex FDM
- Polymaker polyflex FDM
- Formlab's flexible resin SLA

The recreus and the polymaker are used by an FDM 3D printer. They have slightly different characteristics with each other, but both are in the same category of the TPE's. The flexible resin, is a photopolymer that used by SLA printers. The general characteristics of those three materials, can be met with the typically flexible, flexographic plate. The dimensions ordered can be seen in the following figure.

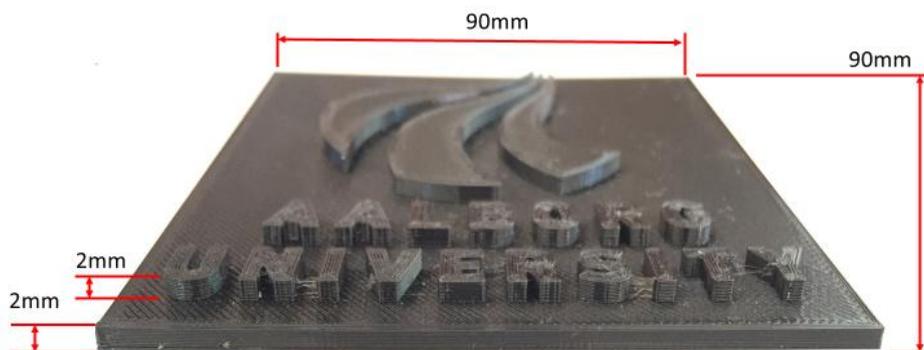


Figure 12 dimensions for the FDM 3DP flexo plates⁶

Flexography can give high quality results but still there are other printing processes that providing a better resolution on the printing images. Nevertheless, the purpose of this work, is to get into the factory and experiment with the different materials and techniques, evaluate the results and come up with possible suggestions. The following figures 12-19, presents the first prototypes.

The 3DP flexo-plates have obviously the necessary flexibility which will make it possible to get mounded on the main cylinder. A closer look though shows the first difference in between the two materials showing in figures, 16&17. The printing quality is an important factor, as well the material choice.

⁶ The SLA 3DP flexo-plate had 5 mm plate thickness and 1mm relief.

Recreus filaflex FDM



Figure 13 Recreus Filaflex 3DP flexo plate



Figure 14 Recreus Filaflex 3DP flexo plate bended

Polymaker polyflex FDM



Figure 15 Polymaker polyflex 3DP flexo plate



Figure 16 Polymaker polyflex 3DP flexo plate bended

Printing surfaces close inspection

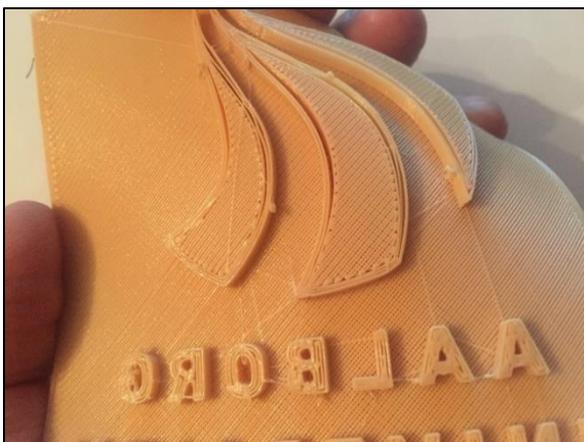


Figure 17 Recreus Filaflex 3DP flexo plate closer look



Figure 18 Polymaker polyflex 3DP flexo plate closer look

The last 3DP flexo-plate was created with the SLS technique. In figures 11 & 12 it can be seen.

Formlab's flexible resin



Figure 19 Flexible resin 3DP flexo plate



Figure 20 Flexible resin 3DP flexo plate bended

Production Flow

The production flow of a printing process is presented in the following three main phases.

Prepress, is the group of all necessary work which needs to be performed before the real printing itself. By means all the information required to be printed on the substrate as well as all technical / practical work required. Prepress processes include preparation fields such as *composition* (text formatting), *reproduction* (pictures and graphics) *assembly* (generally all kind of editorial preparation, as well as the platemaking, machine calibration etc. [4]

The construction of the printing plates (platemaking), labeled as a prepress process, gathers all information and it is the one responsible part of delivering the print directly on the substrate. The core of the flexography lies here on this surface and this is the focus area of the current report. The Predominating techniques with the use of photo-polymeric plates, that are exposed to UV light.

Printing process. The actual printing process, having all inputs is producing the product and moving them forward to the post press processes. Here flexographic plate is mounded to the devoted cylinder that while it turns, comes in contact with the ink supply cylinder, known as **anilox cylinder**. Tiny cavities on the anilox's cylinders surface, withholds enough ink ready to be supplied on the plate. The cylinder is in contact with an ink tray that makes sure the continues flow of ink into the process.

Post printing. All following processes after the printing, fall in the category. Depending on the type of work and on the machines characteristics, cutting and folding processes might follow, as well as the final packaging, batching, dispatching takes place. Figure 21 depicts the previously described overall process. In figure 22 is observed a linear flowchart presenting the flow within the system

The SIPOC high level process map in the following figure 23, presents an overall view of the system, and is focusing in the flexographic printing process.

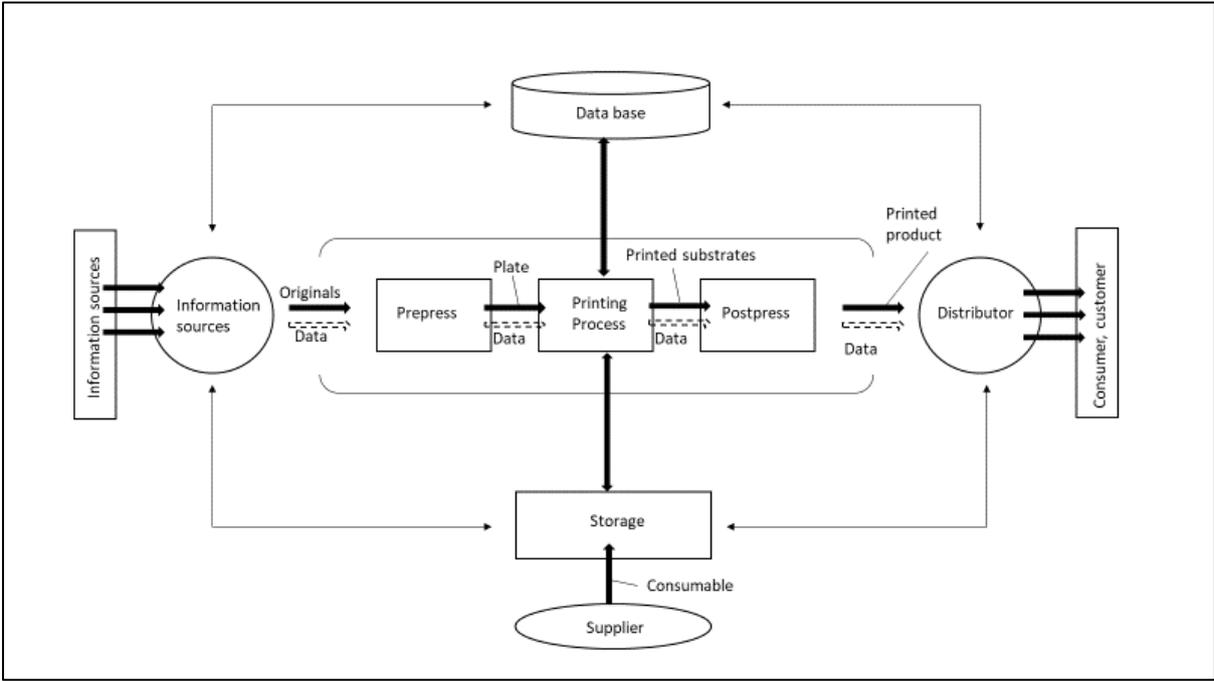


Figure 21 Production Flow adapted from Handbook of printing

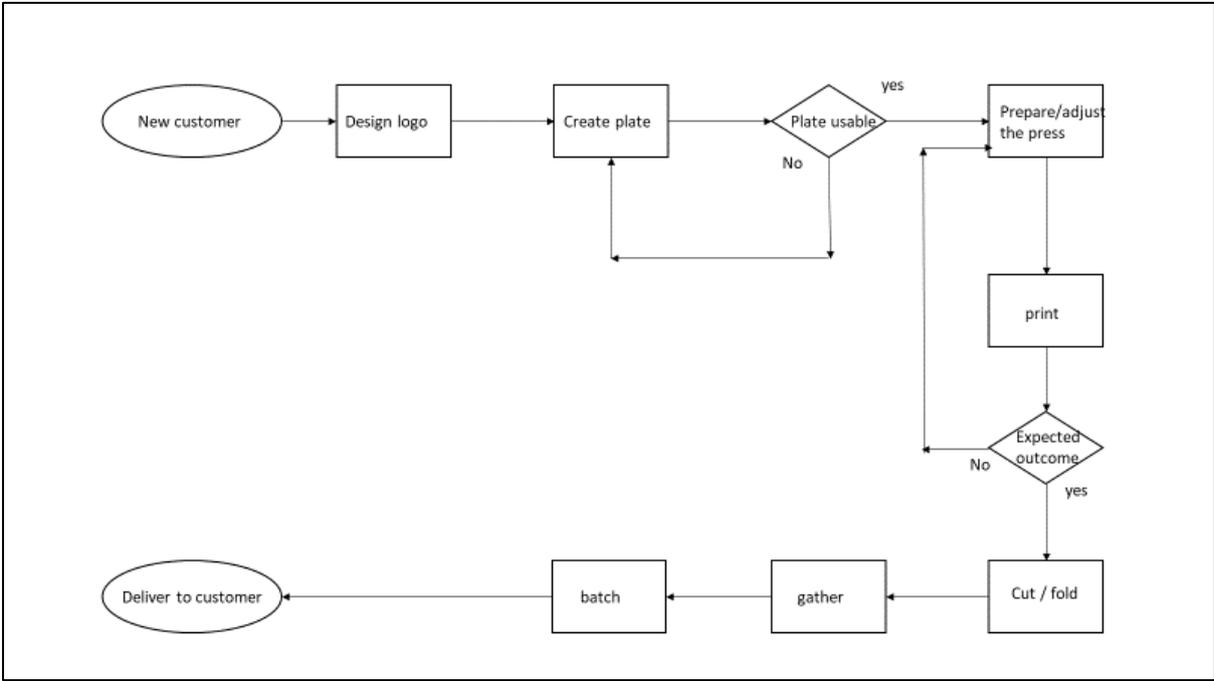


Figure 22 Hartopolis Production Flow chart

Experiment

The setup requires pre-settings adjustments, to prepare the machine and make sure everything is in order, before the actual printing. Firstly, the 3DP flexo-plates needs to be cleaned. The surface on back-side will be in touch with the flexo-plate cylinder and the presence of any particles of dust would be problematic throughout the cylinders rotation. The cleaning liquid used for that purpose, is the nitro thinner. The same liquid will be used for the plate cylinder to be cleaned properly as well. The following figures 1,2,3 shows the processes explained.

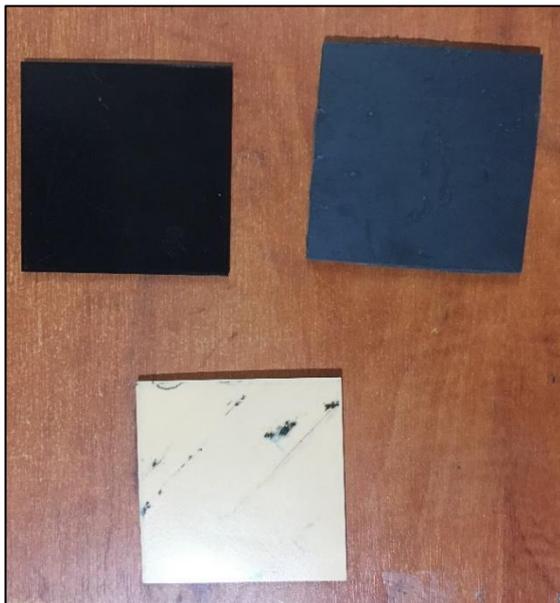


Figure 24 3DP flexo-plates back side



Figure 25 3DP flexo-plates front side



Figure 26 Cleaning the plate cylinder

Secondly, a high quality double sided tape, is used to keep firmly mounded the 3DP flexo-plate on the plate cylinder. The rotation on high speed and with the pressure applied, from the group of cylinders working together, might damage or move from its position the plate, therefore it must be very well and carefully attached. The 3DP flexo-plate is glued on the plate cylinder. Vertical lines over the cylinder helps to adjust the item on the exact point that is needed. In this experiment, small paper bags will be created, and the logo will be in the middle of the surface. It can also be observed that initially, there is a gap in between the plate cylinder and the substrate. In the figures 4,5,6,7 can be seen the second step.



Figure 27 Double sided taped adjusting



Figure 28 Double sided taped adjusting



Figure 29 3DP flexo-plate glued on the printing cylinder



Figure 30 Gap in between printing cylinder & substrate

In the next step the admitted tray needs to be supplied with ink. Throughout the process, the ink travels with the help of two cylinders working together, to the 3DP flexo-plate and from there on the substrate. The current machine can print up to three different colours, but for the current experiment only one colour will be used. The tray must be filled with blue ink to match the Aalborg's university logo and that is showed on the following figures 8,9.



Figure 31 Ink trays or Flexographic printing units



Figure 32 Suppling the ink tray

Finally, the flexographic printing unit, must come closer to the substrate. In figure 7, is observed that gap, which needs to be eliminated to the point that the 3DP flexo-plate, meets the substrate and the imprint appears on it. The unit can be adjusted with the use of a certain lever and screws, until the final and proper position of the cylinders are in place. Figures 10,11,12,13 provide a closer look to the lever and screws for the final step before the printing.

After all those preparations are accomplished, the machine can be operated and gradually speed up the process. The imprint's quality, is based on the rotation speed that the machine will be operated.

The speed is adjusted manually by pushing an analogue button. The scale has five steps that gradually increases on demand by pushing that button. From scale two, can be seen the imprint's quality, as it will be in the final product. That means that the pressure applied is the proper, that will give a good result. Scales from three to five just only speed up the process and produce more items per minute.



Figure 33 3DP setting flexo-plate



Figure 34 Printing cylinder-substrate gap



Figure 35 Final adjustments of the ink tray

The gap now is reduced to the point that the 3DP flexo-plate is slightly touching the substrate. The following figure shows the result.



Figure 36 Reduced gap in between printing cylinder & substrate

From the experiments, can be observed that the first imprints are not complete. Either the colour or the shape are not printed as it should and that is due to many different factors such as, the machine's calibrations, pre-settings, speed, pressure. In that case, this is a sign of the start-up of the machine, which needs some time to reach the necessary speed for the proper operation, therefore those fade imprints are produced. Nevertheless, as soon as the machine reaches the demanded speed by the operator, the imprint should appear correctly, by using the full potential of the ink and the 3DP flexo-plate. In the following tables, the imprint process is presented from the start to the end of the machines operation. The quality for each case will be observed and that will provide an overall clear picture for each individual case.

The experiment failed to use the potentials from the flexible resin. This 3DP flexo-plate was produced with the SLA technique and it was the only photo polymeric material that could come closer to the cyrel plate making. As the next figures shows, the plate was too thick with no bending flexibility which made impossible its attachment on the printing cylinder.

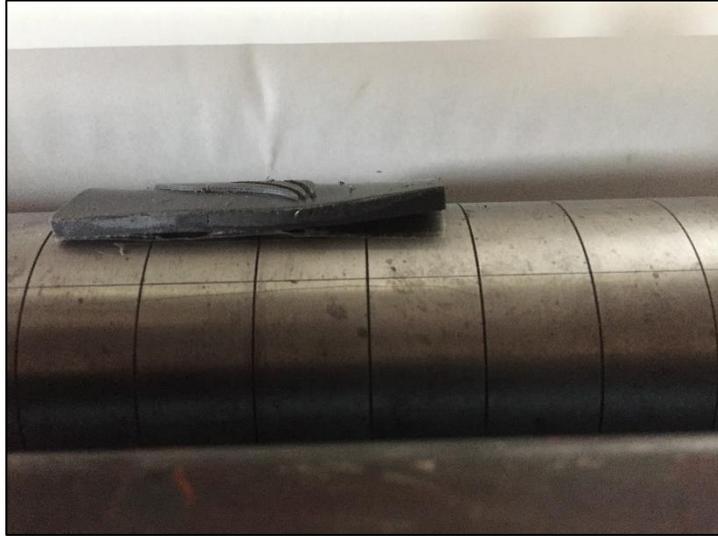


Figure 37 Flexible resin on the printing cylinder



Figure 38 flexible resin on the printing cylinder

The following pictures presenting a random sampling taken from the processes for each of the two 3DP flexo-plates tested in the press. The overall produced line, for each individual 3DP flexo-plate, will be found in the appendix B.

Recreus filaflex random sampling

Figure 38 shows the difference in between the second and 16th items, which it is obvious how the imprint appeared on the substrate. Very important to note the quality of the imprint each time. The quality check shows deformation of the imprint and that the logo's surface is not as it should, and lines can be seen all over its surface. Those lines as the constructed layers from the 3DP. In figure 39, the imprint seems to have gained the proper result, the outline is visible as well as the body of the letters and logo but still the deformation is visible, meaning that the current material was too elastic for that purpose. That also shows that its durability would be challenged very soon throughout a normal production day. One more thing to be noticed is that the overall surface is not covered by ink, but instead the thin lines grouped together from the 3D printing technique are visible.

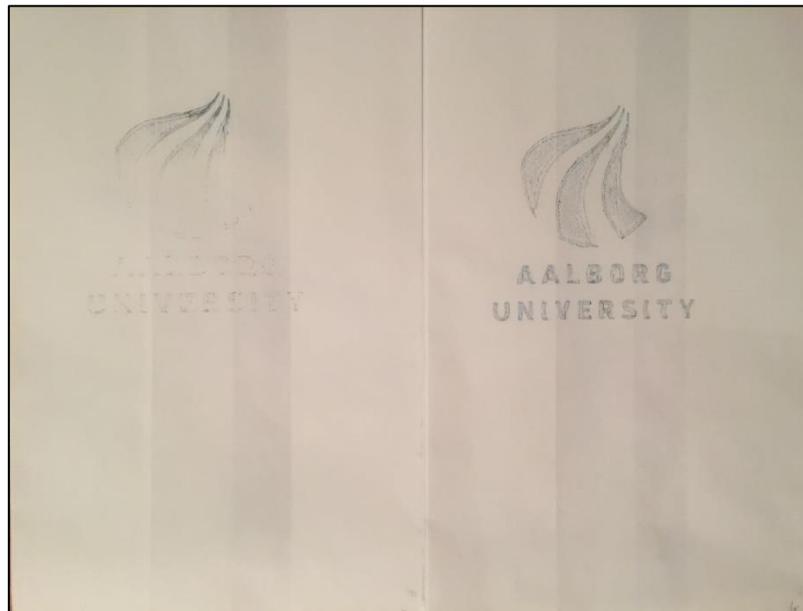


Figure 39 Recreus filaflex items 2,16



Figure 40 Recreus filaflex items 27,42

After examining the logo carefully, it can be seen its deformation due to the pressure applied on the material.



Figure 41 Recreus filaflex closer observation

"I" deformation

Polymaker's polyflex random sampling

The second 3DP flexo-plate made from the polymaker polyflex material, shows the same signs on how by accelerating the speed was more visible and better printed on the substrate, with no deformation of the letters at all. That is a very good sign, but still the imprint was never able to be fully printed as it should, and the ink didn't cover the surface as it should. Figures 41,42,43 shows how the imprint appeared over time on the substrate.

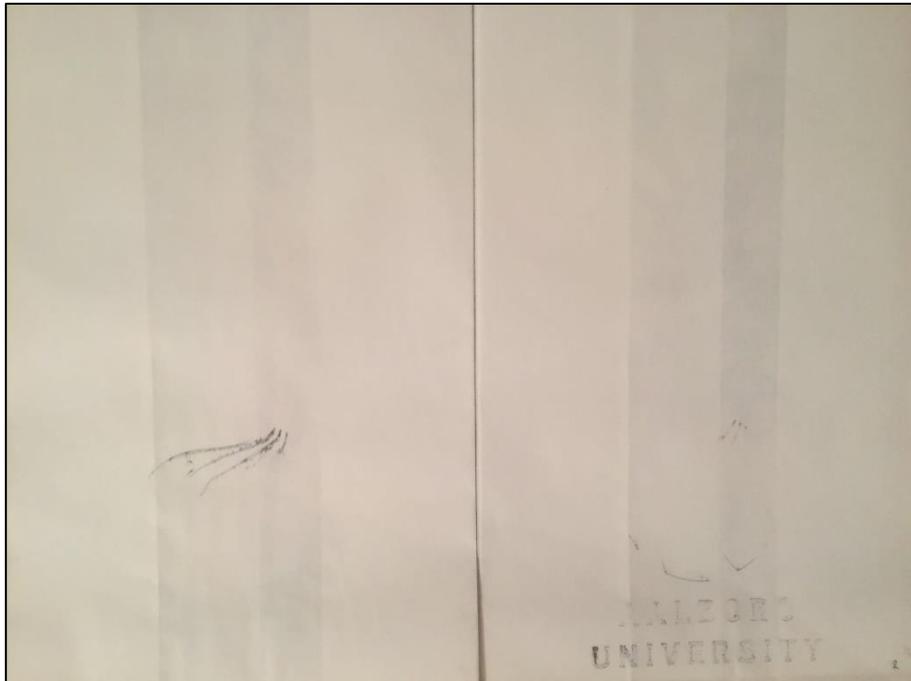


Figure 42 Polymaker's Polyflex items 1,2

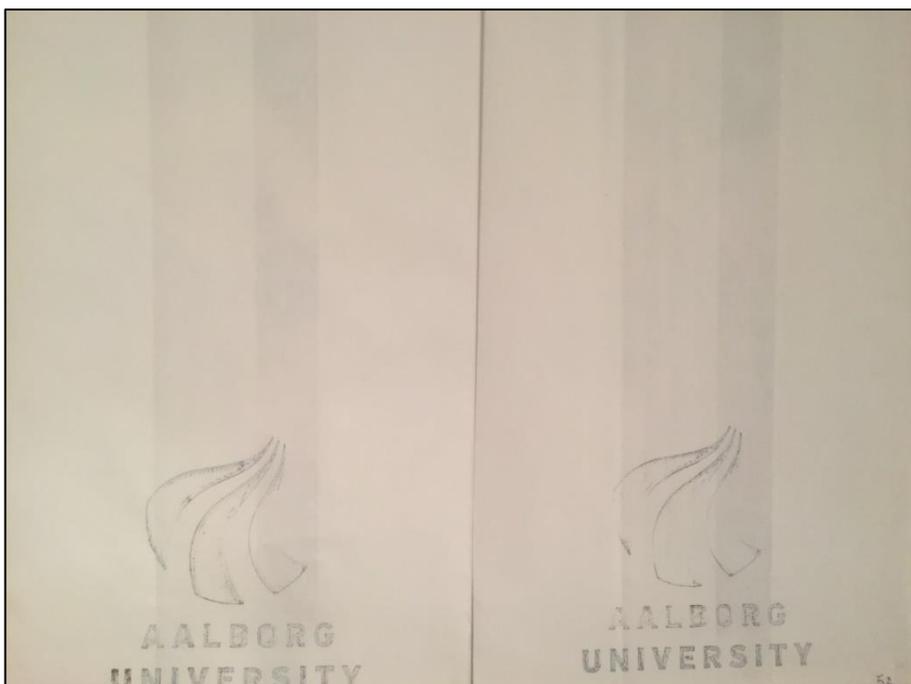


Figure 43 Polymaker's Polyflex items 25,52



Figure 44 Polymaker's Polyflex items 62,67

Experiment's Pivot tables

The following Pivot tables 3,4,5 presents the data overall view from the experiments where can be seen clearly the printing quality for each different flexo-plate and the number of paper bags that have been produced. The ranking explanation is presented in table 6. All numbered produced items for the materials tested, are detailed presented in appendix B.

Speed	Results		
	Very Low	Low	Acceptable
1	1/1	0/1	0/1
2	1/48	7/48	40/48

Table 3 Recreus Filaflex Pivot table

The table 3, depicts the speed which the machine was operated from start to end, on the left column. The start-up from speed 1 to speed 2, produced papers bags in very low and low-quality ranking, but after the speed 2, was stable, an acceptable rank quality was observed during the quality control. It should be noticed that the acceptable ranking, which indicates the complete imprint's visibility, doesn't indicates the materials quality as well. As it has been reported previously, the imprint shows a deformation of the printing area, meaning the lack of the material to fulfil its purpose. Nevertheless, this is a positive overall outcome, leading the report to a more concrete conclusion as it will be present at the last chapter of the report.

Speed	Results		
	Very Low	Low	Acceptable
1	1/1	0/1	0/1
2	58/68	0/68	10/68

Table 4 Polymaker polyflex Pivot table

In table 4, was observed that during the start-up and the accelerating of the machine, the quality was ranked very low, having randomly very few paper bags, ranked as acceptable. The fact is that this 3DP-flexo plate, even though that had a majority of very low-quality ranking, the imprint, didn't show any sign of deformation contradicting the previous material, which have had many more acceptable ranked items, but with visible the deformation of the 3DP flexo-plate under the operational impression cylinder's pressure.

Table 5, shows the total failure for the 3DP flexo-plate to get tested, due to its thickness and hardness of the material.

Speed	Results		
	Very Low	Low	Acceptable
0	0/0	0/0	0/0

Table 5 Formlabs flexible resin Pivot table

Table 6 presents, the quality labels used to rank the results of each product created.

ranking label	ranking explained
very low	incomplete imprint
low	completed imprint / faded
acceptable	completed imprint acceptable visibility not very detailed
high	completed imprint high visibility some details
very high	completed imprint very high visibility all details

Table 6 rankings explanation

Experiment evaluation

The factory visit, proved to be fruitful and the results gave the opportunity for further thinking and evaluation over the case study. The two out of the three 3DP flexo plates, tested during the experiment, were able to be mounded on the printing cylinder as it should, and their flexibility seemed to very similar to cyrel flexographic printing plates. One of the 3DP flexo plates, failed to stay glued on the printing cylinder and the experiment couldn't take place.

The recreus filaflex 3DP flexo-plate, as it has been observed from the final imprint on the substrate, showed that the letters were deformed, and the final logo was not visible as it should.

The letters and logo shape, were curved see figure 41, which means that the pressure applied from the impression cylinder, was higher than the printing plate could receive. Nevertheless, the machine it did work, with the 3DP flexo plate being correctly in place, with and 49 paper bags were printed, folded

and exited the process. Figures 39,40, shows randomly taken steps from the process. The whole process can be found in appendix B.

The polymaker polyflex, seemed to be a flexible material as well and it could be used and attached on the printing cylinder. The imprint was better than the previous material which appeared to be more clear and complete on the substrate. The experiment showed that this material could withstand pressure with no any deformation at all on the surface of the 3DP flexo plate.

A fact is that to gain a more spherical knowledge on their strength under pressure and general durability and material life cycle, the experiment in both cases should be tested for more time. Running for more time the machine, could have shown for how long the materials can be used under realistic conditions and a better understanding would have given a more concrete result for its mechanical strengths.

The flexible resin 3DP flexo-plate, failed to give any results, since it was too hard to be mounded on the printing cylinder. There was a thought for the thickness to be reduced, by using a cutting tool. Flexography though demands the minimum tolerance on the printing plates dimensions. The flexo-plates, requires having an even surface as possible, with no differences from side to side. The following figures visualize the issue.

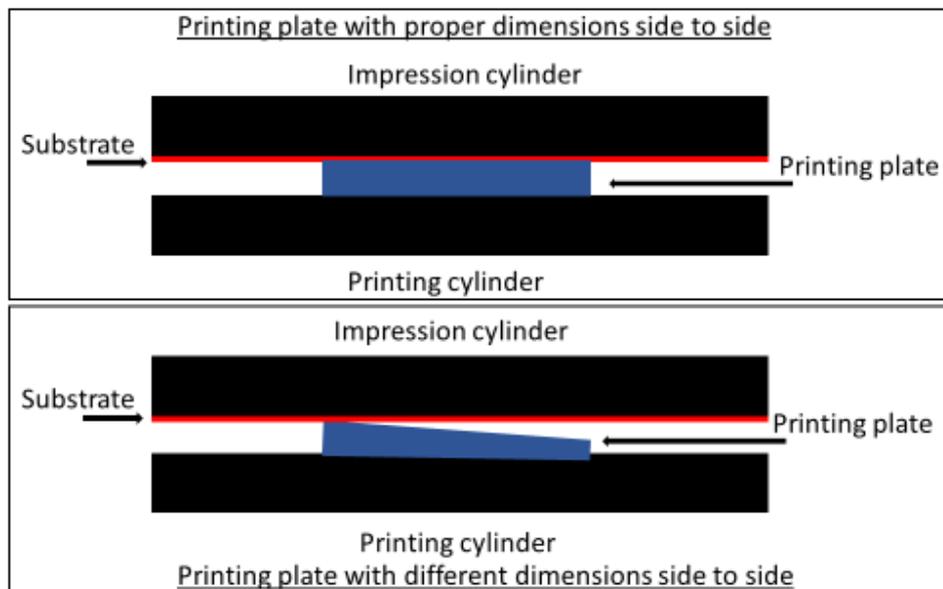


Figure 45 Printing plate even / uneven surface own production

A shorter side of the plate would have been created an imprint bold on one side and faded on the other side, meaning that the plate was produced faulty. Using a cutting tool by hand it wouldn't give an accurate, and the try couldn't have been a successful one.

looking back the two 3DP flexo-plates, that were tested, it can be understood the importance of the material that needs to be chosen in the flexographic printing. A very important part as well, is the design of the printing surface itself. It's not enough to create the flexo plate using a 3DP, but the printing surfaces as well needs to be designed with a proper and more knowledgeable background. Depending on the number of colours, each printing surface of each printing plate, requires a certain dots structured surface, which deliver the ink very close to each other, Like the pixels which are grouped together to create a picture.

Economic feasibility

For a more complete understanding, for the use of those technologies which have been involved in the experiment and the Cyrel printing plate making, the costs of each methods must be observed.

In the following tables the costs from both technologies, Cyrel platemaking and 3D printing, are presented.

Cost in Euro	Cyrel av. plate	Total cost
0,5€ / cm ²	12,5cm x40cm = 500cm ²	250€

Table 7 Cyrel average plate's cost

Recreus Filaflex

minimum fee FDM	Cost/hour	3D printing in hours	Total cost
10€	5€	4	20€

Table 8 Recreus filaflex plate cost

Polymaker Polyflex

minimum fee FDM	Cost/hour	3D printing in hours	Total cost
10€	5€	4	20€

Table 9 Polymaker Polyflex cost

Flexible Resin

minimum fee SLA	Cost/hour	3D printing in hours	Total cost
15€	10€	5	50€

Table 10 Flexible resin cost

The SLA printing, is also taking into consideration the volume of the object created, plus the supports. If the price based on the volume, exceeds the price based on the hours which the printer was occupied, that will be the final cost. The volume and cost calculation for the AAU logo follow:

$$9\text{cm} \times 9\text{cm} \times 0,5\text{cm} = 40,5 \text{ cm}^3$$

Each cm³ costs 1,5€ therefore the final price for the 3DP flexo-plate used the SLA method was:

$$40,5 \text{ cm}^3 \times 1,5\text{€} = 60,75\text{€}$$

Based on the prices from the previous tables, prices for the same dimensions of all flexographic platemaking methods is shown:

Plate	Cyrel	Recreus filaflex	Polymaker Polyflex	Flexible resin
9cm x 9cm	9cm x 9cm	9cm x 9cm	9cm x 9cm	9cm x 9cm
Cost	40,5€	20€	20€	60,75€

Table 11 Platemaking cost for all different methods

Compared to Cyrel, the FDM methods seems to have lower prices. The SLA method lifts the cost a lot higher, even more than the cyrel method.

Hypothesis

The next table presents hypothetical numbers accumulated based on the average cost of one cyrel printing plate per year.

If an average cyrel plate 250€ life cycle 3 years

$$250\text{€} / 3 \approx 84\text{€} / \text{year}$$

Cyrel	Recreus filaflex	Polymaker polyflex	Flexible resin
1 plate	≈ 4 plates	≈ 4 plates	≈ 1.4 plates

Table 12 accumulated number of 3DP flexo-plates

Which means that from another point view, since there is no possibility of testing the 3DP flexo-plates for their life cycle, it will be compared with the annual average cost of a single cyrel plate.

It seems that, for one year the FDM techniques for the same amount of money could have resulted into four plates and the SLA 1.4 plates. Having in mind the seasonal need for a Christmas printing for one customer order:

Average size order	Producing time	Cost 3DP flexo-plates
185kg paper	≈ 1.3 hours (1ton 7 hours)	84€

Table 13 average paper production

Based on the hypothesis, the average size order requires approx. 1.3 hours to be produced, and there are four 3DP flexo-plates for that purpose. What remains an issue which needs to be tested and evaluated is the life cycle. If a 3DP material can be found, fulfilling the requirements that flexography has, then a 3DP flexo-plate constructed with the FDM method, seems to be economically affordable.

Conclusion

Throughout this project, the theoretical background, the different readings and the case study, were grouped together and resulted to this work. It is quite fascinating for someone to see how it was built up during that period and gladly there have been concrete results that gave some extra information regarding the 3D printing technology and flexographic packaging paper printing.

To start with a general overview, it seems that the 3D printing technology could be used effectively for flexographic printers. The flexographic plates that have been used in the project were only three available options, based on the circumstances, which narrowed down the possibilities of this technological merging. Nevertheless, the problem statement, seems to be positively answered and that 3D printing technologies, can be applied for producing flexographic printing plates.

With a more detailed look in the current flow process of the flexographic printing, it seems that the cyrel platemaking is an expensive method, but comparing it with its life cycle seems to be a trustworthy product, which can be utilized in flexography effectively. It always needs to be taken into consideration that this work tried to find out an alternative, which seems technically feasible although the 3DP flexo-plates costs seems to be in a range including lowered prices than cyrel and a lot higher.

The material selection it should be the main investigation of this issue, since that is what can make the difference and provide as closer as possible the same printing results to the dominating printing plate making techniques. More time in a laboratory and the opportunity to experiment with more materials in different harness scales. As it has been reported earlier in this work, the applied pressures during the rotation of the cylinders are one of the main factors, to influence the life cycle of the printing plate and therefore the proper materials are important to be chosen, with the most suitable mechanical characteristics.

The printing surface of the printing plate, should also be the focus since FDM method, cannot produce a unified surface, which results in a printing with visible grids. Those grids they could have been avoided if a in final process, the product could be sprayed with some kind of coating, or polished to result a smoothed surface. Here again a laboratory would have been the best way to test those ideas.

As the economical overview showed, depending on which 3D printing method will be used, the costs can vary, but nevertheless, the comparison to cyrel and its long-life cycle seems not to be competitive. It should be also noticed that apart the direct cost of a cyrel plate, the lead time, that can be in between one and two weeks, has an impact on the production and here 3DP gives the advantage of a direct use in house, eliminating the platemaking time and the cost of not being able to print in the factory, while waiting for the cyrel delivery. It should be also noticed the advantage of replacing four manufacturing processes in the photo-polymeric method with only one 3D printer. In that case, training is needed as well, since the 3DP technology requires experience in using the printer, CAD programs and a very good computers skill.

This work could initiate a further testing and experimentation. There is a need for the most suitable materials and finishing methods to be chosen, to create products effectively and efficiently, which could be used in flexographic printing packaging industry. The utilization of this alternative to the current printing plate manufacturing method, has potentials that needs attention, which hopefully in the future could influence and the packaging industry.

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Appendices

Appendix A, characteristics of 3D printing materials

FLEXIBLE FLFLGR02					
	METRIC ¹		IMPERIAL ¹		METHOD
	Green	Postcured ²	Green	Postcured ²	
Mechanical Properties					
Ultimate Tensile Strength ³	3.3 – 3.4 MPa	77 – 8.5 MPa	483 – 494 psi	1110 – 1230 psi	ASTM D 412-06 (A)
Elongation at Failure ³	60 %	75 – 85 %	60 %	75 – 85 %	ASTM D 412-06 (A)
Compression Set ⁴	0.40 %	0.40 %	0.40 %	0.40 %	ASTM D 395-03 (B)
Tear Strength ⁵	9.5 – 9.6 kN/m	13.3 – 14.1 kN/m	54 – 55 lbf/in	76 – 80 lbf/in	ASTM D 624-00
Shore Hardness	70 – 75 A	80 – 85 A	70 – 75 A	80 – 85 A	ASTM 2240
Thermal Properties					
Vicat Softening Point ⁶	231 °C	230 °C	448 °F	446 °F	ASTM D 1525-09

NOTES:

¹Material properties can vary with part geometry, print orientation, print settings and temperature.

²Data was obtained from parts printed using Form 2, 100 µm, Flexible settings and post-cured with 80.5 mW/cm² of 365 nm fluorescent light for 60 minutes.

³Tensile testing was performed after 3+ hours at 23 °C, using a Die C dumbbell and 20 In/min cross head speed.

⁴Compression testing was performed at 23 °C after aging at 23 °C for 22 hours.

⁵Tear testing was performed after 3+ hours at 23 °C, using a Die C tear specimen and a 20 In/min cross head speed.

⁶Thermal testing was performed after 40+ hours with a 10 N loading at 50 °C/hour. Cracks formed in samples during testing.

Figure 46 Flexible resin's characteristics⁷

Filaflex® MEDIUM FLEX 95A		
<i>Filaflex is a Thermoplastic Polyether-Polyurethane elastomer with additives that allow high printability in FDM printers, Filaflex® has a remarkable hydrolysis resistance, high resistance to bacteria and low temperature flexibility properties in printed parts.</i>		
PHYSICAL PROPERTIES	TYPICAL VALUE	Test method
Density	1,15 g/cm ³	ISO 1183-1-A
Hardness Shore A	95	ISO 7619-1
Elongation at break	540%	ISO 37
Tensile strength	55 Mpa	ISO 37
Abrasion loss	25mm ³	ISO 4649-A
Flammability rating	HB	UL 94
PRINTING PROPERTIES	VALUE	
Printing Temperatures	215-235 °C	
Printing Speed	20-40 mm/s	
Hot-Bed temperature	40 °C	
Optimal layer height	0,2mm	
Minimal Nozzle diameter	0,3MM (0,4mm or higher recommended)	
Retraction parameters	3,5-6,5 mm (speed 20-160 mm/s)	

Figure 47 Recreus Filaflex's characteristics⁸

⁷ <https://formlabs.com/materials/>

⁸ <https://recreus.com/img/pdf/FILAFLEX%2095A%20TECHNICAL%20SHEET%20&%20MSDS%202017.pdf>

PolyFlex™

Technical Data Sheet

PolyFlex™ is a highly flexible yet easy to print 3D printing material. Featuring good elasticity and a large strain-to-failure, PolyFlex™ opens up a completely new realm of applications.

Physical Properties

Property	Testing Method	Typical Value
Density (g/cm ³ at 21.5 °C)	ASTM D792 (ISO 1183, GB/T 1033)	1.17 - 1.24
Glass transition temperature (°C)	DSC, 10 °C/min	Not available
Softening temperature of filament (for 1.75 mm; °C)	Custom method	Not available
Melt index (g/10 min)	210 °C, 1.2 kg	10 - 12
Moisture content ¹ (%)	Thermogravimetric	≤ 0.1%
Odor	/	Almost odorless
Solubility	/	Insoluble in water

Note:

1. For newly opened filaments; filaments may absorb higher levels of moisture during use.

Mechanical Properties¹

Property	Testing Method	Typical Value
Shore A hardness	ASTM D2240 (ISO 7619, GB/T 531)	~ 95A
100% modulus (MPa)	ASTM D412 (ISO 37, GB/T 528)	9.4 ± 0.3
Tensile strength (MPa)	ASTM D412 (ISO 37, GB/T 528)	29.0 ± 2.8
Elongation at break (%)	ASTM D412 (ISO 37, GB/T 528)	330.1 ± 14.9

Note:

1. All testing specimens were printed using a MakerBot Replicator 2 under the following conditions:
Printing temperature = 225 °C, printing speed = 90 mm/s, number of shells = 2, and 100% infill.

Figure 48 Polymaker's Polyflex characteristics⁹

⁹ http://www.polymaker.com/wp-content/uploads/2015/06/PolyFlex_TDS-v1.pdf

Appendix B, final printed paper bags
Recreus Filaflex's imprints



Figure 49 Recreus filaflex's imprints 1-8



Figure 50 Recreus filaflex's imprints 9-16

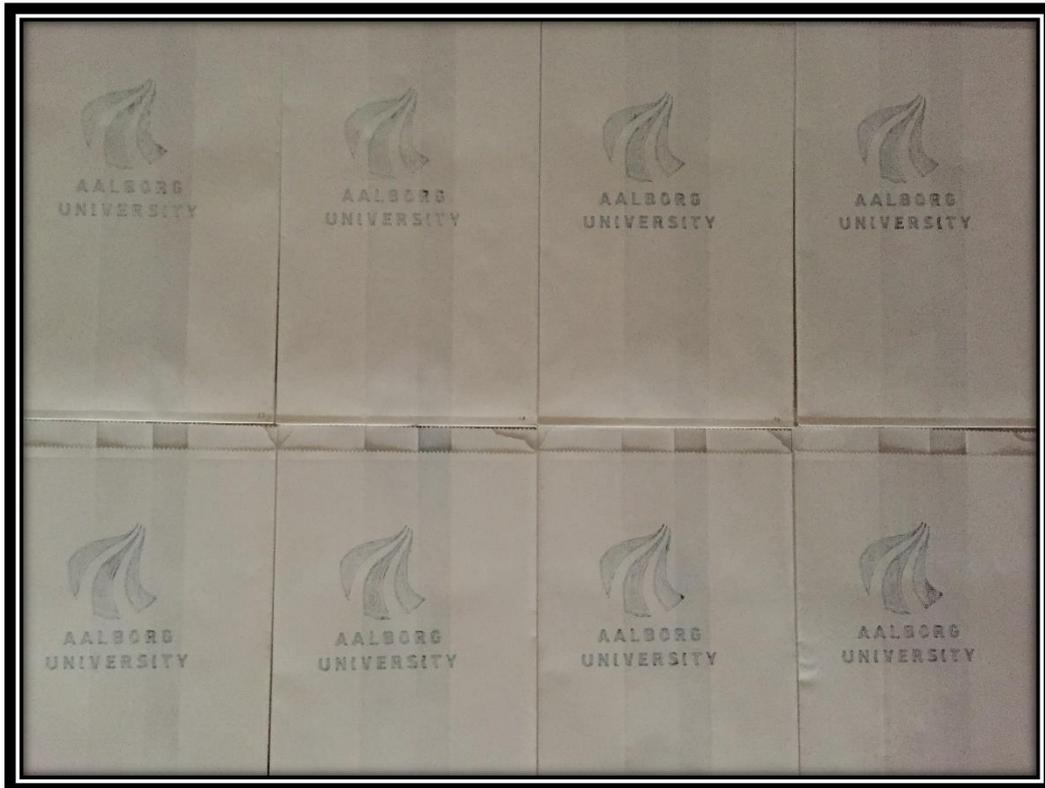


Figure 51 *Recreus filaflex's* imprints 17-24



Figure 52 *Recreus filaflex's* imprints 25-32



Figure 53 *Recreus filaflex's* imprints 33-40

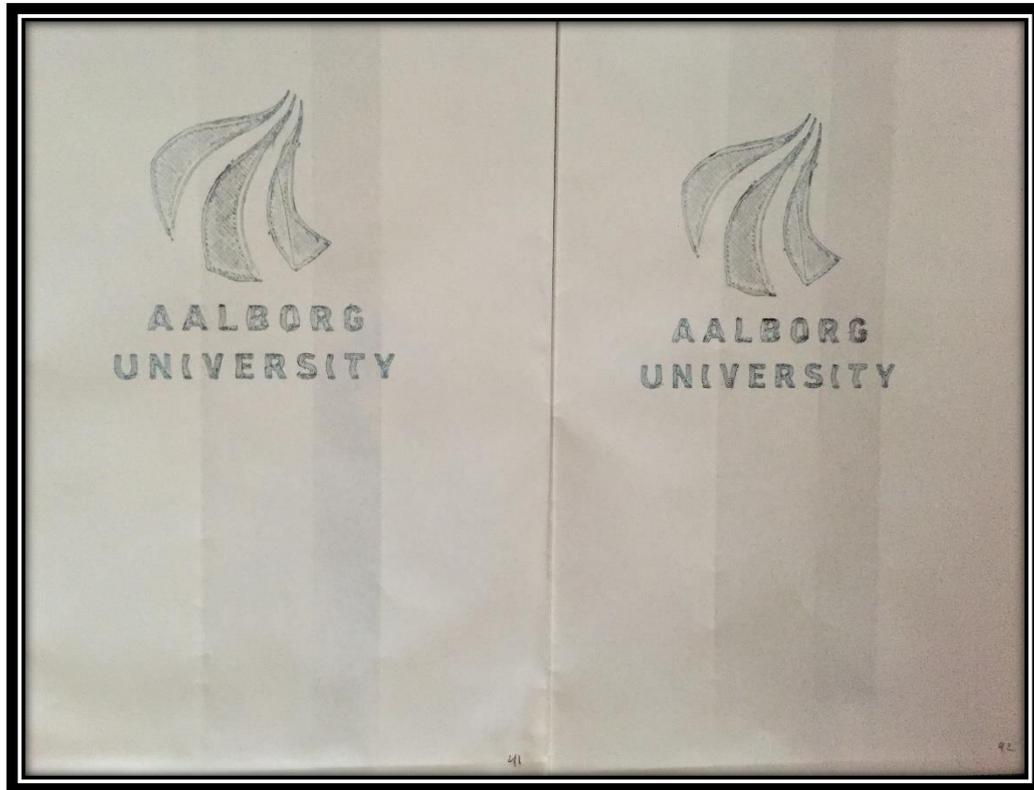


Figure 54 *Recreus filaflex's* imprints 41-42

Polymaker polyflex's imprints

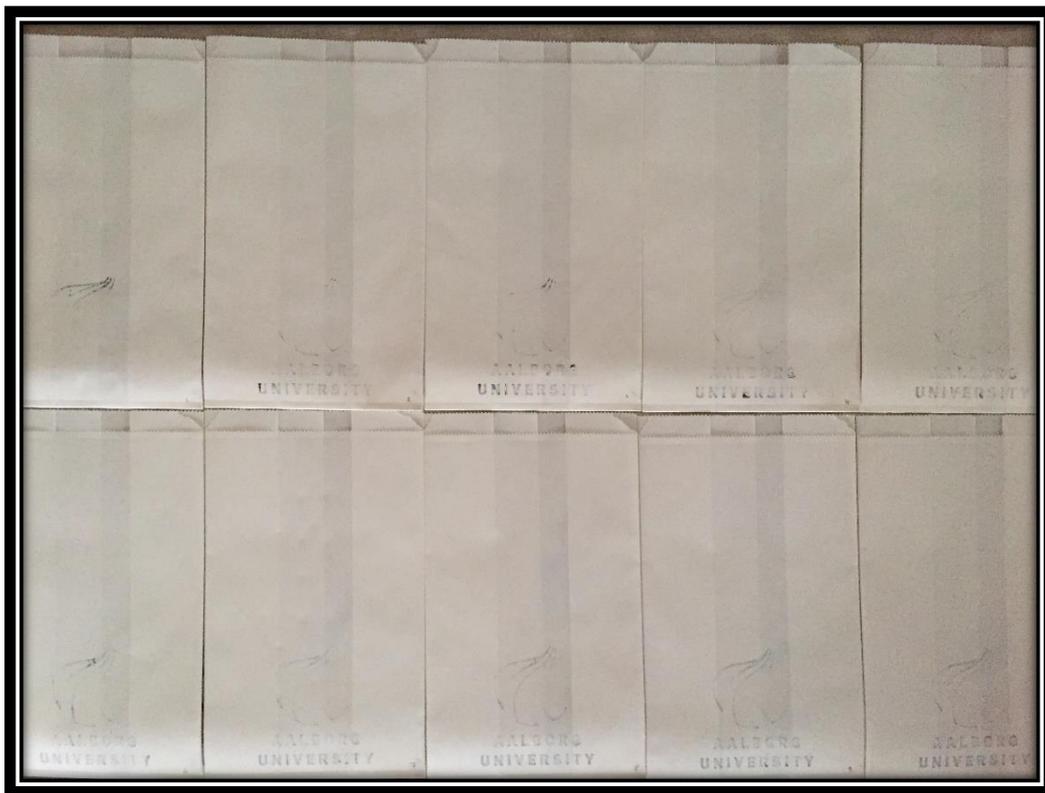


Figure 55 Polymaker's polyflex imprints 1-10

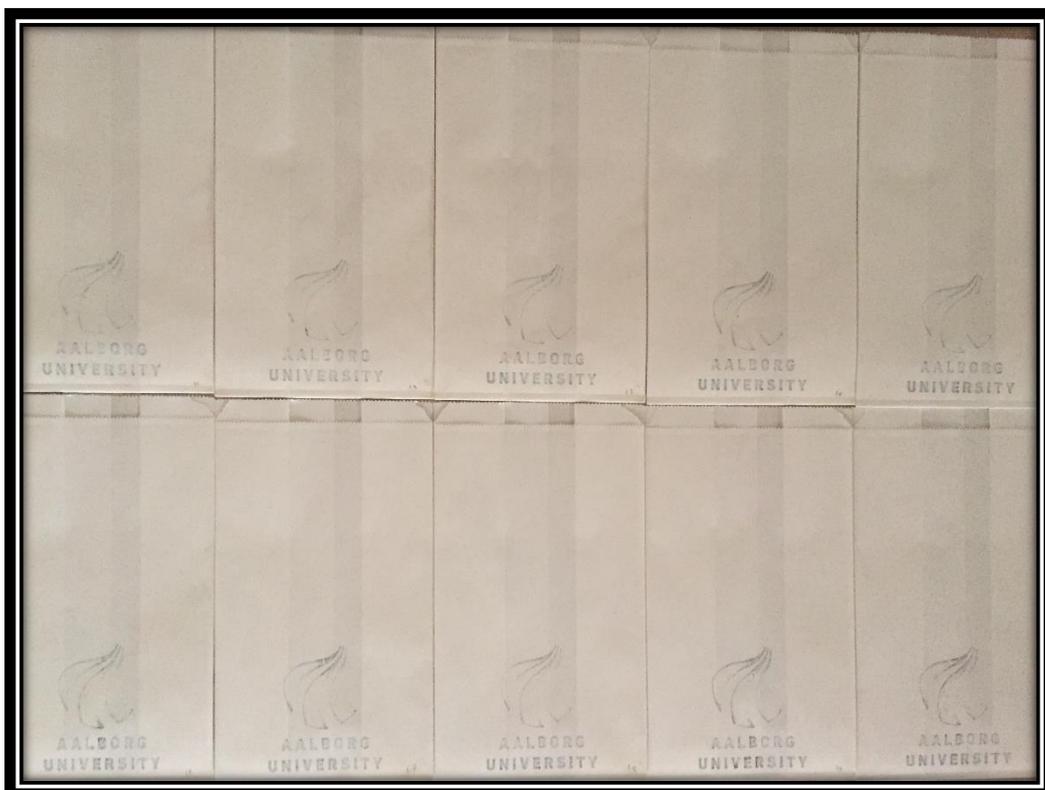


Figure 56 Polymaker's polyflex imprints 11-20



Figure 57 Polymaker's polyflex imprints 21-30



Figure 58 Polymaker's polyflex imprints 31-40



Figure 59 Polymaker's polyflex imprints 41-50



Figure 60 Polymaker's polyflex imprints 51-60



Figure 61 Polymaker's polyflex imprints 61-69

Appendix C, experiment's detailed data

paper bags printed identification number	3DFlexo-plate	Speed	visual quality check
1	Recreus filaflex	1	very low
2		2	very low
3		2	low
4		2	low
5		2	low
6		2	low
7		2	low
8		2	low
9		2	low
10		2	acceptable
11		2	acceptable
12		2	acceptable
13		2	acceptable
14		2	acceptable
15		2	acceptable
16		2	acceptable
17		2	acceptable
18		2	acceptable
19		2	acceptable
20		2	acceptable
21		2	acceptable
22		2	acceptable
23		2	acceptable
24		2	acceptable
25		2	acceptable
26		2	acceptable
27		2	acceptable
28		2	acceptable
29		2	acceptable
30		2	acceptable
31		2	acceptable
32		2	acceptable
33		2	acceptable
34		2	acceptable
35		2	acceptable
36		2	acceptable
37		2	acceptable
38		2	acceptable
39		2	acceptable
40		2	acceptable

41		2	acceptable
42		2	acceptable
43		2	acceptable
44		2	acceptable
45		2	acceptable
46		2	acceptable
47		2	acceptable
48		2	acceptable
49		2	acceptable

paper bags printed identification number	3DFlexo-plate	Speed	visual quality check
1	Polymaker polyflex	1	very low
2		2	very low
3		2	very low
4		2	very low
5		2	very low
6		2	very low
7		2	very low
8		2	very low
9		2	very low
10		2	very low
11		2	very low
12		2	very low
13		2	very low
14		2	very low
15		2	very low
16		2	very low
17		2	very low
18		2	very low
19		2	very low
20		2	very low
21		2	very low
22		2	very low
23		2	very low
24		2	very low
25		2	very low
26		2	very low
27		2	very low
28		2	very low
29		2	very low
30		2	very low

31		2	very low
32		2	very low
33		2	very low
34		2	very low
35		2	very low
36		2	very low
37		2	very low
38		2	very low
39		2	very low
40		2	very low
41		2	very low
42		2	very low
43		2	very low
44		2	very low
45		2	very low
46		2	very low
47		2	very low
48		2	acceptable
49		2	very low
50		2	very low
51		2	very low
52		2	very low
53		2	very low
54		2	very low
55		2	acceptable
56		2	acceptable
57		2	acceptable
58		2	acceptable
59		2	acceptable
60		2	acceptable
61		2	acceptable
62		2	acceptable
63		2	very low
64		2	very low
65		2	acceptable
66		2	very low
67		2	very low
68		2	very low
69		2	very low
0	Formlabs flexible resin		0

Appendix D, photos and tables



Figure 62 typical example of a 3 coloured imprint on a paper pag



Figure 63 typical cyrel mounded on printing cylinder



Figure 64 Hartopolis imprints



Figure 65 Hartopolis imprints



Figure 66 Hartopolis imprints



Figure 67 Hartopolis imprints



Figure 70 Hartopolis imprints, 3 colours



Figure 71 Machine A

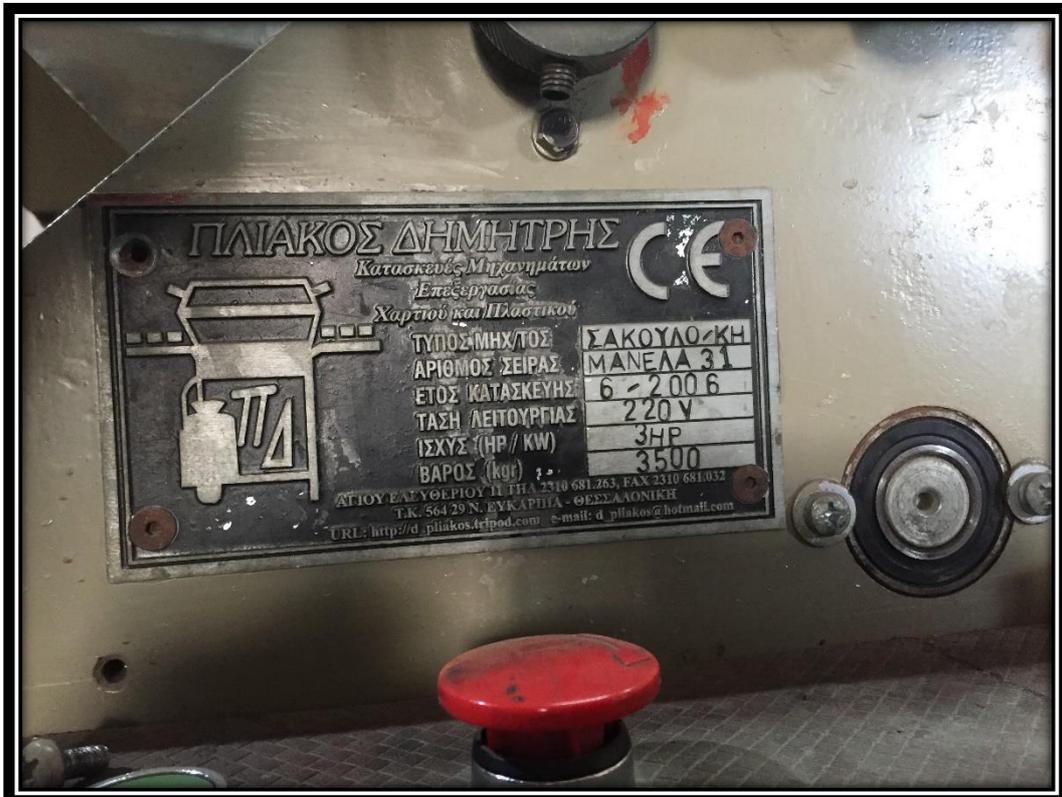


Figure 72 Machine B



Figure 73 Cyrel on printing cylinder

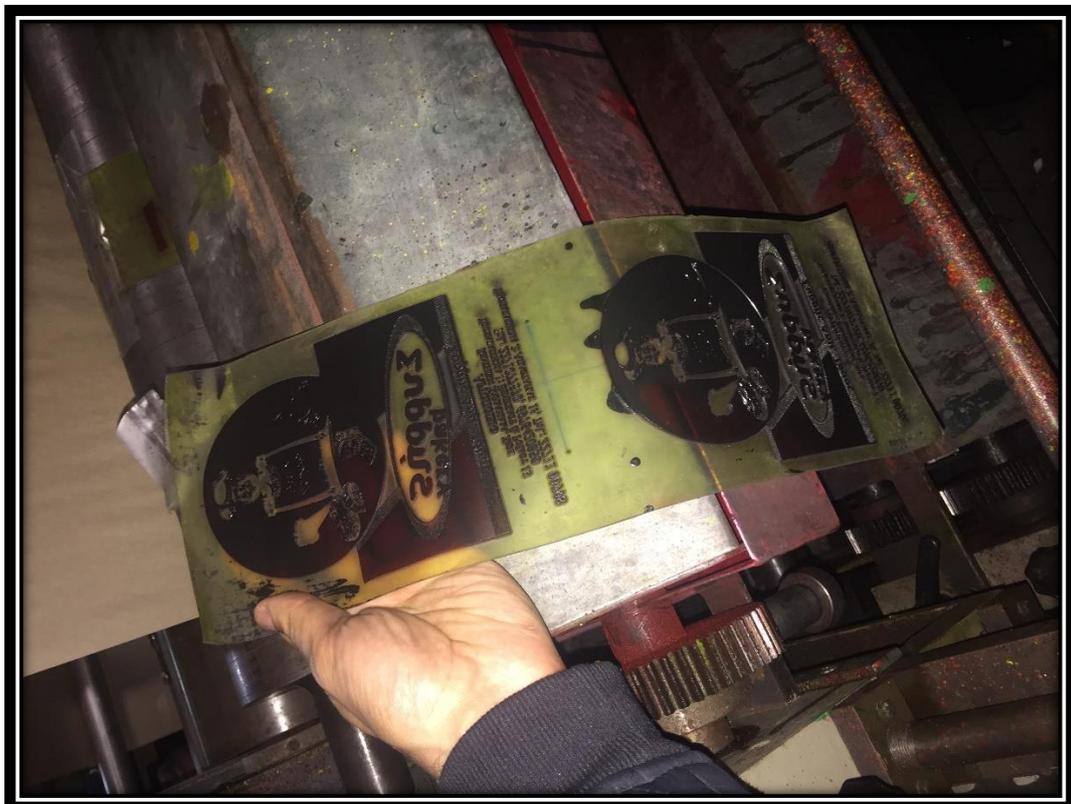


Figure 74 Cyrel flexographic printing plate

TABLE 4.1 Volumetric properties in U.S. customary units for selected engineering materials.						
Material	Density, ρ		Coefficient of Thermal Expansion, α		Melting Point, T_m	
	g/cm^3	lb/in^3	$^{\circ}\text{C}^{-1} \times 10^{-6}$	$^{\circ}\text{F}^{-1} \times 10^{-6}$	$^{\circ}\text{C}$	$^{\circ}\text{F}$
Metals						
Aluminum	2.70	0.098	24	13.3	660	1220
Copper	8.97	0.324	17	9.4	1083	1981
Iron	7.87	0.284	12.1	6.7	1539	2802
Lead	11.35	0.410	29	16.1	327	621
Magnesium	1.74	0.063	26	14.4	650	1202
Nickel	8.92	0.322	13.3	7.4	1455	2651
Steel	7.87	0.284	12	6.7	^a	^a
Tin	7.31	0.264	23	12.7	232	449
Tungsten	19.30	0.697	4.0	2.2	3410	6170
Zinc	7.15	0.258	40	22.2	420	787
Ceramics						
Glass	2.5	0.090	1.8–9.0	1.0–5.0	^b	^b
Alumina	3.8	0.137	9.0	5.0	NA	NA
Silica	2.66	0.096	NA	NA	^b	^b
Polymers						
Phenol resins	1.3	0.047	60	33	^c	^c
Nylon	1.16	0.042	100	55	^b	^b
Teflon	2.2	0.079	100	55	^b	^b
Natural rubber	1.2	0.043	80	45	^b	^b
Polyethylene (low density)	0.92	0.033	180	100	^b	^b
Polystyrene	1.05	0.038	60	33	^b	^b

Compiled from, [2], [3], [4], and other sources.
^aMelting characteristics of steel depend on composition.
^bSoftens at elevated temperatures and does not have a well-defined melting point.
^cChemically degrades at high temperatures. NA = not available; value of property for this material could not be obtained.

Figure 75 Volumetric properties for different materials

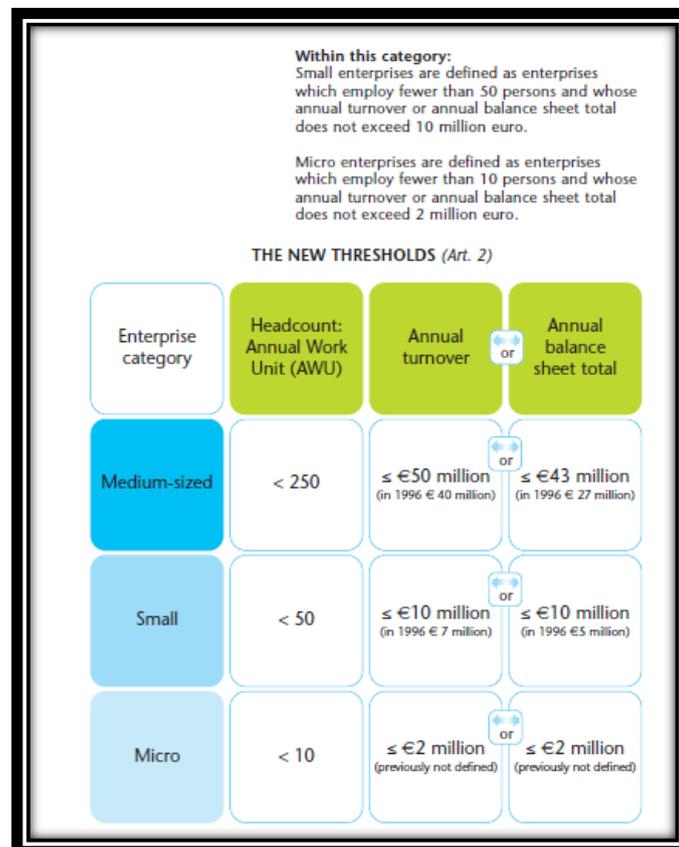


Figure 76 Small & medium sized enterprises thresholds

Appendix E, project's Gantt chart

Project Planner

Period Highlight: 117

Plan Duration Actual Start % Complete Actual (beyond plan) % Complete (beyond plan)

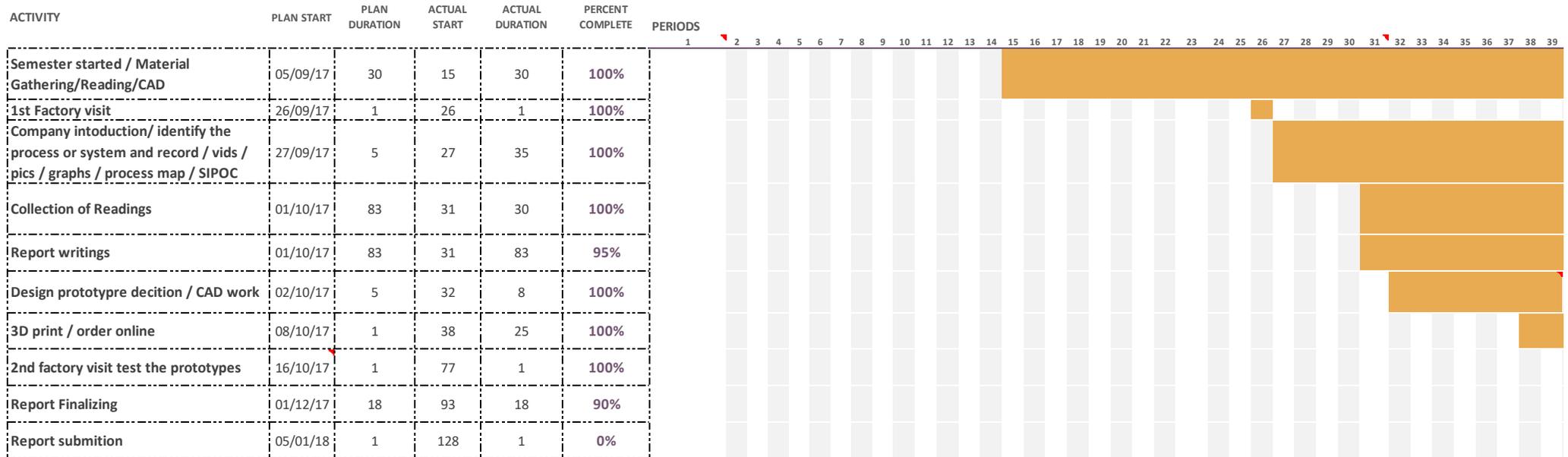


Figure 77 Project's Gantt chart

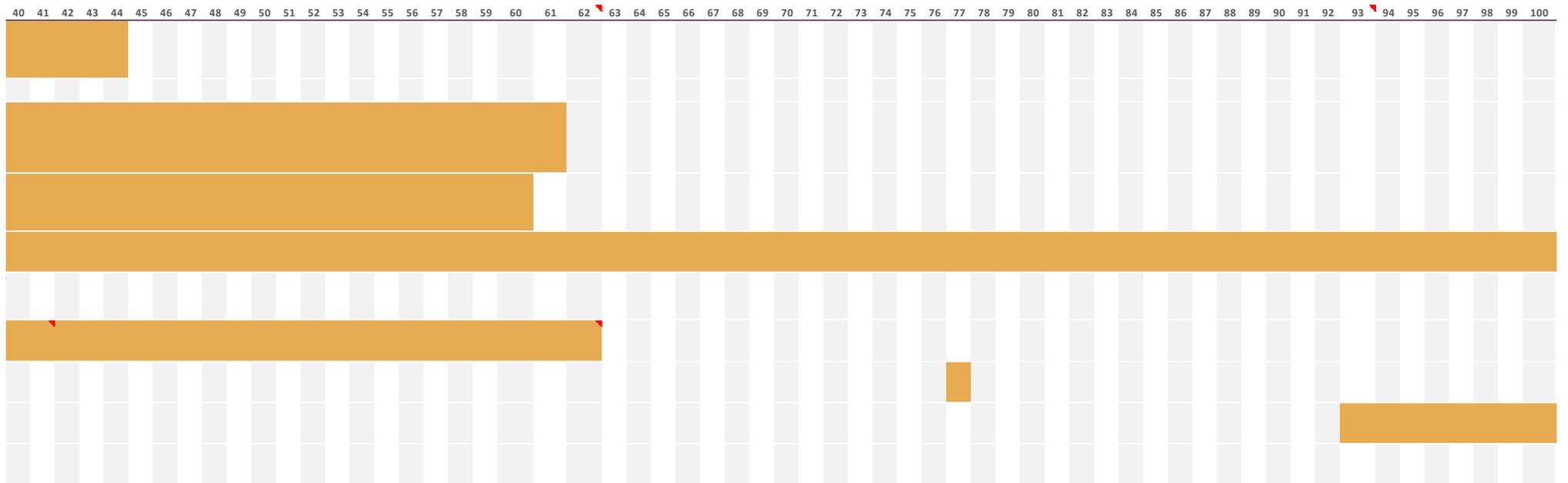


Figure 78 Project's Gantt chart cont

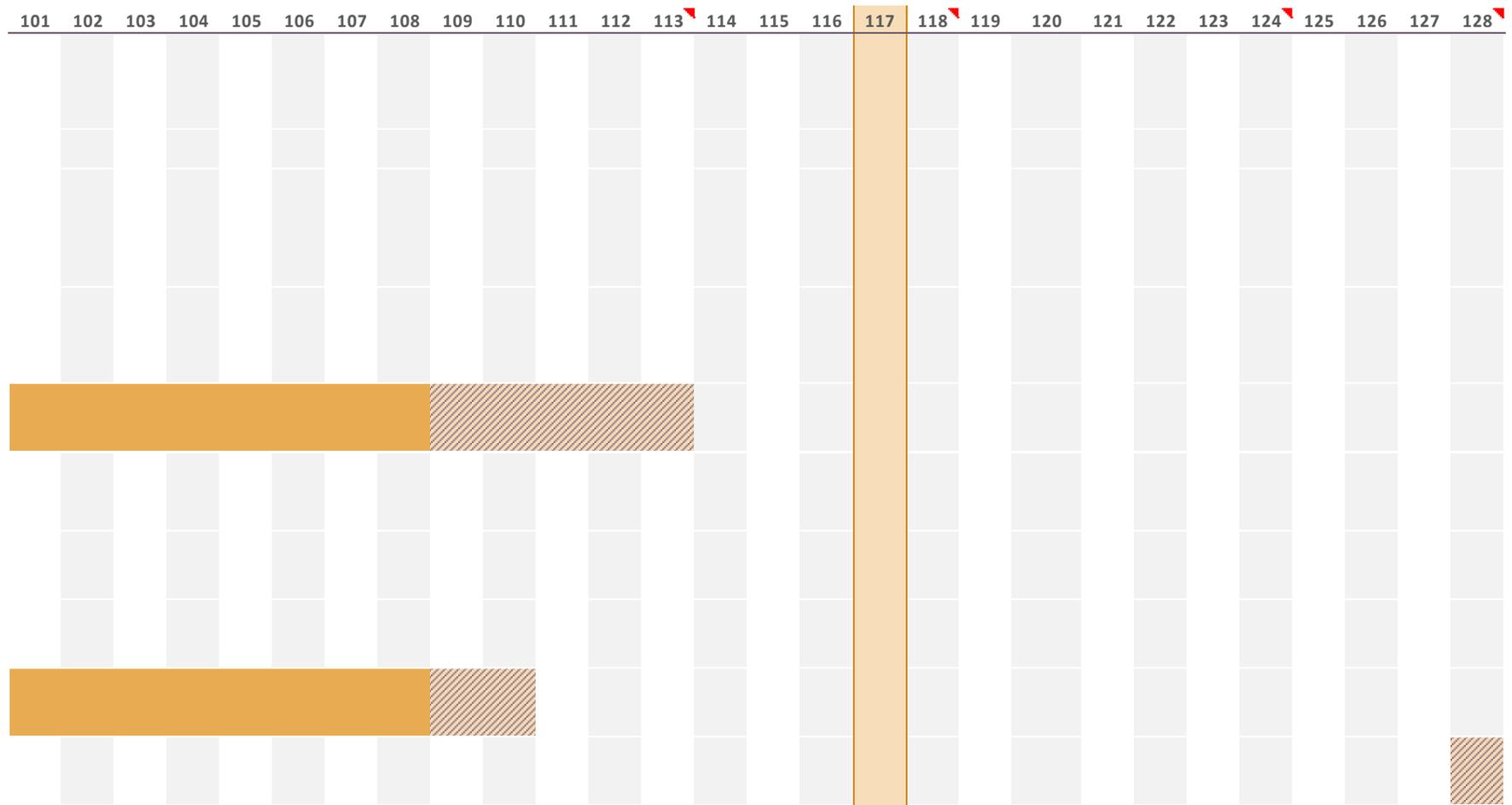


Figure 79 Project's Gantt chart cont