COFFEE POWDER REUSED AS A COMPOSITE MATERIAL

A STEP IN THE RIGHT DIRECTION

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DISSERTATION FOR MASTER'S DEGREE IN PRODUCT AND INDUSTRIAL DESIGN

U. PORTO

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08.11.2016

José Júlio Xavier Canavarro
[1948 – 2015]

I dedicate this work to my Father, who passed away in 2015, during my first year as a student at this Master's Degree and one of his last wishes was that I completed the course.

Esta é para ti, Pai.

RESUMO

Este estudo tem como objetivo confirmar a possibilidade de utilização de resíduos de café na criação de objetos de Design, bem como documentar e descrever o tipo de aplicações que existem hoje, em diferentes áreas, para a reutilização desta substância e que estratégias são praticadas atualmente na produção de materiais criados com base no pó de café, com a capacidade de serem usados por meio de moldagem ou fabrico aditivo.

A relevância deste estudo é justificada pelas características sui generis do café, tais como odor, aparência visual ou textura, assim como pela enorme abundância desta matéria-prima em potencialidade que é, normalmente, descartada após cumprir a sua principal função. Portanto, aqui são apresentados dados estatísticos relativamente aos resíduos em geral, com foco especial no café. Esta informação destina-se a mostrar a sua evidente abundância.

Também é demonstrado por trabalho experimental, qual o aglutinante ideal para a criação do material desejado e que métodos foram utilizados na execução desta tarefa.

Com base na pesquisa feita, são apresentadas algumas propostas de Design com base no material desenvolvido ao longo deste estudo, com aplicações em diferentes áreas e uma proposta de fabrico por moldagem das peças desenvolvidas.

Palavras-chave

Borra de café, resíduos, reutilização, design, fabrico aditivo.

ABSTRACT

This study aims to confirm the possibility of using coffee waste to create design objects as well as to document and describe the type of applications that exist today, in different areas, for re-use of this substance and what strategies are carried out currently in the production of materials created based on coffee grounds, with the ability to be used by means of moulding or additive manufacture.

The relevance of this study is justified by the coffee sui generis characteristics, such as odor, visual appearance or texture, as well as the huge abundance of this raw material in capability, which is normally discarded after serving its primary function. Therefore, here is presented statistical data regarding the waste in general, with special focus on coffee. This information is intended to show its obvious affluence.

It is also demonstrated by experimental work, which is the ideal binder for the creation of the desired material and which methods were used in performing this task.

Based on the research done, some design proposals based on the material developed throughout this study are presented, with applications in different areas and a manufacturing proposal by moulding of the developed parts.

Keywords

Coffee grounds, waste, reuse, design, additive manufacturing.

ACKNOWLEDGEMENTS

With the completion of this stage of my life, I want to thank the contributions that allowed this study to take place. I want to thank first of all to the classmates, whom in one way or another supported me, especially the two that started this project with me, Ricardo Pinto and José Pedro Ferreira.

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SYMBOLS AND ABBREVIATIONS

Abbreviations

2D	Two-Dimensional
3D	Three-Dimensional
AM	Additive Manufacturing
CAD	Computer Aided Design
CAGR	Compound Annual Growth Rate
COL I	Type I Collagen
DGEBA	Diglycidyl Ether Of Bisphenol A
DSC	Differential Scanning Calorimetry
DWG	Drawing File format
ESCG	Extract Of Spent Coffee Grounds
EU	European Union
Eurostat	Statistical Office of the European Union
E-Waste	Electronic Waste
FAEE	Fatty Acid Ethyl Ester
FAME	Fatty Acid Methyl Ester
FAO	Food and Agriculture Organization of the United Nations
FBAUP	Faculdade de Belas Artes da Universidade do Porto
FDA	Food and Drug Administration
FDM	Fused Deposition Modelling
FEUP	Faculdade de Engenharia da Universidade do Porto
FFAs	Free Fatty Acids
FLW	Food Loss And Waste
GHG	Greenhouse Gas
HLPE	Panel of Experts on Food Security and Nutrition
ICO	International Coffee Organization
IHC	Immunohistochemistry
INEGI	Institute of Science and Innovation in Mechanical and Industrial Engineering
ISWA	International Solid Waste Association
LED	Light-Emitting Diode

MDIP	Master's Degree in Product and Industrial Design
MMPs	Matrix Metalloproteinase
MSW	Municipal Solid Waste
PLA	Polylactic Acid / Polylactide
PMHS	Polymethylhydrosiloxane
SCAA	Specialty Coffee Association of America
SCG	Spent Coffee Grounds
SOFC	Solid Oxide Fuel Cell
STL	Stereolithography
U.S.	United States of America
UK	United Kingdom
UNEP	United Nations Environment Programme
USA	United States of America
UV	Ultra-Violet
WM	Waste Management

Symbols

%	Percent
CO_2	Carbon Dioxide
g	Gram
Hf	Heat of Fusion
kg	Kilogram
km^3	Cubic Kilometre
mg	Milligram
ml	Millilitre
mm	millimetre
MPa	Megapascal
Nm	Newton Metre
^oC	Centigrade Degree
oz.	Ounce
Tg	Glass transition Temperature
Tm	Melting Point
x	Times (mathematics)

CHAPTER I

INTRODUCTION

1.1. Background

This work is carried out within the structure of the Master's Degree in Product and Industrial Design (MDIP), at the Faculty of Engineering (FEUP) and Faculty of Fine Arts (FBAUP) from the University of Porto.

This chapter aims at presenting the Master' s thesis titled "Coffee Reused as a Composite Material – A Step in the Right Direction". Here is a brief introduction to the subject's framework done within this project and the goals to be achieved, the methodology used and a description of the dissertation's structure.

With the technological and industrial development, many products have toxicity problems and the rate at which people consume new raw materials has become unsustainable. The markets have been undergoing changes and manufacturing materials tends to be more affordable, but they still have problems related with pollution and other ecological concerns. The impact that mankind's hunger for consumption, has upon nature and how that contributes to the slow end of natural resources, is well known. For this reason, alternative processes concentrate upon the reuse of waste.

This theme has emerged as a way to combat this problem of great environmental impact through design.

From this point of view, this thesis aims to present a composite material from reused ground coffee leftovers. Because at the moment it is treated mostly as junk, it may therefore be used as an innovative material for the production of several objects.

1.2. Goals

The main goal to be achieved within this research is to obtain a mouldable material, formed by the coffee grounds and a suitable binder found through experimentation and study. It is also intended that the material created is both durable and washable, with prospects of extending the number of ways in which it can be used.

To validate this, it is intended the creation of a set of products made from the developed material, which can be extended to numerous areas of Design, from simple kitchen utensils to lamps.

From the point of view of sustainability the idea is to extend the life cycle of coffee, eliminating the waste phase, to which it is largely subjected nowadays, after consumption.

1.3. Methodology

During the course of this work, an in-depth research was done on the type of use that is given today to this type of waste, from furniture applications, fertilizer, fuel, or even materials with 3D printing capabilities. This research focused on scientific articles, books and even dissertations, as well as websites related to the objectives of this work. At the same time, a study has been done to try to understand the statistical data of waste, with a special focus on coffee.

In a more detailed way and trying to direct the research towards this thesis, it was tried to realize in which stage is the evolution of coffee grounds as a material with the ability to be moulded or extruded through 3D printing and what kind of progress, if any, is being made in that direction.

Completed the research phase, all the relevant information was analysed to allow for knowledge development and broaden understanding about the chosen topic.

During the entire process of knowledge gathering and information collection, some experiments with mixtures between the coffee waste, and a variety of binders were made, both biological and man-made, to realize what could work best for achieving the desired, physical and visual characteristics, thus reaching the expected and wanted material.

Later, from the standpoint of design, some products were developed with the aid of CAD software and the respective prototypes were created, with the ability to be tested in real circumstances in order to finally be validated.

So, in order to summarize this study, it is divided into three major parts. The first one being the investigation work, the second is the experimentation and finally the Design process.

1.4. Dissertation's Structure

This dissertation is divided into six chapters.

The first chapter concerns the introduction, which in turn is divided into four parts. Here can be found the historical justification and framework of this study, the objectives intended to be achieved, the adopted methodology and the structure of the dissertation.

In the second chapter there is access to statistical data that provides information relative to waste in general and coffee in particular, as global or specific countries consumptions with relevance to the study.

The state of the art is presented in chapter three and is divided into four sections. The first is on the coffee reuse strategies, the second deals with the theme of coffee reuse solutions in additive manufacturing, the third section shows the kind of products that are being created based on this reuse in the area of Design and last some tests made to a composite material made between PLA and spent coffee grounds are presented.

Chapter four shows all the experimental work done within the development of this thesis. It is divided by the materials used and describes them as well as the procedures used in each experiment. It also shows the results of those experiments and an analytical description of them, with a greater emphasis on the chosen binder.

The Design proposal appears in the sixth chapter with a main project, from which a prototype was made. Then, other design possibilities for the developed material appear and finally a production proposal is presented.

In the seventh and final chapter of this document, conclusions are taken from what has been done and what kind of future prospects exist in this area of study, for the developed material.

CHAPTER II

STATISTICAL DATA

For further understanding on the grandiosity of the problem faced with material waste, biological or artificial and to contextualize this study, this chapter will focus on showing some data relative to this issue.

It is intended to demonstrate waste numbers, regarding waste in general, food waste (from which coffee is a part of) and what type of treatment is given to it, in an attempt to show why this is a problem and that many wasted substances can and should be reused at the end of their life cycle.

Additionally, it tries to confirm through statistical data, that coffee is one of the best substances to be reused, by its sheer abundance and characteristics.

2.1. Waste

According to Eurostat (Statistical Office of the European Union), Portugal generated in 2012, 14.184.456 tons of waste (Eurostat 2015b). On the other hand, Europe (28 Countries) ended the same year with 2.514.220.000 tons and in the United States are generated daily 624.700 tons of solid waste and the forecast made by The World Bank Organization through the document "What a Waste" (Bhada-Tata 2012, 83) is that by 2025 it will be 701.709 tons.

Table 1 - Global waste generation. Adapted from "Global Waste Generation Clock" (Atlas 2016).

	Quantity
Tons/hour	182.65 – 228.31
Tons/day	4.38 – 5.48 million
Tons/month	133.33 – 166.67 million
Tons/year	1.6 – 2.0 billion

On Table 1, the global waste generation by hour, day, month and year is shown and we are told by the same source that the current annual Municipal Solid Waste (MSW) generation is estimated to 1.9 billion tonnes with almost the 30% of it to remain uncollected. As for the collected MSW, 70% is led to landfills and dumpsites, 19% is recycled or recovered and 11% is led to energy recovery facilities. The number of people that lacks access even to the most elementary Waste Management (WM) services is estimated to at least 3.5 billion. If we continue with a "Business as Usual" practice, the situation seems to worsen significantly, with forecasts to estimate that the population that will have no access to WM services in 2050 will be around 5.6 billion (Atlas 2016).

As further demonstrated by Daniel Hoornweg, Perinaz Bhada-Tata and Chris Kennedy in their publication for Nature magazine, "Waste production must peak this century", the amount of waste generated globally shows a growth tendency up to the year 2100 (Figure 1), with Sub-Saharan African countries taking the leadership (Daniel Hoornweg 2013, 616). It can, therefore, be recognized that waste generation by the human being will hardly decrease in the next years and one of the solutions to this decrease might be in its reuse or recycling.

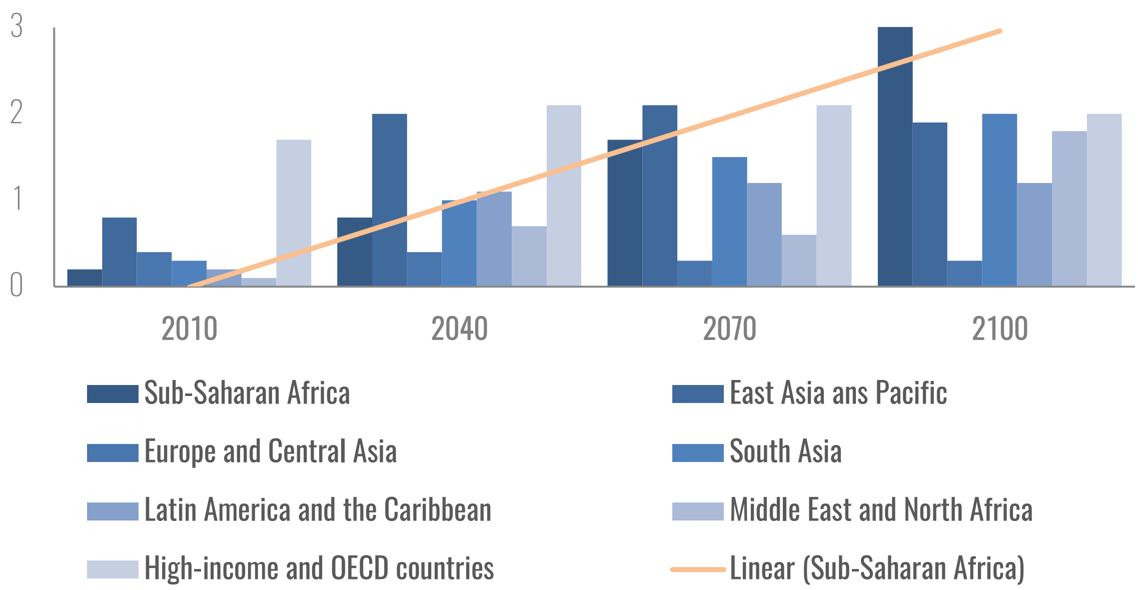


Figure 1 - Projected waste generation by region (millions of tonnes per day) up to the year 2100. Adapted from "Waste production must peak this century" (Daniel Hoornweg 2013).

Food Waste

In their article, "Determinants of consumer food waste behaviour: Two routes to food Waste", Violeta Stancu, Pernille Haugaard and Liisa Lahteenmaki conclude that there are two routes to food waste behaviour, the intentional one and the routinized one. Their findings suggest that food-related routines (i.e. planning, shopping and leftovers reuse) are main drivers of food waste in addition to perceived behavioural control. Among the routines, the leftovers reuse routines were the most important contributors to food waste but were closely followed by shopping routines. Planning routines contributed only indirectly through shopping routines (Violeta Stancu 2016).

In regards to food waste, which coffee is a part of, the Food and Agriculture Organization of the United Nations (FAO) says that the global volume of food wastage is estimated at 1.6 billion tonnes of "primary product equivalents". Total food wastage for the edible part of this, amounts to 1.3 billion tonnes. Food wastage's carbon footprint is estimated at 3.3 billion tonnes of CO_2 equivalent of greenhouse gas (GHG) released into the atmosphere per year. The total volume of water used each year to produce food that is lost or wasted (250km3) is equivalent to the annual flow of Russia's Volga River, or three times the volume of Lake Geneva. Similarly, 1.4 billion hectares of land - 28 percent of the world's agricultural area - is used annually to produce food that is lost or wasted. A low percentage of all food wastage is composted: much of it ends up in landfills, and represents a large part of municipal solid waste. Methane emissions from landfills represent one of the largest sources of GHG emissions from the waste sector. Home composting can potentially divert up to 150 kg of food waste per household per year from local collection authorities. Developing countries suffer more food losses during agricultural production, while in middle- and high-income regions, food waste at the retail and consumer level tends to be higher. The direct economic consequences of food wastage (excluding fish and seafood) run to the tune of $750 billion annually (Nations 2016).

Next, some food wastage volumes, provided by FAO in their 2013 report "Food Wastage Footprint – Impact on Natural Resources", will be shown and interpreted.

In Figure 2 it is observed that the global volume of food wastage in 2007 was estimated at 1.6 gigatonnes of "primary product equivalents". The total food wastage for the edible part of food only was 1.3 gigatonnes. This amount can be weighed against the sum of the domestic agricultural production of all countries, which is about 6 gigatonnes (this value includes also agricultural production for other uses than food).

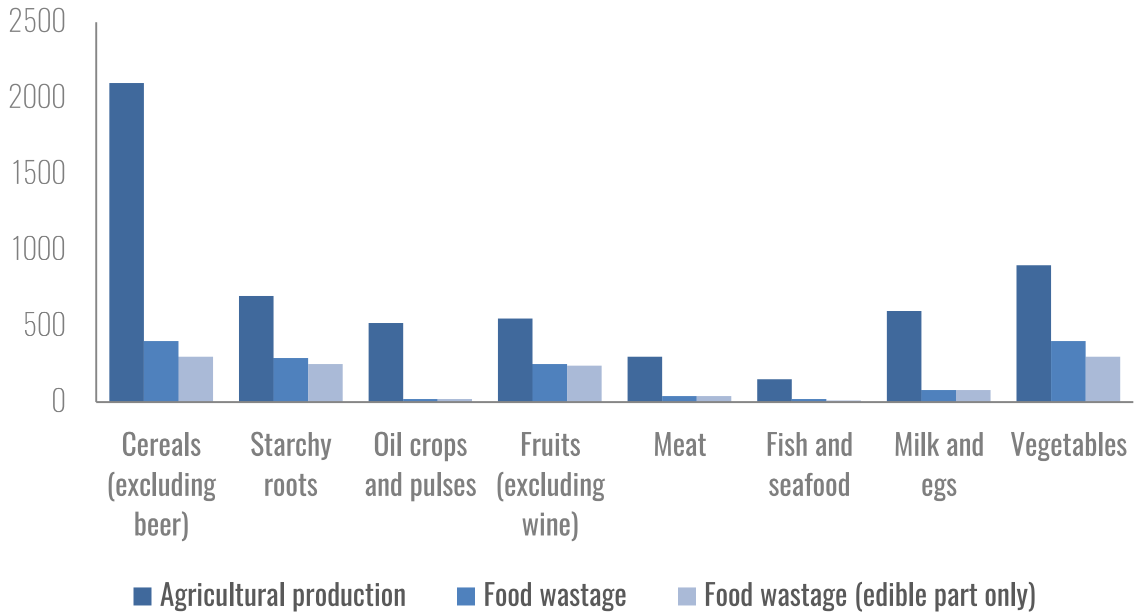


Figure 2 - Total agricultural production vs. food wastage volumes (million tonnes) in 2007. Adapted from "Food wastage footprint - Impacts on natural resources" (Nations 2013).

The same report shows the amounts of food wastage along the food supply chain. Agricultural production, at 33%, is responsible for the greatest amount of total food wastage volumes. Upstream wastage volumes, including production, post-harvest handling and storage, represent 54% of total wastage, while downstream wastage volumes, including processing, distribution and consumption, are 46%. Thus, on average, food wastage is balanced between the upstream and downstream of the supply chain (Figure 3).

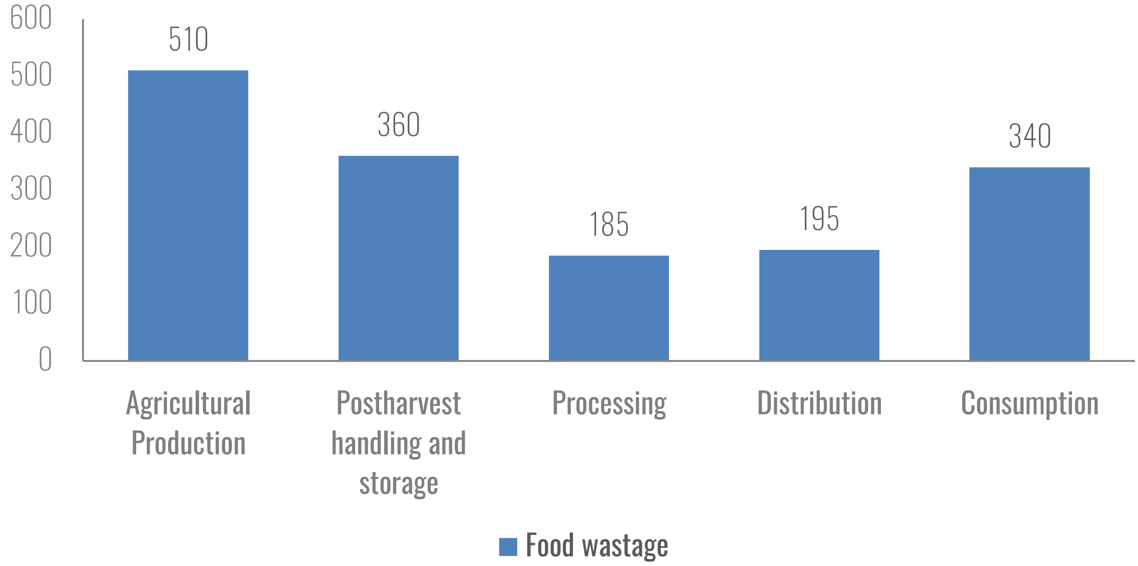


Figure 3 - Food wastage volumes, at world level by phase of the food supply chain (million tonnes). Adapted "Food wastage footprint - Impacts on natural resources" (Nations 2013).

On the other hand, the High Level Panel of Experts on Food Security and Nutrition (HLPE) tries to demonstrate the potential impacts of food losses and waste on the sustainability of food systems (Table 2).

Regarding economic impacts to food chain actors and to consumers, different actors/agents suffer different economic impacts and net costs (or even gains), which depend on their position in the food system. Any effect of price increase, due to food loss and waste (FLW), is different for net sellers versus net buyers of food. Also, depending on their market or purchasing power, and/or on their position and capacity of coordination in the production chain, some agents may suffer less from FLW and "push" the costs of inefficiency to less well-positioned agents. In non-competitive markets, most likely the consumer ultimately pays for the inefficiency and economic losses in the production process. In markets where there is greater competition, economic losses can be assumed by subaltern agents that under contract must submit to the standards imposed by the "chain coordinator" (often a major supermarket company, a trader or even a processing industry). However, even in those cases where there is competition, the inefficiency of the food systems always translates into a higher price of food for consumers, everything else being equal. Large amounts of FLW lead, everything else being equal, to proportionally less efficient outcomes of public resources used for productive programmes for agriculture, capacity building, training and subsidies.

Table 2 - Examples of potential impacts of food losses and waste on the sustainability of food systems. Adapted from "Food losses and waste in the context of sustainable food systems" (Security 2014).

Level/Dimension	Economic	Social	Environmental
Micro (household or individual enterprise)	Businesses and consumers spend a larger portion of their budget on foods that will not be sold or consumed.	Lower wages. Consumers with fewer resources for purchase. Lack of products.	Amount of garbage and waste. Contamination of individuals in rural and urban areas.
Meso (food chain)	Imbalance in production flows and need for more investments such as construction of silos and warehouses for intermediate stocks. Profit reduction. Inefficiencies in supply chain. Costs of disposal and treatment of waste.	Low labour productivity. Difficulties for companies to make their planning.	Multiplication of landfills.
Macro (food system and beyond)	Unrealized economic effort. Public investment in agriculture and infrastructure being less productive and turning into an opportunity cost. Reduction in financial resources for investment in other areas.	Higher level of food prices and difficulties in access to food. Larger number of people below the poverty line.	Pressure on natural resources: water and soil. Emission of greenhouse gases. Occupation of forests and conservation areas. Depletion of fishery resources. Pressure on wildlife. Greater spending on non-renewable energy.

With regards to social impacts, the high volume of losses in agriculture in developing countries ends up impacting also on labour productivity (marketable output per worker) and therefore on wages, which in turn can slow down the expansion of the consumer market, which would have boosted the producers for the acquisition of new technologies. From the social point of view, this is a vicious cycle that reduces the availability of resources both in the hands of producers and consumers. It is challenging to exit this cycle. Production cost is an important decision element at micro level.

Relatively to environmental impacts, FLW entails both a needless use of resources used to produce the food lost and wasted, and the impact of putting waste at disposal, with emissions of methane, a potent GHG (Security 2014).

Waste treatment

Some of the conclusions from the paper "Waste – Investing in energy and resource efficiency" (Modak 2011), written for Green Economy magazine, are that the increasing volume and complexity of waste is posing threats to ecosystems and human health, but opportunities do exist to green the waste sector. These opportunities come from the growing demand for improved waste management and for resource and energy recovery from waste. This change in demand is driven by cost savings, increased environmental awareness and increasing scarcity of natural resources.

The growth of the waste market is a reflection of the underlying demand for greening the sector, especially the new paradigm of linking waste to resource use across the life-cycle of products. Different countries face different waste related challenges, but the path to greening the waste sector shares common milestones. Prevention and reduction of waste at source is essential for all countries, although this is particularly important in developing countries given their higher level of population growth and increasing material and resource consumption. The absolute growth of population and income implies that the absolute volume of waste is unlikely to decline. Greening the sector is therefore the only way to go.

Concerning waste treatment, Eurostat tells that in 2012, some 2 302 million tonnes of waste were treated in the EU-28; this includes the treatment of waste imported into the EU and the reported amounts are therefore not directly comparable with those on waste generation (Eurostat 2016) .

Figure 4 shows the development of waste treatment in the EU-28 for each of the main treatment categories during the period from 2004 to 2012. The quantity of waste treated by disposal in 2012 was slightly (0.4 %) lower than it had been in 2004. The quantity of waste recovered (excluding energy recovery) grew from 890 million tonnes in 2004 to 1 053 million tonnes in 2012, and increased by 18.3 %. As a result, the share of recovery in total waste treatment rose from 42.1 % in 2004 to 45.7 % by 2012. Waste incineration (including energy recovery) saw an overall increase between 2004 and 2012 of 27.4 % (Eurostat 2016).

Their News release from 2015 goes even further as to demonstrate the Municipal waste generation and treatment in the EU from 1995 to 2013 (Figure 5).

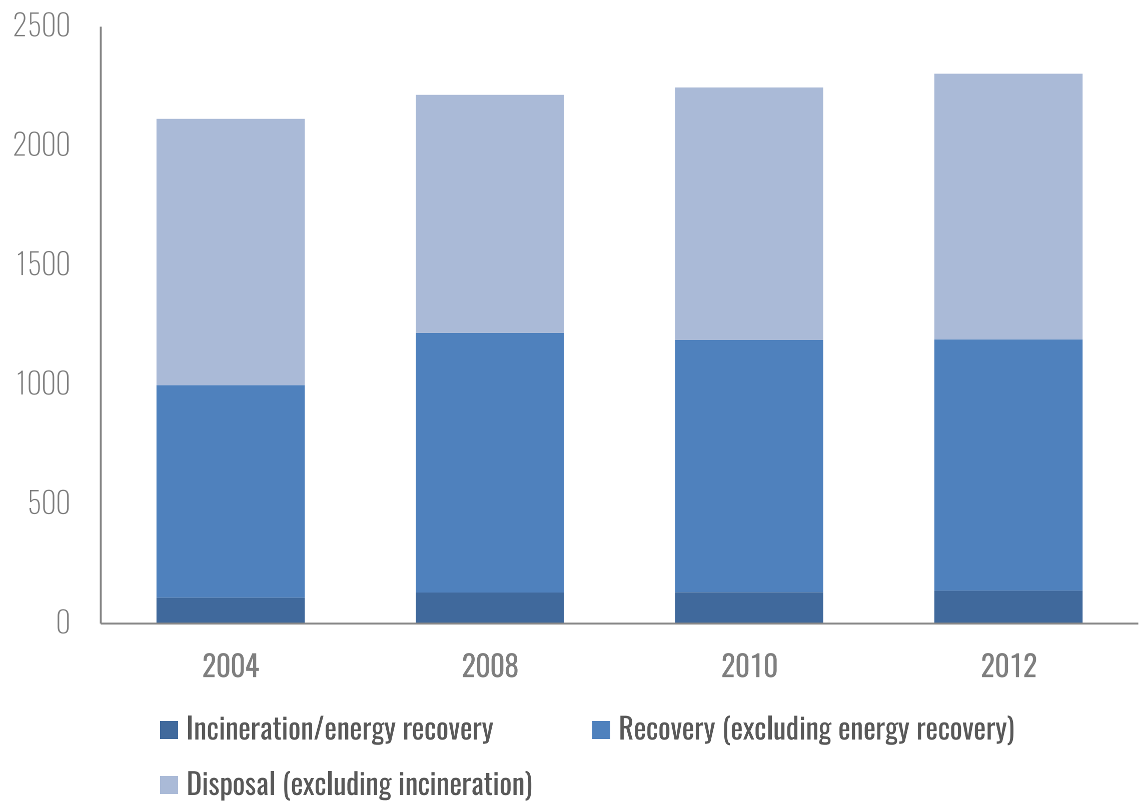


Figure 4 - Development of waste treatment in the EU-28 (million tonnes). Adapted from "Waste statistics" (Eurostat 2016).

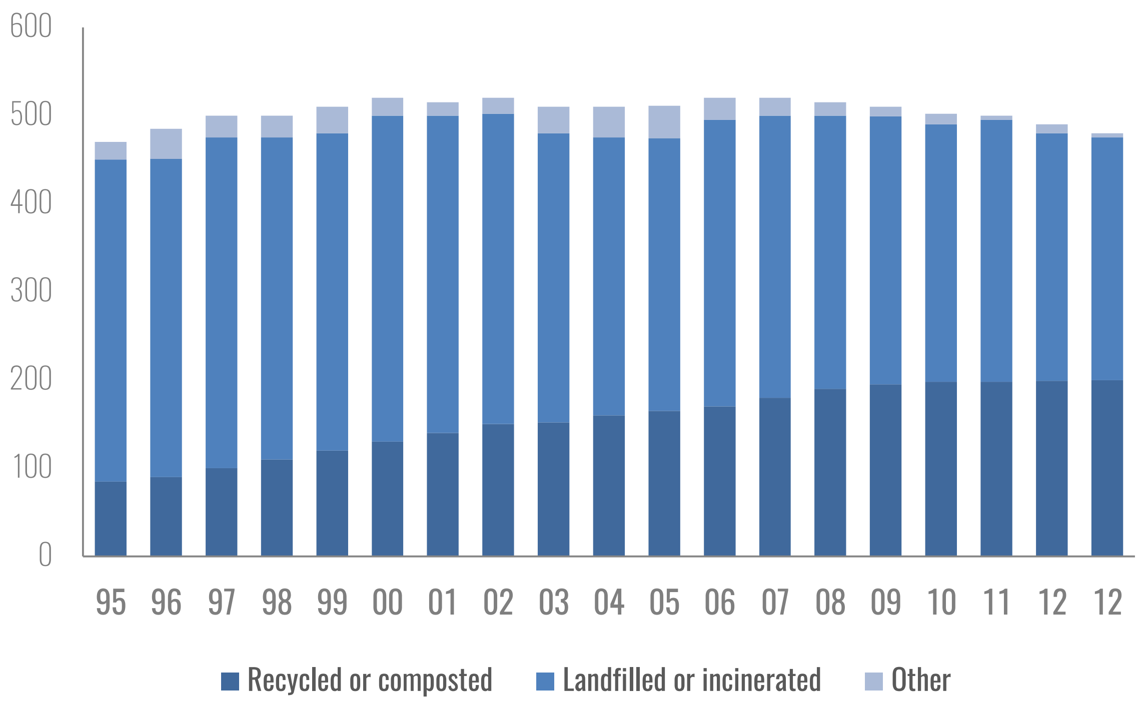


Figure 5 - Municipal waste generation and treatment in the EU (refers to EU27, excluding Croatia, for the years 1995 to 2006 and to EU28 from 2007 onwards) in kg per person. Adapted from "Generation of waste by economic activity" (Eurostat 2015a).

"In the European Union (EU), the amount of municipal waste generated per person in 2013 amounted to 481 kg, down by 8.7% compared with its peak of 527 kg per person in 2002. Since 2007, the generation of municipal waste per person has constantly decreased in the EU to below its mid-1990s level. Of the 481 kg of municipal waste generated per person in the EU in 2013, 470 kg per person were treated. This treatment followed different methods: 31% was landfilled, 28% recycled, 26% incinerated and 15% composted. The share of municipal waste recycled or composted in the EU has steadily increased over the time period, from 18% in 1995 to 43% in 2013" (Eurostat 2015a). It is possible to see an obvious increase in recycled or composted waste from 1995 to 2013 and can only hope that it continues like this.

Figure 6 displays the number of dumpsites accepting different combinations of waste types around the world, as can be found on the 2014 report "Waste Atlas – The World's 50 Biggest Dumpsites" (Atlas 2014). Almost all cases accept mixed municipal solid waste (MSW); and in almost half (24 out of 50) co-disposal of hazardous waste is practiced. Co-disposal of E-Waste is also common (6 out of 50), whereas in a few cases indescribable (other waste) find their way there.

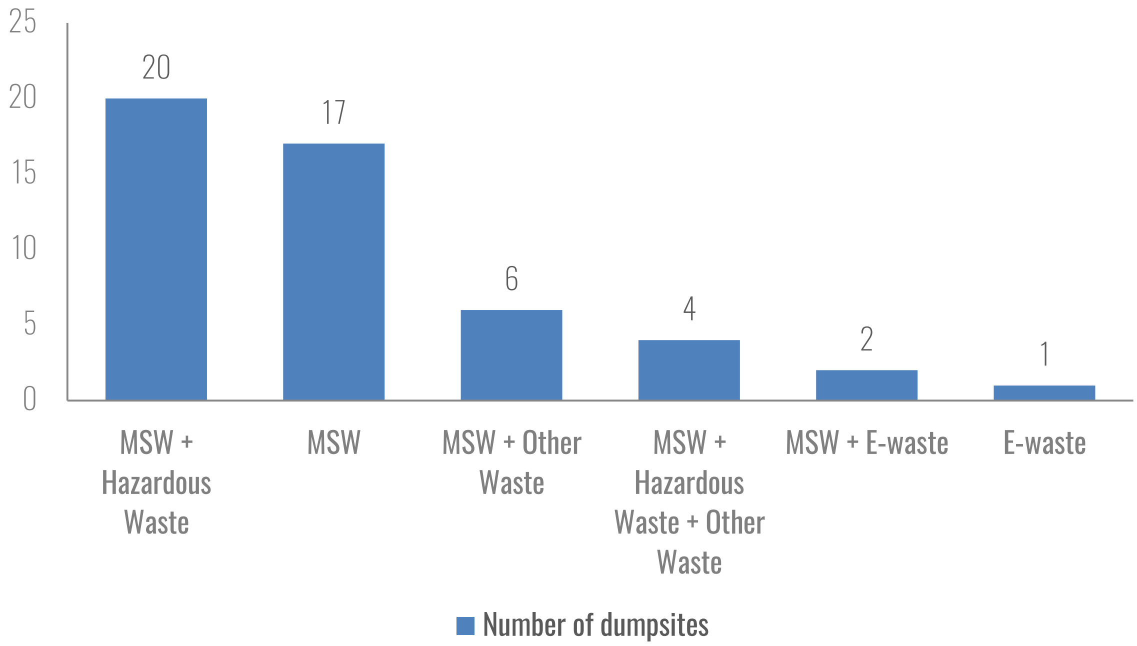


Figure 6 - Number of dumpsites accepting different combinations of waste types. Adapted from "Waste Atlas - The World's 50 Biggest Dumpsites" (Atlas 2014).

So, there is undoubtedly action, towards waste management, being taken around the world. However, there is still a long road for it to be perfect or even positive in a noticeable way.

Table 3 shows a glimpse at what the costs of this inaction can be, based the document from 2012, "Global Waste Management Outlook - Summary for Decision-Makers", by David C. Wilson and others, integrated in the United Nations Environment Programme (UNEP) and with the cooperation of the International Solid Waste Association (ISWA)

The same source alerts for the fact that proper waste management makes economic sense but still has a financial cost, since affordability is a major challenge in developing countries, even the poorest will pay something when they can see and raising finance for investment in modern facilities continues to be a challenge in all countries.

The benefits are, nevertheless, substantial. Making less that goes to waste saves business money on raw material, energy and labour costs and the estimated savings to business worldwide are in the hundreds of billions of dollars per year (David C. Wilson 2012).

Table 3 - Costs of inaction towards waste management. Adapted from "Global Waste Management Outlook - Summary for Decision-Makers" (David C. Wilson 2012).

Areas of Impact	Costs of Inaction
Public health impacts of uncollected waste	Gastrointestinal and respiratory infections, particularly in children. Blocked drains aggravate floods and spread infectious disease.
Environmental impacts of open dumping and burning	Severe land pollution and freshwater, groundwater and sea pollution. Local air pollution and climate change.
Costs to society exceed the financial costs per capita of proper waste management by a factor of 5-10	Health care. Lost productivity. Flood damage. Damage to businesses and tourism.

Because this dissertation is directed towards Product and Industrial Design, these 12 principles of green engineering are presented (Table 4) from the authors Paul Anastas and Julie Zimmerman (2003). It is sometimes said that small steps can be giant leaps in the direction of achieving greater things. Maybe these twelve steps can be the beginning of something in the right direction.

Table 4 - 12 Principles of Green Engineering. Adapted from "Through the 12 Principles - Green Engineering." (Paul T. Anastas 2003).

Principles	Description
1	Designers need to strive to ensure that all material and energy inputs and outputs are as inherently non-hazardous as possible.
2	It is better to prevent waste than to treat or clean up waste after it is formed.
3	Separation and purification operations should be designed to minimize energy consumption and materials use.
4	Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
5	Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials.

6	Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
7	Targeted durability, not immortality, should be a design goal.
8	Design for unnecessary capacity or capability (e.g., “one size fits all”) solutions should be considered a design flaw.
9	Material diversity in multicomponent products should be minimized to promote disassembly and value retention.
10	Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.
11	Products, processes, and systems should be designed for performance in a commercial “afterlife”.
12	Material and energy inputs should be renewable rather than depleting.

2.2. Coffee Statistics and Data

Having in mind that coffee becomes a waste at the end of its life cycle and trying to contextualize this study even further, some figures are presented next.

According to data from the International Coffee Organization (ICO), it's estimated that its global consumption in 2014 was 149.8 million 60 kg bags (Organization 2015b).

In Portugal, in the same period, the consumption amounted to 823.000 bags and the consumption per capita was around 4.7 kg (Organization 2015d).

As stated by the same source, the annual coffee consumption from 2011 to 2014 has suffered an increase of 2.4% (Figure 7). It is also clear that this is a gradual increase as it happened yearly. We can therefore assume that it will continue to exist in the near future.

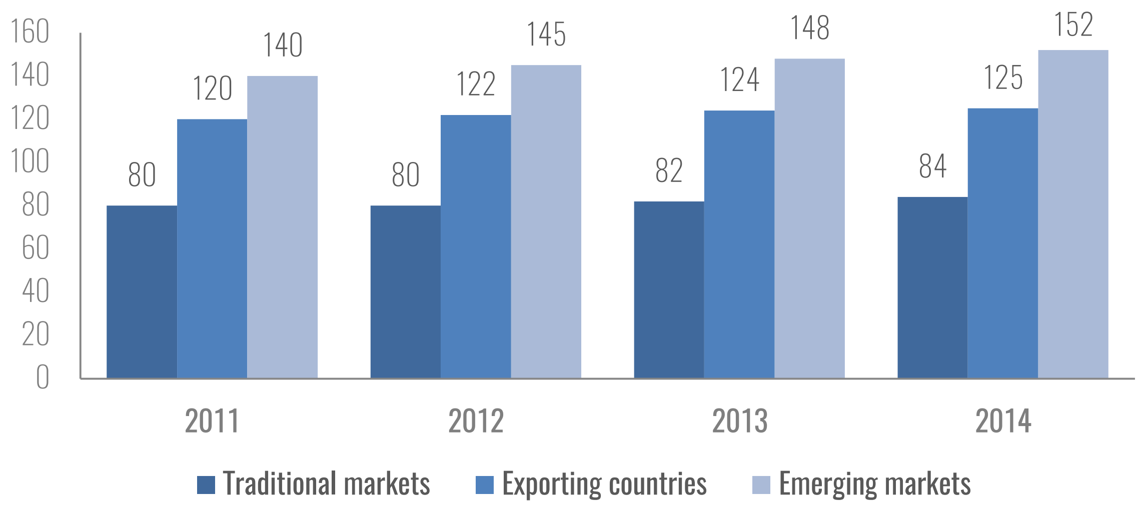


Figure 7 - Average annual growth rate (million bags) in global coffee consumption since 2011. Adapted from "The Current State of the Global Coffee Trade" (Organization 2015b).

From 2010 to 2015 there was an increase in total production of coffee by all exporting countries by almost 100 thousand 60kg bags and the October group of nations was always on the lead, being the July group the less productive (Table 5).

Table 5 - Total production by all exporting countries in thousand 60kg bags. Adapted from "Total production by all exporting countries" (Organization 2015e).

Crop Year	2010/11	2011/12	2012/13	2013/14	2014/15
April Group	64 494	59 701	71 294	67 953	60 342
July Group	1 887	1 678	2 222	1 886	2 086
October Group	67 258	75 192	74 077	76 963	78 753
Total	133 640	136 572	147 593	146 801	141 732

Figure 8 provides information on coffee production by continent from 2012 to 2014. The values remain similar from one crop year to the other, but there is, however, an evident aggrandizement from South America where production achieves greater numbers.

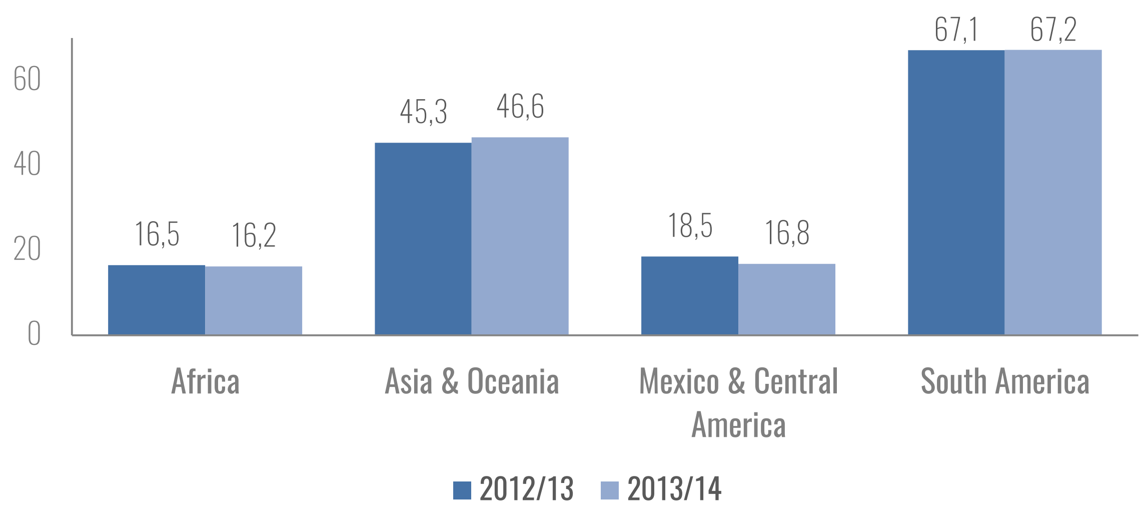


Figure 8 - Coffee production by continent in million bags. Adapted from "Annual Review 2013-2014 Strengthening the global coffee sector through international cooperation" (Organization 2015a).

By analysing the composition of world consumption (Figure 9), it becomes evident that although the traditional markets are still on the lead, their leadership is also decreasing while emerging markets kept growing for the last 20 years and as ICO explains in their annual review 2013/14 (Organization 2015a), a particularly strong growth has been observed in East and Southeast Asia, such as Indonesia, Vietnam and South Korea. Traditional consuming markets have registered more modest growth rates of around 1.3% per annum. Coffee demand in the European Union has stagnated somewhat recently, although consumption in the USA has shown some resurgence. Traditional consuming markets account for over 50% of the world total, but this percentage share is diminishing, and the strongest potential for further growth can be found in emerging markets.

On Table 6, the consumption of selected importing countries from 2004 to 2014 is revealed, where it is easily understood that consumption in total has been rising as well and there is a clear difference in numbers between the European Union and the USA relatively to the other regions.

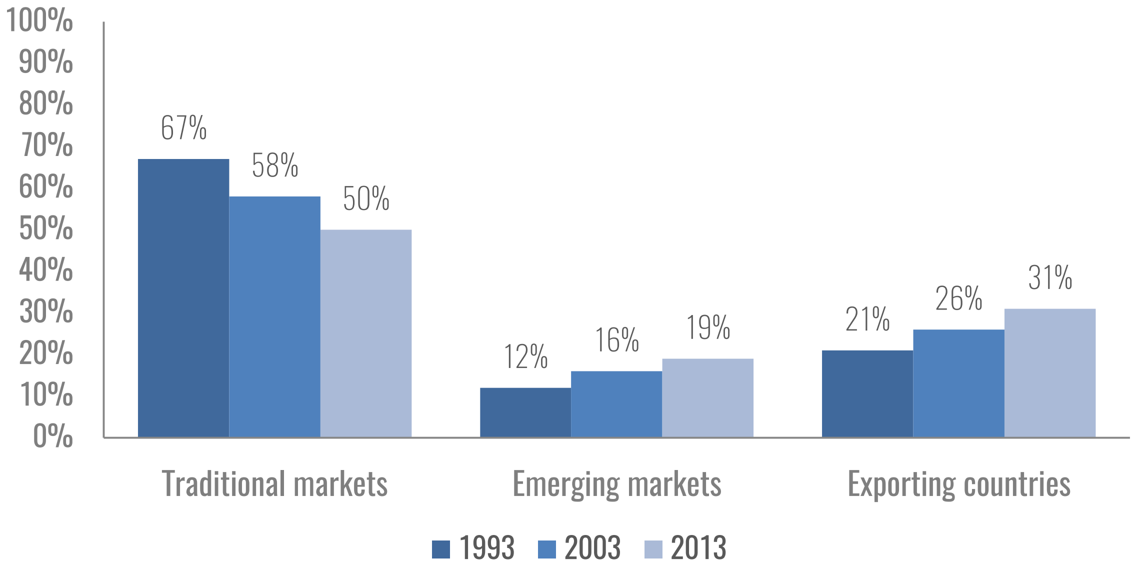


Figure 9 - Composition of world consumption. Adapted from "Annual Review 2013-2014 Strengthening the global coffee sector through international cooperation" (Organization 2015a).

Table 6 - Disappearance (consumption) in selected importing countries in thousand 60kg bags. Adapted from "Disappearance (consumption) in selected importing countries" (Organization 2015c).

Year	2004	2006	2008	2010	2012	2014
European Union	41 743	41 586	40 700	41 207	41 018	41 648
Japan	7 117	7 268	7 065	7 192	7 131	7 494
Norway	709	721	715	746	723	729
Switzerland	722	932	1 149	1 012	1 047	1 028
Tunisia	263	200	317	301	421	460
Turkey	403	497	484	610	681	929
USA	20 973	20 667	21 652	21 783	22 232	23 761
Total	71 930	71 872	72 082	72 851	73 252	76 049

If, on the other hand, one wants to see how coffee consumption has been between continents from 2011 to 2014, Table 7 displays exactly this. On the right column is the compound growth rate (constant rate of return over a time period) where there is an obvious raise in consumption all over, except for Central America and Mexico, with the most apparent rise coming from Africa.

Table 7 - World coffee consumption in thousand 60kg bags. Adapted from "World coffee consumption" (Organization 2015f)

Year	2011	2012	2013	2014	CAGR
World Total	139 483	143 140	147 113	149 823	2.4%
Africa	9 170	10 081	10 624	10 809	5.6%
Asia & Oceania	26 452	28 014	29 159	30 446	4.8%
Central America & Mexico	4 974	5 035	5 030	4 979	0.0%
Europe	49 311	49 461	50 493	51 109	1.2%
North America	25 618	25 730	26 931	27 674	2.6%
South America	23 958	24 820	24 875	24 807	1.2%

Specialty Coffee Association of America (SCAA) also affirms that the consumption in the five leading importing countries (France, Germany, Italy, Japan, and the United States) bounced to about 37.3 million bags during the period January to September 2010, as compared to with 36.5 million bags for the same period the previous year. While traditionally viewed as an export crop, coffee consumption in coffee producing countries on the rise, increased by 3.9% between 2004 and 2008. Many experts predict that Brazil will displace the United States as the single largest coffee consuming market in the world within the next few years, somewhere from 2014 to 2016. Emerging markets (considered those outside of the EU, US, and Japan) are another source of growth, with consumption increasing 4.7% between 2004 and 2008. The United States imported more than 21.5 million bags during the 2008/09 coffee year, accounting for more than one quarter of global coffee (un-roasted) imports, making it the world's largest single buyer. Brazil, Colombia, and Vietnam account for 21%, 19%, and 11% of those imports, respectively. Drip coffee sales improved to 4.7% in the 4th quarter of 2010 compared to up 3.5% in the 3rd quarter. Espresso grew 4.1% in the 4th quarter, fairly similar to the 3rd quarter. In recent years, there has been a huge surge in Arabica coffee demand from large, emerging markets including Brazil, India, and China. These countries have growing middle classes which been providing high demand for good coffee and they are competing with the United States to purchase these gourmet coffee beans. Coffee preparation at home is up 4 percentage points with 86% of past-day coffee drinkers reporting that they made coffee at home (America 2012).

As can be seen by the information provided on Figure 10, the USA is still the top coffee consuming country, followed closely only by Brazil. For this reason, the next two figures show data only relative to the United States of America.

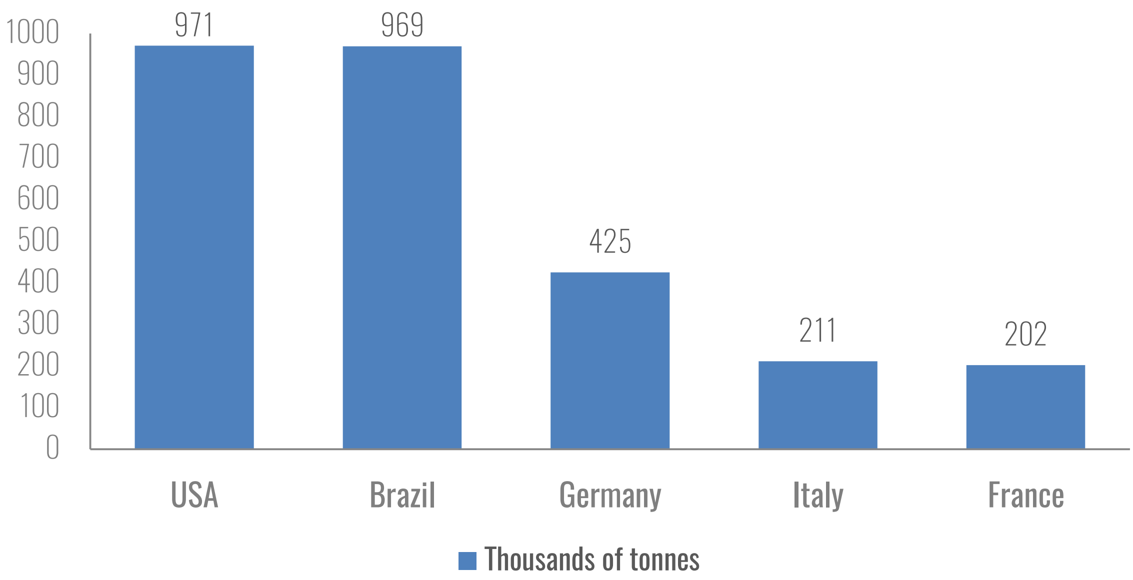


Figure 10 - Top 5 Countries by Sheer Tonne Coffee Consumption. Adapted from "Caffeine (Coffee) Consumption by Country" (Foster 2016).

Figure 11 represents the source of caffeine for individuals (Americans) 22 years old and over, just so we can comprehend how much more of it is consumed through coffee, relatively to other sources of caffeine and is, therefore, coffee such a good choice for reuse as a material.

The graph on Figure 12 gives an idea of the range of ages that consume the most coffee daily and these are, in fact, the ones that have the financial condition to buy it regularly.

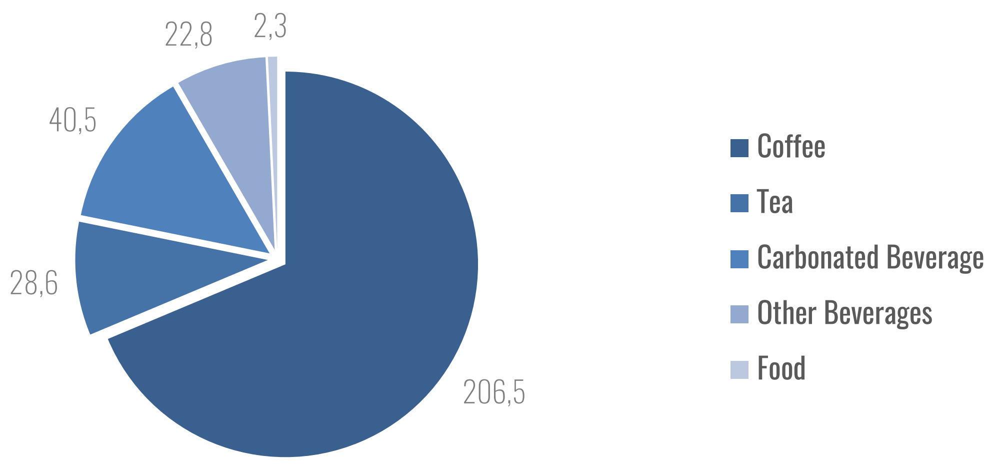


Figure 11 - Source of caffeine for individuals 22 years and over in milligrams. Daily intake: 300.7 milligrams. Adapted from "Caffeine Intake by the U.S. Population" (Somogyi 2010).

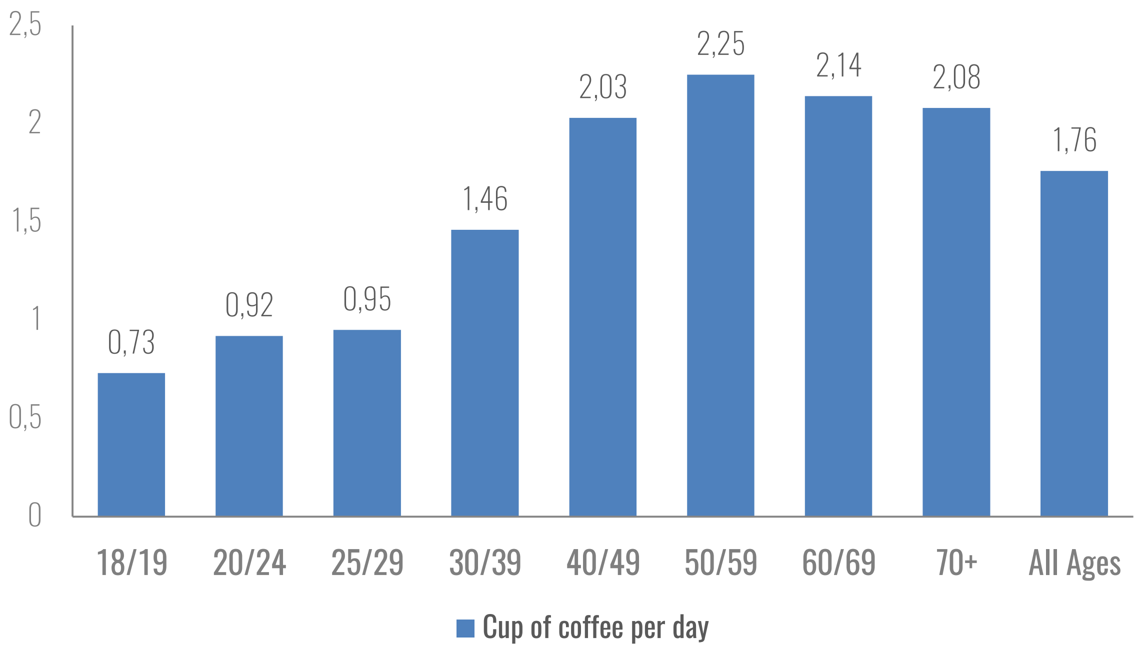


Figure 12 - Daily consumption of coffee by the U.S. population in 2009. Adapted from "Caffeine Intake by the U.S. Population" (Somogyi 2010).

On the infographic by Food Republic from 2015, it can be learned that the coffee business has grown to be huge and it doesn't seem to be showing any signs of stopping. In fact, between 2000 and 2010, the value of world coffee exports grew by over 85%, from $8.3 billion to $15.4 billion (Republic 2015).

One of the reasons for this to happen might be explained with the 1999 paper titled "Actions of Caffeine in the Brain with Special Reference to Factors That Contribute to Its Widespread Use" (Bertil B. Fredholm 1999), where it's concluded that it is clear that caffeine cannot really be considered a model drug of dependence, at least not if by "model" is meant "typical". Its weak reinforcing properties are due to a unique and atypical mechanism of action. The drug is self-limiting and subjects do not gradually increase the dose, because tolerance development to both the reinforcing and aversive effects is limited. There are few negative consequences of caffeine use in moderation and the withdrawal affects are modest and transient in the individuals that experience them. Because caffeine will, according to current drug classification schemes, be designated a drug of dependence, and that it will not, in this respect, be different from drugs such as amphetamine, morphine, ethanol, or nicotine, it is possible that, in addition to the qualitative criteria, some quantitative criteria of relative abuse potential and negative health consequences would be useful in a modified drug classification scheme. This is particularly true for a drug whose use is so entrenched in normal societal activities. So, in short, although coffee might be considered a drug for its own characteristics and addictive properties, its behaviour on the brain doesn't work in the same way as other drugs.

Another reason for this is that the world's coffee industry has responded to any crisis by working tirelessly to increase coffee consumption worldwide. The ongoing effort to increase coffee consumption has included identifying market saturation points, developing quality control mechanisms, encouraging farmers to maintain high standards and rewarding coffee roasters for developing new varieties and blends of coffee. The efforts of the International Coffee Organization to raise coffee consumption around the world are paying off. Despite the fact that coffee prices have risen, there is more coffee traded, sold and enjoyed each year. Marketing thrusts by the ICO have turned coffee drinking into a fine art and encouraged people to think of coffee as an affordable luxury (Larkin 2016). Nonetheless, it's pretty clear that coffee's consumption is not stopping any time soon and by all the data presented on this chapter, it's just logical to assume that it will continue to grow.

This chapter appears as a way to validate the use of coffee waste as a design material. The first section shows that waste in general is growing and there are no predictions for this growth to slow down. And although there are already waste treatment strategies in place, if it could be reused in the same or in a similar way that this study is trying to demonstrate for spent coffee grounds, this problem might not exist in a near future.

Section two focuses on coffee because it is the base material for this thesis and to further demonstrate that if nothing is done regarding its reuse, its consumption will still continue to grow as it is such an intrinsic part of our society and it would be a shame to let such a substance, with so many interesting characteristics go to waste.

Furthermore, for the time being, the use of most wastage materials allow for a no cost approach, making this an unrivalled advantage. For all these reasons, it becomes apparent on this chapter that coffee waste really is a good choice for a substance to be reused as a material on the creation of design products. It is also obvious that its abundance will continue to exist and designers should see this as an opportunity.

CHAPTER III

STATE OF THE ART

On this chapter is presented the state of the art, regarding coffee reuse strategies. Some simpler than others, but their goal remains the same. It is also intended to exhibit the type of solutions for coffee waste in additive manufacturing, as well as some design applications for the same purpose.

The last section focuses on the characteristics of the material symbiosis between coffee waste and PLA (polylactic acid), through testing. These tests are justified and an integral part of this study, as will be demonstrated further on this document, on chapter four.

The obvious reason for this, is to understand if there is already action being taken towards the reuse of the chosen substance or not, and if more could be done.

In order to give some context to the theme, coffee's historical background and origins are provided next.

Coffee's beans, from which coffee is brewed, constitute the primary source of caffeine. The caffeine content in coffee varies widely, depending on the type of coffee bean and the method of preparation; even beans from a given coffee bush can vary in their caffeine concentration. Roasted coffee beans contain 0.8–2.5% caffeine. Generally, dark-roast coffee has less caffeine than lighter roasts because the roasting process reduces the bean's caffeine content. Arabica coffee normally contains less caffeine than the Robusta variety. In general, one serving of coffee ranges from 64 mg for a single cup (30 ml) of espresso to about 145 mg for an 8 oz. (ounce) cup (237 ml) of automatic drip coffee (Somogyi 2010).

All commercial coffee species originate from Africa and belong to the genus Coffea. The high quality Coffea Arabica species originates from the rainforests in the southwestern highlands of Ethiopia. One theory suggests that the Ethiopians took it to Yemen when they conquered the country by AD 500. Another hypothesis says that Arab merchants brought it initially to Yemen and the Arabian Peninsula, where it was cultivated and has contributed to the prosperity of the seaport of Mocca. This explains why Arabica coffee is associated with the name Mocca, although the prime centre of origin and diversity is on the African continent (Hermann A. Jurgen Pohlan).

Pecevi, an Ottoman historian of the early seventeenth century, writes: "Until the year 962 (1554-55), in the High, God-Guarded city of Constantinople, as well as in Ottoman lands generally, coffee and coffeehouses did not exist. About that year, a fellow called Hakam from Aleppo and a wag called Shams from Damascus came to the city: they each opened a large shop in the district called Tahtalkala, and began to purvey coffee. These shops became meeting places of a circle of pleasure seekers and idlers, and also of some wits from among the men of letters and literati, and they used to meet in groups of 20 or 30" (Kafadar 2016).

3.1. Reuse Strategies for Coffee

In the particular case of coffee, there are already reuse strategies in several areas, from agriculture to fuel and to begin with, next are displayed 14 genius ways to recycle used coffee grounds, by Natural Living Ideas (Table 8).

Table 8 - 14 Genius Ways To Recycle Used Coffee Grounds. Adapted from "14 Genius Ways To Recycle Used Coffee Grounds" (Ideas 2014).

Area of Interest	
Garden	Pest Repellent
	Fertilize Your Garden
	Compost it for Later
	Caffeine for Carrots
Around the House	Absorb Food Odours
	Natural Abrasive
	Beautiful Golden Dye
	Homemade Candles
	Clean Out the Fireplace
Health and Beauty	Exfoliate Skin
	Rejuvenating Facial
	Caffeinated Soap
	Coffee for Your Hair
	Cellulite Treatment

This list is divided by areas of interest such as garden, around the house and health and beauty and the author presents some pretty ingenious ways for coffee grounds waste reuse.

Regarding the garden area, it's already well known that coffee has particularities that might be of interest. On the around the house area we can see five inventive ways of reusing coffee, like absorbing food odours or making homemade candles. There are even solutions for it on health and beauty like making creams for the skin or even treatments for hair. Another good solution is the caffeinated soap.

These are the simpler solutions for which coffee waste can be reused by anyone. Next we will be looking at some more serious answers for this problem, also in different areas of interest.

Coffee waste has been consolidating itself as one of the most abundant biological resources of the world for use as green energy (Gómez-de la Cruz 2015). There are several investigators, from different parts of the planet, already studying the possibility of transforming coffee waste as a biofuel.

Figure 13 - Graphical Abstract (Hansaem Jang 2015).

For instance, researchers from South Korea have written a paper titled "Direct power generation from waste coffee grounds in a biomass fuel cell" (Hansaem Jang 2015), where they highlight that waste biomass is directly employed as a fuel with no any special treatment. Waste coffee ground is a fuel for SOFC-based (solid oxide fuel cell) carbon fuel cell technology. Carbonization and gasification take place under experimental temperature. Produced in-situ gaseous compounds highly enhance electrochemical reaction. They write "We demonstrate the possibility of direct power generation from waste coffee grounds via high temperature carbon fuel cell technology". Figure 13 illustrates what they are trying to do, by turning coffee waste into electrical energy by means of carbon fuel cell technology. And their work is not being unnoticed, as they are mentioned in Fuel Cells Bulletin journal (Bulletin 2015), where it's said that researchers at Kwangju Institute of Science and Technology in South Korea have succeeded in generating power from used coffee grounds, in a high-temperature direct carbon fuel cell. This performance is expected to offer new possibilities as an energy source while contributing to environmental protection, by providing stable electric power utilising recycled coffee grounds.

But there are several other teams of research working on this subject. Other example comes from another group from South Korea, but in this case they conclude that it's not the coffee grounds that may be converted into energy, but instead it's the crude lipids extracted from them. They state "The sequential co-production of bioethanol and biodiesel from spent coffee grounds was investigated. The direct conversion of bioethanol from spent coffee grounds was not found to be a desirable option because of the relatively slow enzymatic saccharification behaviour in the presence of triglycerides and the free fatty acids (FFAs) found to exist in the raw materials. Similarly, the direct transformation of the spent coffee grounds into ethanol without first extracting lipids was not found to be a feasible alternative. However, the crude lipids extracted from the spent coffee grounds were themselves converted into fatty acid methyl ester (FAME) and fatty acid ethyl ester (FAEE) via the non-catalytic biodiesel transesterification reaction". And finish with "Thus, this study clearly validated our theory that spent coffee grounds could be a strong candidate for the production of bioethanol and biodiesel" (Eilhann E. Kwon 2013), concluding that it is in fact possible to use the waste from coffee grounds and turn it into bioethanol and biodiesel.

And it doesn't end here, as a team in Germany wrote an article for the Journal of Energy Chemistry in 2015 titled "Spent coffee ground as source for hydrocarbon fuels" (Peter Dohlert 2015), where can be learned that the conversion of triglycerides (coffee oil) obtained from spent coffee ground to produce hydrocarbon fuel (diesel) was studied. They finish by saying that it was established a protocol for the conversion of coffee oil (triglycerides) derived from spent coffee ground to hydrocarbons, which can be applied as diesel fuel. With tris-(pentafluorophenyl)-borane as catalyst the coffee oil was hydro-deoxygenated applying polymethylhydrosiloxane (PMHS) as cheap reductant under mild reaction conditions. For instance, from 1 kg spent coffee ground potentially 77 g of hydrocarbons can be produced.

As in almost every area of interest and progress, the United States are always present and this couldn't be different. Researchers from the University of Nevada have also written a paper in 2008 (Narasimharao Kondamudi 2008), which describes an approach to extract oil from spent coffee grounds and to further transesterify the processed oil to convert it into biodiesel. It continues by saying that this process yields 10-15% oil depending on the coffee species (Arabica or Robusta). The biodiesel derived from the coffee grounds (100% conversion of oil to biodiesel) was found to be stable for more than 1 month under ambient conditions. It is projected that 340 million gallons of biodiesel can be produced from the waste coffee grounds around the world. The coffee grounds after oil extraction are ideal materials for garden fertilizer, feedstock for ethanol, and as fuel pellets.

However, there are other completely different areas that are studying possibilities for reusing coffee waste. In Japan, scholars have shown that it can be used in adsorption of dyes onto carbonaceous materials produced from coffee grounds by microwave treatment. They say that "organic wastes have been burned for reclamation. However, they have to be recycled and reused for industrial sustainable development. Carbonaceous materials were produced from coffee grounds by microwave treatment. There are many phenolic hydroxyl and carboxyl groups on the surface of carbonaceous materials. The base consumption of the carbonaceous materials was larger than that of the commercially activated carbon. The carbonaceous materials produced from coffee grounds were applied to the adsorbates for the removal of basic dyes (methylene blue and gentian violet) in wastewater" (Mizuho Hirata 2002).

On the other hand, from Seoul comes a study with the title "Spent coffee ground extract suppresses ultraviolet B-induced photoaging in hairless mice" (Hyeon-Son Choi 2015), from 2015 which showed that extract of spent coffee grounds (ESCG) inhibited UV-derived photoaging of skin in a hairless mouse model. The protective effect of ESCG administration in mice exhibiting skin photoaging was supported by the down-regulation of matrix metalloproteinase (MMPs), which are responsible for the degradation of collagen, and evidenced by the increase in type I collagen (COL I), observed via immunohistochemistry (IHC) analysis. Therefore, they propose that spent coffee grounds, which are generally thrown away as a by-product, could be used as a protective agent for skin health.

To finalize this section of the chapter, an article in Bioresource Technology journal in 2009 (A.J. Adi 2009), concluded that the study definitely reveals that coffee grounds can be decomposed through vermicomposting by using L. rubellus (species of earthworm) value-added material. Coffee grounds can also play a role in stabilizing kitchen waste condition that indirectly provides a better environment for fostering population growth of earthworms and produces a high quality vermicompost as end product.

So, it is definitely safe to recognize that coffee grounds waste is and has been studied for its characteristics in order for it to be reused in the most various ways and on different areas of interest.

3.2. Reuse Solutions for Coffee in Additive Manufacturing

Additive manufacturing (AM), or three-dimensional (3D) printing, is receiving unprecedented attention. AM is a suite of emerging technologies that fabricates three-dimensional objects directly from digital models through an additive process, typically by depositing and "curing in place" successive layers of polymers, ceramics, or metals (Ford 2014).

"There is a growing consensus that 3D printing technologies will be one of the next major technological revolutions" (Thierry Rayna 2015).

The first three examples presented here are not made with coffee grounds left-overs, but they have been chosen because of the similarities they have with coffee, since they are all dusty or granulated materials and the same result could probably be achieved using coffee waste.

Salt

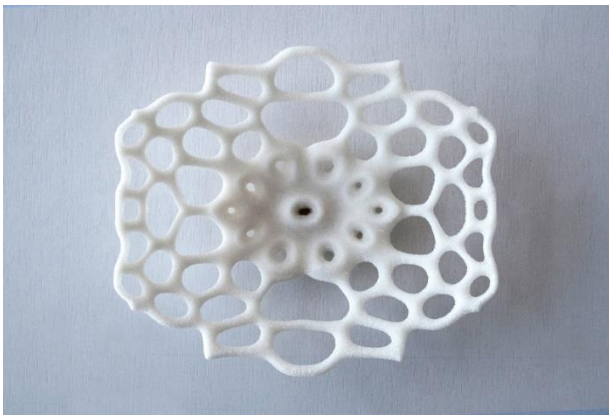


Figure 14 - Salt (Ronald Rael).

The first example can be seen on Figure 14, and the material used here is salt. The type of binders the authors have used to create these objects are not known, but they seem stable and as Ronald Rael states, this material is strong and even waterproof. "Salt for 3D printing uses salt harvested from the San Francisco Bay. The salt is harvested from 109-year-old salt crystallization ponds in Redwood City. These ponds are the final stop in a five-year salt-making process that involves moving bay water through a series of evaporation ponds. In these ponds the highly saline water completes evaporation, leaving 8-12 inches of solid crystallized salt that is then harvested for industrial use. The material is strong, waterproof and translucent" (Ronald Rael).

The Utah Tea Set

Figure 15 - The Utah Tea Set (Virginia San Fratello 2015).

Another example (Figure 15) is called "The Utah Tea Set" and is based on a very well-known computer aided design (CAD) model, the Newell Teapot. Not only are the creators of the object trying to demonstrate new materials for 3D printing, they are also creating a semantic cycle by making a tea set, out of tea. "With the advent of 3D printing users are able to materialize digital designs. While one might consider ceramic the obvious material for 3D printing the Utah Teapot, we have chosen instead to 3D print it out of actual tea. This means the Utah Tea Set, which includes tea cups also 3D printed out of tea, is doubly, characteristically self-referential meta and then meta again" (Virginia San Fratello 2015).

Sawdust Screen

Figure 16 - Sawdust Screen (Virginia San Fratello).

"The Sawdust Screen is fabricated from 3D printed walnut and the surface retains the layering effect from the additive manufacturing process, which simulates natural wood grain. The screen is comprised of individual 3D printed wood components which are affixed together to form a variably dimensional enclosure and surface. The Sawdust Screen is inspired by the vessels found in the microscopic analysis of wood anatomy in hardwoods" (Virginia San Fratello). On Figure 16, the "Sawdust Screen" can be seen, which can be pretty much self-explanatory. It's a 3D printed screen made out of sawdust. This piece is rather interesting, because the characteristics of sawdust can be quite similar to coffee powder.

The next set of examples presented, were all created using coffee waste as a base material and the composition of these creations vary from one example to the other.

Agridust

Marina Ceccolini studied at the University of Design of San Marino and the final project involved studying the use of food waste, and find ways to turn this into a useful, biodegradable material. AgriDust (Figure 17) is a project of recovery and valorisation of waste fruit and vegetables. Working with six chosen waste materials (Coffee grounds, peanut shell, husk tomato, bean pod, orange waste and lemon waste), a biodegradable and atoxic material is born. The material is constituted from 64.5% waste and the remaining 35.5% come from a binder made from potato starch. AgriDust can be used to create pots for plants and packaging, moreover using cold technology, it can be 3D printed, with the classic extruder being substituted by a syringe (Ceccolini 2015).

Figure 17 - Agridust (Ceccolini 2015).

Hoop

“3D printing has taken an interest to our rubbish bins! The Italian Francesco Pacelli, 26 year-old engineer and materials designer, imagines lots of new materials from coffee grounds. Focus on his Hoop project that recycles food waste for 3D printing” (Grellier 2015).

Francesco Pacelli, member of the +Lab of the Politecnico University in Milan, startled by the exponential quantities of food waste from now to 2050, took an interest in the means to recycle the waste lastingly by combining it with an ancestral material, clay. At the same time, he revisits the production of ceramic thanks to new technologies such as 3D printing. The different formulas created by him proved to be more or less convincing. They were then given a shape, either by moulding or extruded by means of a syringe (as in the case of Agridust), so as to design a collection of bricks and modules adapted to the production of storage, cooking and curing devices. Once the material has taken shape, it is either dried in the sun, or cooked in a ceramic furnace at 1,050°C for nine hours, in collaboration with a local ceramic laboratory (Figure 18).

Figure 18 - Hoop by Francesco Pacelli (Grellier 2015).

"The 3D test prints with these new mixed substances were very interesting because by extruding them with a syringe, the flow is better and it's possible to obtain better sediment, more precise and regular than with traditional clay. For the moment, coffee grounds are the most relevant substance to use with extrusion because is it already in powder form. This new ceramic material, lighter and more porous than traditional ceramic, is relevant for applications needing lightness combined with high temperature resistance." Francesco Pacelli (as cited by Grellier 2015).

Wound up

Figure 19 - Wound Up (3Dom 2015).

Wound Up (Figure 19) is a coffee filled 3D printing filament made using waste by-products from coffee. It uses those coffee left-overs to create a special 3D printing material with visibly unique print finishes. The filament produces objects with a rich brown colour and a noticeable natural grain. This is the first in a line of intriguing materials from 3D-Fuel called the "c2composites". More distinctive bio-based products will be released in the near future by the company. It can be printed on any machine capable of printing with polylactic acid (PLA) using standard PLA settings (3Dom 2015).

FEUP bought one of these filaments to experiment with and do some testing. Using one of their 3D printers with the ability of printing PLA, they've tried to make several objects, one of which can be seen on Figure 20. The method used was Fused Deposition Modelling (FDM). "Fused deposition modelling (FDM) is one of the AM processes that build part of any geometry by sequential deposition of material on a layer by layer basis. The process uses heated thermoplastic filaments which are extruded from the tip of nozzle in a prescribed manner in a semi molten state and solidify at chamber temperature" (Samir Kumar Panda 2009). The 3D printer used for this is a RepRap, developed at one of FEUP's laboratories.

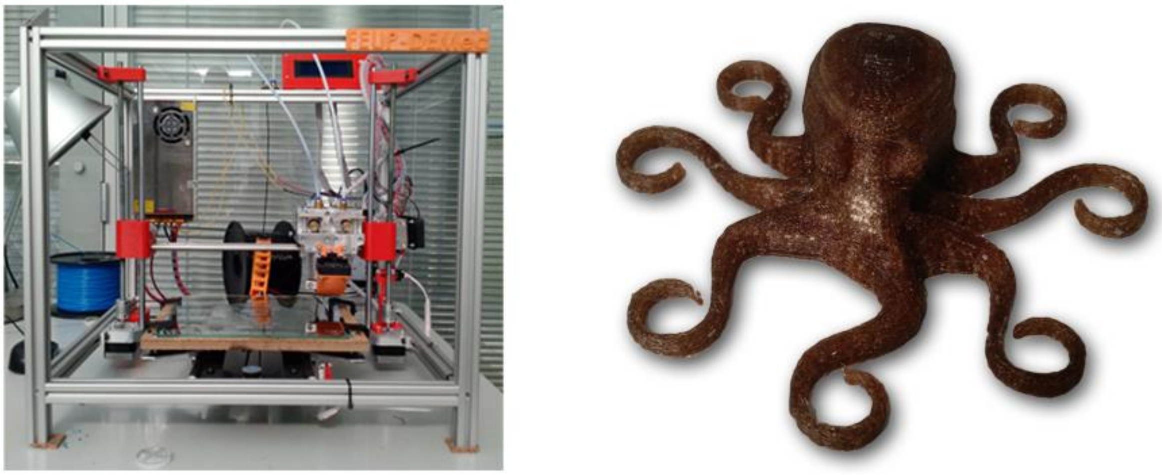
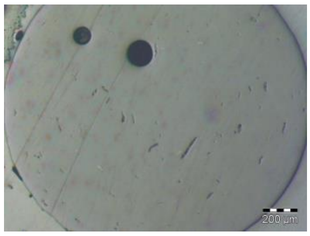
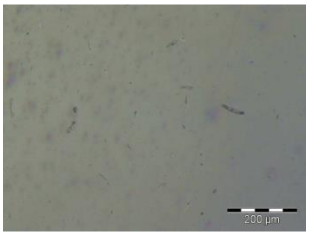
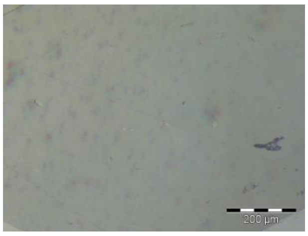
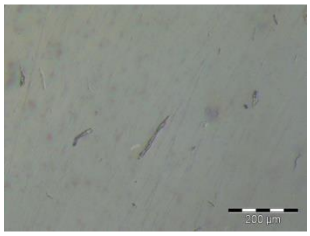
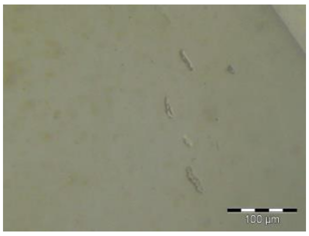
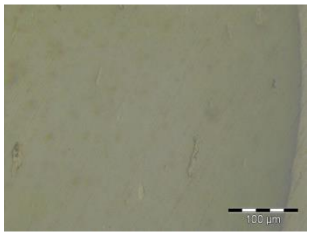


Figure 20 - 3D Printer, property of FEUP (left). 3D printed octopus using 3Dom coffee filament (right).

Moreover, the filament was analysed under an optical microscope to perhaps uncover the amounts of coffee used in relation to PLA (Table 9). The images are divided in three types of magnification (25x, 50x and 100x) and three examples of each are shown. For what is noticeable on these samples, one can apprehend that the percentage of coffee relatively to PLA is not that great. In fact, it looks like a very small amount of coffee is being used in the mixture. Even from the objects printed with this material, this can be seen. The final product presents a clear, light brown finish.

Table 9 - Microscopic analysis from 3Dom coffee filament.

Magnification	Samples		
25x			
50x			
100x			

Although this technology is relatively new to greater audiences, it is safe to say that there are already attempts to use coffee waste in additive manufacturing, with some being more successful than others. Nevertheless, as stated before, this technology is here to stay and it might well be the way for waste reuse in the future.

3.3. Design Applications for Coffee Waste

When it comes to Design, there are also a variety of solutions being developed with coffee waste as a basis. Here are five examples of what's being done in the area, some being only concepts that are not yet being produced for several reasons, and others that are already part of the market as established pieces of consumption.

HIFA coffee system

Figure 21 - HIFA Coffee System (DiStasio 2016).

Columbian-born designer Adrián Pérez and Mauricio Carvajal are the creators of HIFA coffee system (Figure 21). It is still a concept and it brings up the idea of growing mushrooms from coffee. They have idealized a coffee making machine, which reuses the grounds left-overs as a substrate for this purpose. The used grounds, an abundant resource in university districts, creative urban centres, and in pretty much every American household, are basically the perfect material for growing mushrooms. The top of the HIFA unit houses the coffee brewing portion of the device. Grounds are placed in, followed by just off-boil water and then a mesh strainer is plunged down into it to separate the soaked grounds from the divine java. The double-walled carafe can be lifted off the base for pouring, leaving behind the used coffee grounds in a little yellow cup. The coffee is then poured into the divided lower portion of the unit. A little mycelium (mushroom roots) is added, sprayed periodically with water, and after a while mushrooms begin to appear. The cultivation of mushrooms in the HIFA system is very similar to other mushroom-growing kits, which often come preloaded with mycelium. Because the HIFA unit fills the mushroom planter from the bottom up, it could be used as a potentially endless source of edible fungus. When the substrate compartment is full, used grounds could simply be redirected to other destinations, such as a compost pile or outdoor garden beds (DiStasio 2016).

GroCycle


Figure 22 - GroCycle (Cycle).

GroCycle, featured on Figure 22, is a project launched by Fungi Futures CIC, an innovative social enterprise based in Devon, UK. They have been growing Oyster mushrooms from waste coffee grounds since 2011, and are still hugely inspired by the scale of the opportunity. They also want to spread the idea further, and thus have created the GroCycle Urban Mushroom Farm and have designed an easy to use Mushroom Grow Kit to enable you to grow your own gourmet mushrooms at home from waste coffee grounds (Cycle). This product is pretty self-explanatory. As stated before, coffee waste is often used as a fertilizer for plants. In this case it is being used to produce mushrooms. It is pretty much a well-established product on the market by now.

Kaffeeform


Figure 23 - Kaffeeform (Delana).

Another good example of coffee based design products is Kaffeeform (Figure 23). "Kaffeeform is a recycled innovative material created with coffee grounds, vegetable fibers, cellulose and biopolymers. After five years of experimentation and research, an original formula was created to transform old coffee in new products. " (Kaffeeform 2015). German designer Julian Lechner invented this product. Following more than five years of research and development, Lechner developed a method for mixing the used grounds with natural glues and sustainably-sourced wood particles. The mixture becomes a liquid that can be used in injection moulds to create solid objects. This first application for the material, Kaffeeform, is completely appropriate to the medium: espresso cups and saucers also known by the name Kaffeeform. The material is surprisingly hard and strong, it easily stands up to the heat of fresh espresso and it is tough enough to go through a dishwasher with no problem. Each piece is little different thanks to the swirling marbling patterns created by the unique materials. According to Lechner, Kaffeeform products even retain their coffee smell after production. The cup and saucer sets are still technically in the pre-production phase so aren't ready for ordering just yet (Delana).

Eco Sleeve Maker

Figure 24 - Eco Sleeve Maker (Seth 2014).

"The stats are very clear, used coffee grounds are literally dumped by cafés and little thought given to their recycling. Incidentally the grounds are good raw material for dehumidification, deodorization and compost. However, today we focus on the ECO Sleeve Maker, which compresses and converts used coffee grounds into sleeves for the coffee cups" (Seth 2014). The way this product would work is by means of adding water and sugar to the coffee grounds inside a heated chamber to make it stiff and once we've used it, the sleeve could be disposed as compost. The goal of this product would be to prolong the life and efficiency of the materials, while eliminating the need for paper sleeves. It was created by students Choi Seung Ho, Lim Hyun Mook, Han Ji Yeon Yu and Tae Kwon of the University Hanseo. It is, however, just a concept, although it seems to have great potential, having already won recognition as a finalist in the International Design Excellence Awards this year.

Decafé

Raúl Laurí is the creator of "decafé" (Figure 25), a patented material made from used coffee grounds. He reflects on how we could make the most of our every day's wastes. In this case, he has chosen coffee since it is a product which is near to the user, well-known and worldwide consumed. In fact, it is the second most traded commodity in the world. In addition, it is certain that coffee is an 'experience bearer' as we cannot ignore the fact that thousands of stories and events normally take place surrounding a cup of coffee. So, the material is the result of a long experimentation process, patience and enthusiasm (Laurí 2012). "It is the


Figure 25 - decafé by Raúl Laurí (Laurí 2012).

fact of believing in what you do what contributes to give you the necessary strength to achieve any objective you may have", Raúl says. It was achieved basically thanks to experimentation on the use of some traditional culinary techniques. It consists mixing the coffee grounds with a natural binding substance and undergoing the result to a pressure and temperature based transformation process by which it is possible to make the material to have enough consistency to be employed in a large range of products. The creator, however, does not share the recipe, so we don't actually now the details of the mixture. Decafé has already a range of products on the market, like lamps and bowls.

It can thus be concluded that much has been done in relation to coffee waste reuse in several areas, from agriculture to product design, and even the transformation of raw materials into fuel. However, it is also clear that many of these technologies are at the beginning of their existence and much more can still be done.

3.4. PLA + Spent Coffee Grounds Tests

There is a very complete scientific article on this subject which presents results of tests done to this composite, PLA and spent coffee grounds (SCG), so those results will be presented next. The paper is titled "Renewable resource-based green composites of surface-treated spent coffee grounds and polylactide: Characterisation and biodegradability" from author Chin-San Wu, 2015. The tables and figures displayed here are all adapted from Wu's work.

Biodegradation

Table 10 and Figure 26 show the changes in morphology of both the PLA/SCG and PLA characterised as a function of time buried in soil, after 30 and 60 days that illustrate the extent of any morphological changes. The 20% PLA/SCG composite exhibited randomly distributed pits, large and deep. These observations indicate that biodegradation of the SCG phase in PLA/SCG (20%) increased with time. After 30 days, disruption of the PLA matrix became more apparent. This degradation was consistent with the change in mass of the PLA matrix as a function of incubation time, which reached almost -26% after only 60 days. The most likely cause of this mass loss is biodegradation.

Table 10 - Degradation of PLA and PLA/20%SCG as a function of incubation time in soil (Wu 2015).

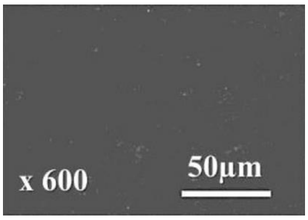
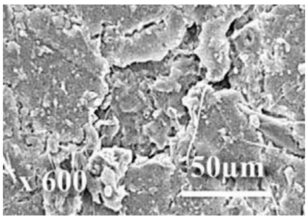
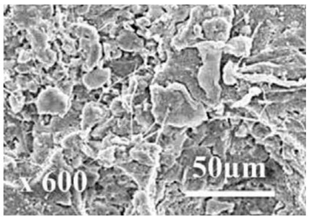
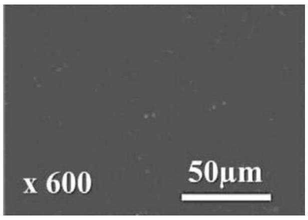
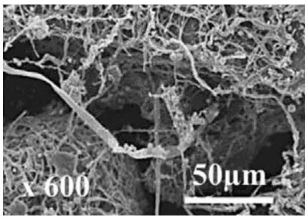
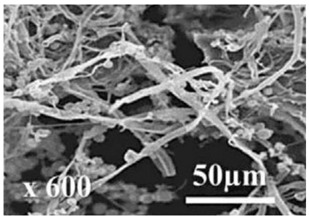
	Day 0	Day 30	Day 60
PLA			
PLA/20%SCG			

Figure 26 shows the percent mass changes as a function of time for PLA/SCG composites buried in soil compost. Composites with 40% SCG degraded rapidly over the first 30 days, losing mass approximately equivalent to the SCG content, and showed a more gradual decrease in mass over the following 30 days (Wu 2015).

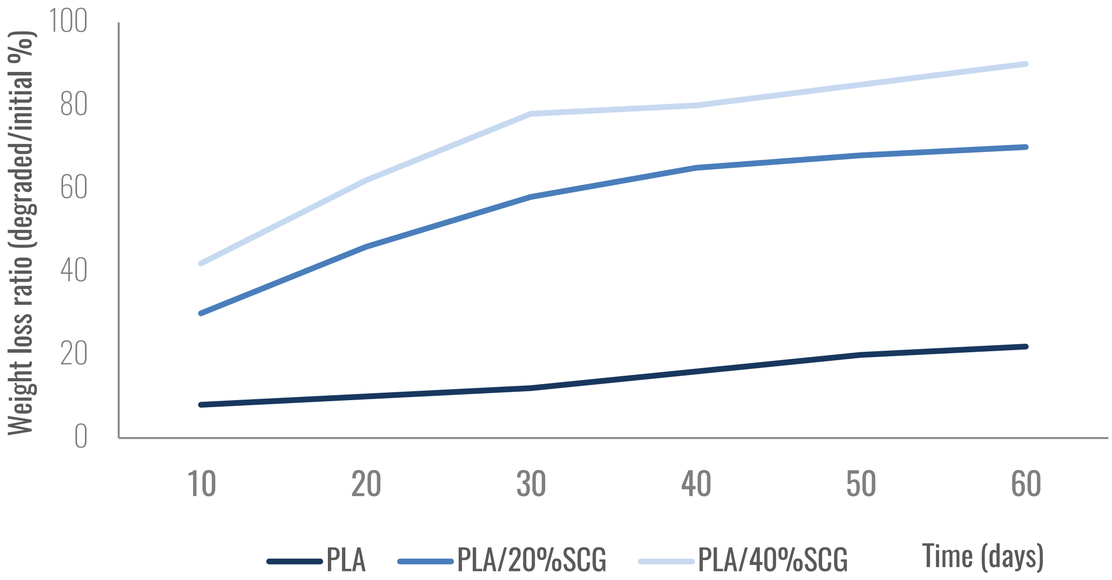


Figure 26 - Mass loss of PLA, PLA/20%SCG and PLA/40%SCG as a function of incubation time in soil (Wu 2015).

Water Absorption

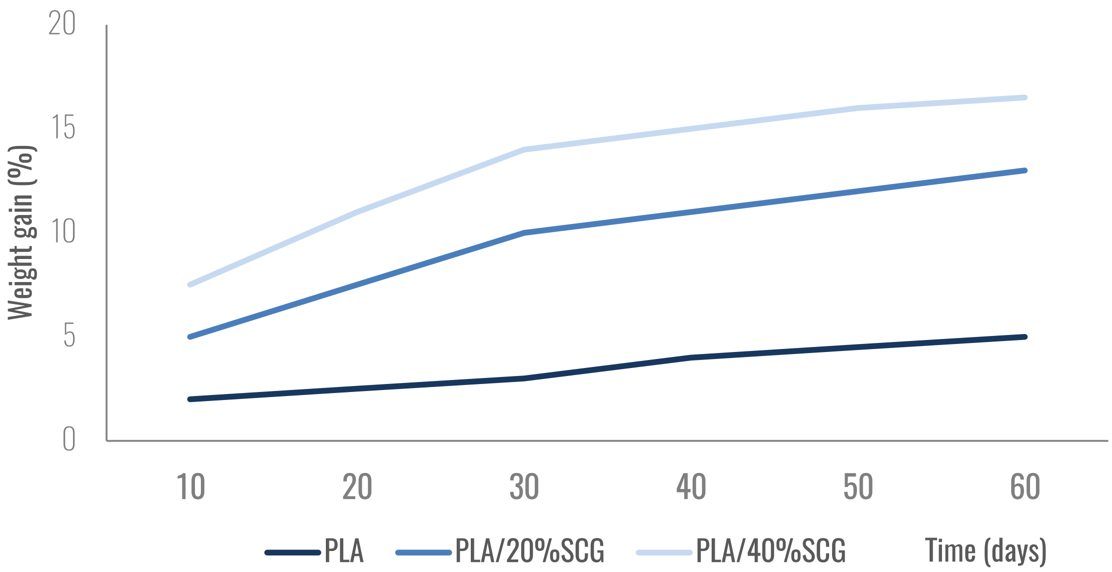


Figure 27 - Percent mass gain due to the absorption of water for PLA, PLA/20%SCG and PLA/40%SCG (Wu 2015).

Figure 27 shows that for PLA/SCG, the percent mass gain over the 60-day test period increased with SCG content. As the dispersion arrangement of the polymer chains in these systems is expected to be random, the above results were likely due to decreased chain mobility at high SCG contents and the hydrophilicity of SCG, which adhered weakly to the more hydrophobic PLA matrix (Wu 2015).

Thermal Properties

The Hf, Tm, and Tg of the PLA/SCG composites as a function of SCG content were determined using differential scanning calorimetry (DSC). The results are shown in Table 11. Tm decreased with increasing SCG content. Conversely, Tg increased with increasing SCG content. This increase is likely a result of the reduced space available for molecular motion as the relative amount of SCG in the composites. Hf may be used as an indicator of blend crystallinity. Although the Hf of the PLA/SCG blends decreased with increasing SCG content, the extent of the decrease was significantly great in PLA/SCG, indicating a lower degree of crystallinity (Wu 2015)

Table 11 - The effects of SCG content on the thermal properties of PLA/SCG composites (Wu 2015).

SCG (%)	Tg (^{o}C)	Tm (^{o}C)	Hf (^{o}C)
0	57.8	161.3	36.5
10	59.1	159.2	29.6
20	60.5	158.2	26.6
30	61.3	157.6	24.6
40	62.2	156.3	22.3

Torque Measurements in Mixing

Figure 28 shows the effects of SCG content and mixing time on the melt torque of the PLA/SCG composite. When preparing PLA/SCG, the polymer was first melted and SCG was added to the melt. Therefore, the resulting polymer composite contained powder filler. The torque decreased with increasing SCG content and mixing time, and levelled off after 8 min of mixing. The final torque decreased with increasing SCG content because the melt torque of SCG was lower than that of PLA. The dynamic mechanical properties of the PLA/SCG composite were measured and used to evaluate their component compatibility (Wu 2015).

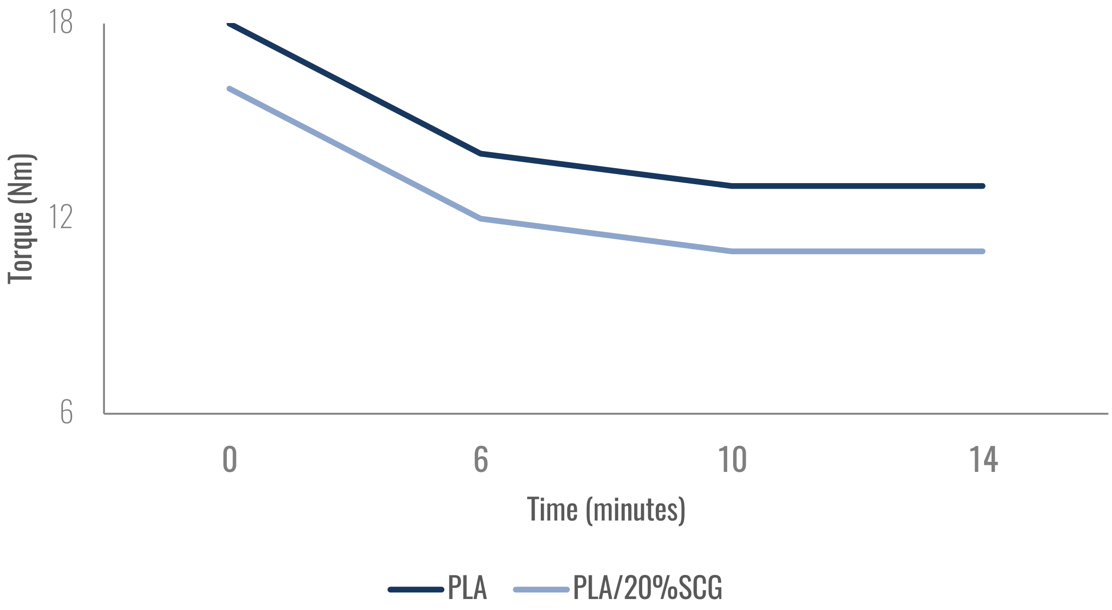


Figure 28 - Torque values as a function of mixing time for the PLA/SCG composite (Wu 2015).

Mechanical Properties

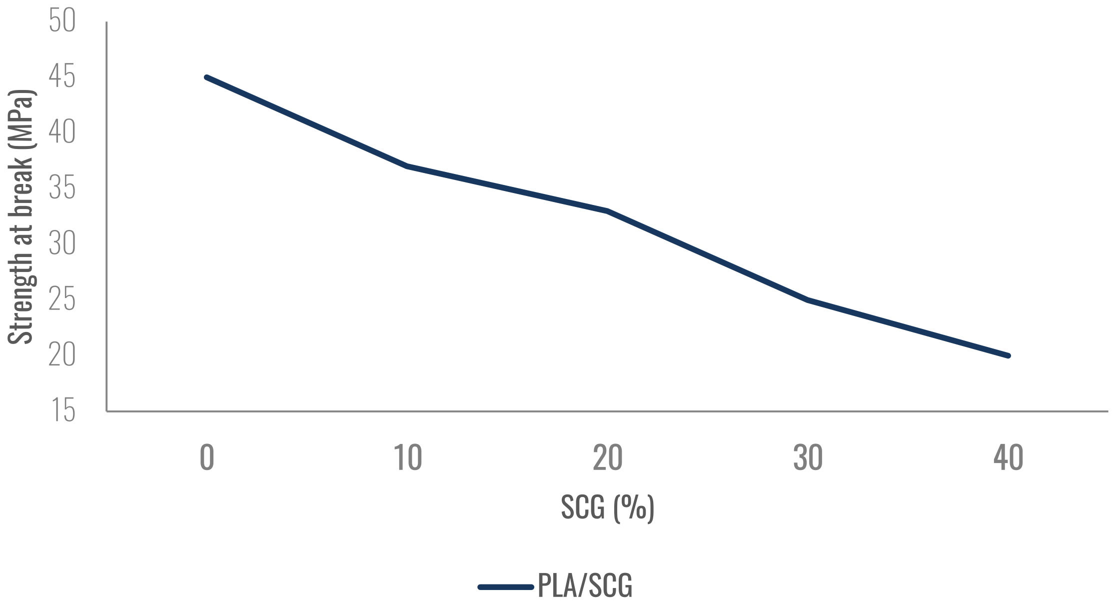


Figure 29 - The effects of SCG content on the tensile strength at failure are shown for the PLA/SCG composites (Wu 2015).

Figure 29 shows the tensile strength at failure as a function of the SCG content in PLA/SCG composites. For the PLA/SCG composites, the tensile strength at failure decreased markedly with increasing SCG content and was attributed to poor dispersion of SCG in the PLA matrix. The effect of this incompatibility on the mechanical properties of the composites was substantial (Wu 2015).

These tests are of great relevance to this study, as will be shown on chapter four where the experimental work of this thesis is described and one of the experiments is made from spent coffee grounds and PLA.

Additionally, it shows that there is already research being done in order to aggregate coffee waste to other substances as a way to turn it into a composite material.

Full definition of research according to the Merriam-Webster Dictionary

1: careful or diligent search

2: studious inquiry or examination; especially: investigation or ***experimentation*** aimed at the discovery and interpretation of facts, revision of accepted theories or laws in the light of new facts, or practical application of such new or revised theories or laws

3: the collecting of information about a particular subject

CHAPTER IV

EXPERIMENTAL WORK

The experimental work appears as a way to establish the main and most suitable material to add to coffee waste, in creating this composite. The base material used in the experiments was spent coffee, obtained domestically.

Regarding these experiments with coffee waste, the only treatment given to it was, in some cases, by heating it in an oven at 100 ^{o}C for 24 hours, in order to eliminate its humidity. In all other cases, it was used as is.

This chapter is divided into five main sections. These sections refer to the materials used. To try to provide some consistency to the base material, several binders were tested, but only one was chosen as the ideal partner, for several reasons that will be explained further along this chapter.

The first material tried was epoxy resin. An epoxy resin is the thermosetting matrix or resin materials, having at least one or more epoxide groups in the molecule. The epoxide also termed as oxirane or ethoxyline group and is regarded as representative unit of epoxy polymer. Most of the commercially available epoxy resins are oligomers of diglycidyl ether of bisphenol A (DGEBA). These oligomers then react with the hardener, the epoxy resin gets cured and becomes a thermosetting polymer (Naheed Saba 2015).

Then, starch was used. Starch is a biopolymer synthesized in a granular form by green plants for energy storage over long periods. Natural polymers, such as gums and mucilage, are biocompatible, cheap, easily available and non-toxic materials of native origin. These polymers are increasingly preferred over synthetic materials for industrial applications due to their intrinsic properties, as well as they are considered alternative sources of raw materials since they present characteristics of sustainability, biodegradability and biosafety (Priscilla B.S. Albuquerque 2016)

The third binder to be tested was pine resin. Resin is a transparent and sticky viscous liquid, yellow brownish, a characteristic odor, which some resinous trees, like pine trees, produce when they suffer any damage or injury to the trunk. Upon leaving the trunk from inside to the outside, it heals the wound, protecting the tree. When it gets in contact with air, it dries and gets hard and brittle (forming crystals). It consists of various substances as acids, alcohol and oil (ICNF 2016). Almost at the same time, wax was added to the coffee and pine resin mix, making it the fourth material used.

Figure 30 - PLA food packaging (Mathilde 2013).

The fifth and last substance used was PLA. "Poly (lactic acid) (PLA) belongs to the family of aliphatic polyesters commonly made from α-hydroxy acids, which include polyglycolic acid or polymandelic acid, and are considered biodegradable and compostable" (Garlotta 2001). PLA is a biodegradable thermoplastic derived from natural lactic acid from corn, maize or milk. It is a thermoplastic derived primarily from annually renewable resources (maize, corn or milk), and it is available in a number of grades, designed for ease of processing. In-line drying may be needed to reduce water content for extrusion and moulding. The recommended moulding temperature is 165 – 170ºC. It resembles clear polystyrene, provides good aesthetics (gloss and clarity), but it is stiff and brittle and needs modification using plasticizers for most practical applications. It can be processed like most thermoplastics into fibres, films, thermoformed or injection moulded. PLA is transparent and has FDA (Food and Drug Administration) approval for food packaging. PLA film and sheet can be printed and laminated. Biopolymers are, however, expensive, costing 2 to 6 times as much as commodity plastics like polypropylene. Food packaging, plastic bags, plant pots, diapers, bottles, cold drink cups, sheet and film are some examples of the typical applications of this material (CES Edupack Software, Granta Design Limited 2016). This information validates the use of this material in the project, having into account its features with regards to food contact.

Regarding the used binders, they all appear with a purpose, not having been chosen at random. The epoxy resin, the first binder to be tested, appears because it was available at INEGI and only in an attempt to understand if it would be possible to mix the coffee residue with other materials. The starch appears because it is a natural and biodegradable polymer and these were fundamental points for this project. The pine resin was used at a time when an ideal binder had not yet been defined and because it was a material whose access was abundant, since other students were using it as base raw material in their own thesis. On the other hand, the wax helped to comprehend if the mixture of pine resin with coffee could be improved, and it was concluded that it would not result. Finally, the choice of PLA arose mainly because of the characteristics that are already recognized. It is a biodegradable thermoplastic, which can be injected and can be used in contact with food. Taking into account the initial objectives of this project, PLA has thus proved to be the ideal candidate.

4.1. Epoxy Resin

As stated before, the first binder to be tried was an epoxy resin, Biresin CR83 with 30% catalyst and the ratios between this material and the coffee have varied, so it could be realized what types of results could be obtained.

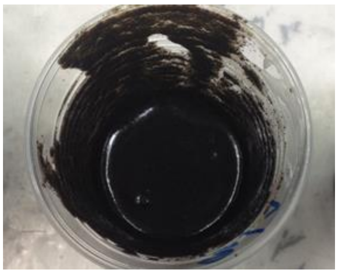
Biresin CR83 is an epoxy resin system with extremely low viscosity designed specifically for the infusion process for the production of high performance fibre reinforced composites parts and moulds. The system has thermal properties up to 80ºC. It also has a low tendency to crystallise. It can be used in the marine and general industrial composite areas. Due to its good wetting properties it is particularly suited for use with carbon fibre reinforcement (SIKA 2016). See Appendix I for product data sheet.

This experiment appears as an attempt to comprehend if it would be possible to create a somewhat mouldable material from coffee leftovers. The method of experimentation used is described on Table 12.

Table 12 - Method of experimentation with the epoxy resin.

Action	Procedure
	The first step was taking the coffee waste to an oven at 100 ^{o}C for 4 hours to eliminate the humidity.
	Next, the epoxy resin was mixed with the 30 % catalyst.

Then the coffee was added to the resin mixture, in different ratios.



Finally, the combinations were deposited in rudimentary moulds and left to dry for 24 hours.

After they were dry, the parts were taken out of the moulds.

Table 13 presents the results obtained with the epoxy resin, using different formulas between spent coffee grounds and resin.

Table 13 - Epoxy resin experiments results.

Results				
				
A	B	C	D	E
	Coffee %	20	30	50

Cups A and B represent experiments performed to symbolise the existing coffee cups on the market and the percentages of coffee used, were not taken into consideration. In object C the percentage of coffee used was 20%, while in object D was 30% and in E 50%. Obviously the different formulas will result in different characteristics on the object, as visual appearance.

These experiments were performed to demonstrate the possibility of mixture between coffee remains and a binder, but have never been seen as a possibility in this project, because the used resin is not safe for food contact.

4.2. Starch

The second material to be used was starch (potato and corn). Several formulas of this material were tried and the cures were made at different temperatures and for various periods of time.

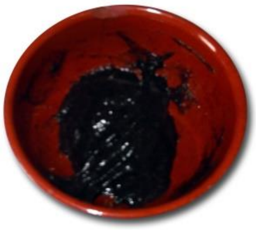
Because it is a natural polymer, the glue obtained from this element does not affect the degradation of the final object, since it is also biodegradable.

There are countless experiments conducted with this substance and its bonding properties are already well known and therefore, it has been used as a binder to join to coffee grounds, for students and researchers who have tried to create from there a building material, as in the case of Agridust by Marina Ceccolini presented in chapter III. Table 14 describes the method used on this experiment.

Table 14 - Method of experimentation with starch.

Action	Procedure
	The starch used in these experiments was potato starch. The first step was mixing the powdered substance with cold water, otherwise it will not mix. Next, the mixture was taken to a gas oven to be heated at a very low temperature and always stirring.
	Almost immediately (no more than one minute) it becomes a blob or a paste.

This paste was then mixed with coffee waste.



The result of the mix between the paste and the coffee grounds is a substance similar to plasticine.

Alternatively, the mixture between the coffee and the starch can be done from the beginning, before the heating process.

In either case, the result was taken to an oven to solidify.

The temperatures and times of the substance in the oven have varied throughout the whole process.

After it has been in the oven it completely solidifies, achieving sometimes the appearance of an artificial polymer.

Table 15 shows some of the results obtained using starch as a binder. These are just the more relevant results, as some of the initial experiments were unsuccessful and their results are not relevant for this study.

Table 15 - Starch experiments results.

Result	% Coffee	Temperature (^{o}C)	Time (min)
	50	200	30
	40	200	20
	30	200	20
	60	250	60
	60	300	60

40	250	60

The results presented here show that there is a possibility of mixing these two materials. As stated before, the final outcome varies, when baking temperatures and times are taken in to consideration. However, this experiment has proven to be unsuccessful for various reasons, since all the results have shown, after some time, moisture signals itself through the appearance of mold, as can be seen in Figure 31.

Figure 31 - Starch experiments showing signs of moisture with the appearance of mold.

Figure 32 - Deteriorated coffee/starch mixture after being submerged in cold water.

Some samples were also submerged in cold water for different periods of time, to be tested. As Figure 32 shows, regardless of the submerging time, the outcome was always the same. After just 30 minutes, the material becomes gelatinous and begins to deteriorate.

4.3. Pine Resin

Later, some experiments were performed using pine resin, as it is a Portuguese material that was readily available at FEUP. Also in this case, the ratios varied and the cure was virtually instantaneous. The resin used was YT 321, produced by YSER. YT 321 is a pentaerythritol ester of rosin and stabilized to ensure a good thermal stability and good oxidation resistance (YSER 2015). For further information on this resin, see Appendix II.

The process of experimentation with this material was simpler. The pieces of resin where taken to a gas oven to be heated at approximately 67.5^{o}C and when it began melting, the coffee powder was added. The result of the mixture was then taken off the heat and left to dry, which happened in just seconds. It was quickly realized that this union would be fruitless, given the fragility of the resin itself. It can still be seen in Figure 33 that most results have become brittle and not very rigid. Additionally, the mixture never became completely homogenised. The ratios were not even considered, given the poor relation between these two materials.

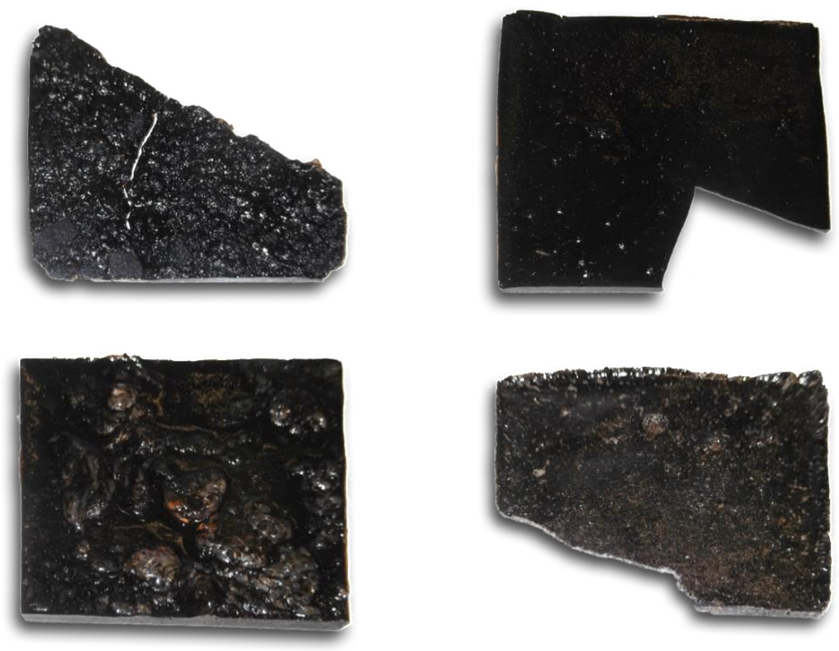


Figure 33 - Pine resin experiment results.

4.4. Pine Resin and Wax

Because pine resin showed very weak results, it was decided to add other materials to the mix in an attempt to give greater strength to the final material. Therefore wax was selected, but the results were still unsatisfactory.

The wax used in these experiments was Cerita Soluble 29-47 by Paramelt. It is a soluble wax suitable for medium to large castings where minimal shrinkage and sink is required. It provides excellent structural strength and fast leaching and is used for nozzles, automotive, boxes and housings, recreational (Paramelt 2011).

The method used was the same as with pine resin, only with the addition of wax. The curing time was longer, taking approximately 10 to 15 minutes.

As shown in Figure 34, very interesting visual results were produced, but the problem of resistance remained and the resulting material was still very brittle, thus this possibility was also discarded.

Figure 34 - Pine resin and wax experiment results.

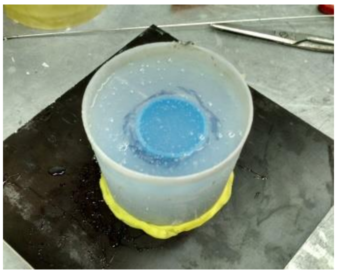
4.5. PLA (Polylactide)

Finally, experiments were made using Polylactide (PLA) as a binder and positive results began to appear.

Ingeo Biopolymer 3251D from NatureWorks was the material used throughout the process of experimentation. It is designed for injection moulding applications. This polymer grade has a higher melt flow capability than other Ingeo resin grades currently in the marketplace. The higher flow capability allows for easier moulding of thin-walled parts. It is designed for injection moulding applications, both clear and opaque, requiring high gloss, UV resistance and stiffness (NatureWorks 2016). For further information on this material, see Appendix III.

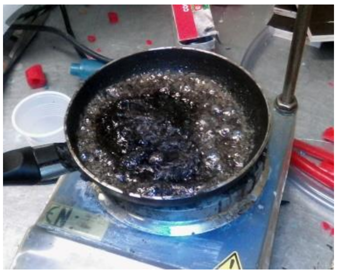
The first method of experimentation with PLA can be seen on Table 16.

Table 16 - Method of experimentation with PLA.

Action	Procedure
	Before the first experiment with PLA, an object (cup) was created in Solidworks (CAD programme) and converted to STL format. It was then printed by method of FDM on one of FEUP's printers. The printer is a RepRap, developed at one of FEUP's laboratories and the filament is a 1.75 mm blue PLA, from 3D Ink.
	From the 3D printed piece, a silicone mould was created in INEGI (Institute of Science and Innovation in Mechanical Engineering and Industrial Engineering).

The silicone used for the mould was 950 VTX, provided by SLM and the catalyst proportion was 10%. The curing time was 24 hours as usual with this type of resin.

With the mould created, the material (PLA) was then taken to a gas oven to heat at 100 ^{o}C minimum.



Once the PLA was melted and stirred, coffee powder left-overs were added little by little and always stirring.

The mixture was then poured in to the mould.

After 10 to 15 minutes, which was normally the time for it to dry, the result could be taken out of the mould.

There are several reasons for this material to have been chosen, although the main reason is the perfect symbiosis with the coffee in the creation of a perfectly mouldable and inert material in contact with food.

In addition, it is also biodegradable and that is a positive thing as it was one of the initial goals for this work. In fact, as can be seen on chapter three, point 3.4, PLA and spent coffee grounds together, accelerate its biodegradability.

Figure 35 represents some of the first mixes of PLA in conjunction with coffee residue. The percentages were not taken into account, but it was rapidly comprehended it would work for the fulfilment of the pre-defined goal. For these samples, the mixture was deposited in to some aluminium cupcake moulds.

Figure 35 - Initial PLA experiment results.

After the initial impression on this material, and already with the first silicone mould created, many experiments were done in order to try and define the ratio coffee/PLA (Figure 36).

Table 17 shows the best results created in this manner. Sample A is composed from 20% spent coffee grounds and 80% PLA, sample B is 30% coffee and C 40%.

It was concluded, therefore, that the greater the proportion of coffee in the blend, the longer will have to be the heating of the two materials in order for them to merge. 40% was the best initial formula for this mixture, with this mould, although this percentage has been increased as will be seen further along this chapter.

Table 17 - Moulded samples with formulas.

	Results		
			
	A	B	C
Coffee %	20%	30%	40%

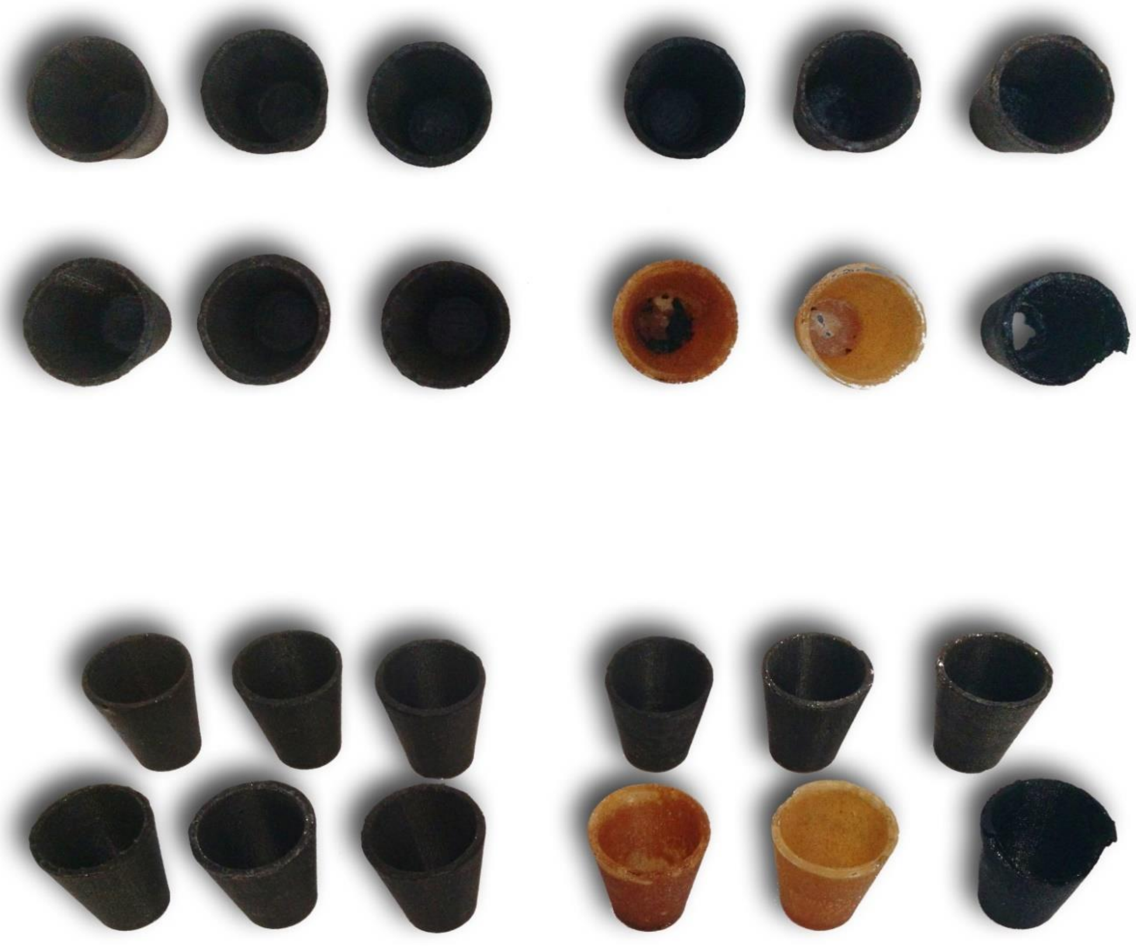


Figure 36 - Experiments with PLA/coffee on a silicone mould.


Figure 37 - Sample after being machine washed.

This mixture presented however a structural problem, since the part cannot be machine washed, due to the high temperatures to which it would be subjected. In this case, the material undergoes irreparable deformation and gets unusable (Figure 37). The piece has therefore to be washed by hand, preferably with cold water.


Figure 38 - Sample with hot coffee.

Another preoccupation was if the material would withstand hot beverages (coffee) temperatures. The part behaved according to the goal, it even had some insulation, and tolerated the contact with hot coffee, fulfilling part of its function (Figure 38). However, after a couple of minutes it began to show signs of softness, and became wobbly. For this reason, we do not believe the material to be completely tolerant to hot liquids at this stage.

On Table 18 is possible to see samples of various formulas made between coffee and PLA without the aid of a mould. The mixture was done in the same exact way as before and as soon as it was liquid and homogenised, it was deposited on a clean, smooth surface.

Table 18 - Samples of various formulas PLA/coffee without being moulded.

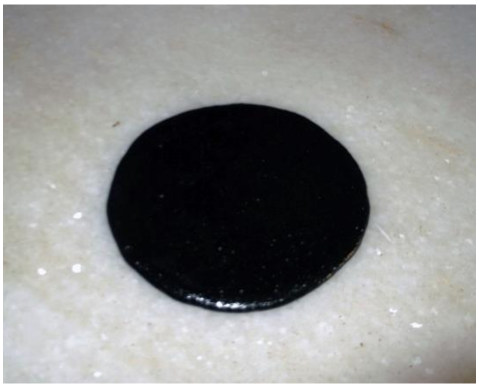
Sample	% Coffee	Description
	5	This first sample has 5% coffee residue and is smooth to the touch. It is also somewhat transparent when placed against a light source.

10 The result with 10% coffee doesn’t change much from the previous sample. The surface is also smooth but firm and it is also somewhat transparent.

15 From these experiments, 15% was the limit to attribute some transparency to it, although it may vary with higher thicknesses. Again, smooth surface finish.

20 At 20% coffee waste we lose the transparency of the material. Although the surface maintains a smooth finish.

30 30% and 40% present very similar results, but there’s an obvious difference in the surface roughness, especially to the touch. On the 40% sample it’s already possible to see some of the coffee paste.

	40	
	50	With 50% the change is obvious, either by touch or just visual. It is clearly a rougher material.
	60	Without a mould, just pouring the mix on to a surface, 60% was the higher percentage we could achieve, as the material begins to not flow as easily. However, some good visual effects may be taken out of it.

As the first mould was too small, another one was created in the same way for the cup (Figure 39) and more experiments were done using different percentages of each material, as can be seen on Table 19.

The difference between this mould and the first one, besides the scale, was that the printed part was also treated with a high performance 3D print coating from Smooth-on, Inc. called XTC-3D, to give it a smoother surface. The results obtained are, consequently, also smoother.

Figure 39 - Creation of a second, bigger mould for the cups.

Table 19 - Samples of various formulas of PLA/coffee using a mould.

% Coffee	Samples		
10			
20			
40			
50			

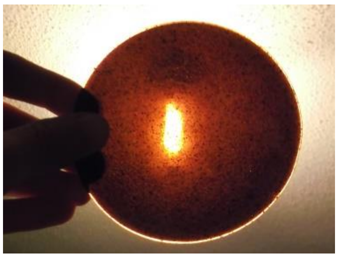
60			
70			
80			

As suspected with the first attempt with the smaller mould, it is possible to exceed the 40% coffee waste mark, but our limit was reached at about 60%. We do think it is possible to even exceed this value, but it has to be done on a different mould that is not pressed by hand.

As Table 19 reveals, from 10% to 40%, the visual result is more or less the same, with a smooth surface finish, although on the 10% coffee samples there is a slight transparency that the 20% doesn't show. Also starting at 40%, there's a noticeable thicker paste and the surface becomes rougher. From 50% onwards it becomes even thicker and rougher. On the 60% mark it is still possible to shape the object on a mould, by hand, but it becomes harder. 70% and 80% are almost impossible to shape this way and the surface is clearly lumpier and the paste less liquid. The next step would be to experiment with the material on an injection mould, to understand if these marks could be exceeded.

Next, Table 20 displays samples of the composite with high transparency when placed against a light source.

Table 20 - Samples with high transparency.

Sample		Description
	A	The three samples pictured here, represent mixtures from 5% to 15% spent coffee grounds and are all somewhat transparent. It allows for a unique effect when placed against a light source. These samples where achieved in the same manner as samples from Table 18. B is made out of 10% coffee waste and is the more transparent of the three. A is 10% and C 15%. It is clear that the amount of coffee changes the visual effect, letting more or less light pass through. These samples brought a new side to this study, since for a designer, the visual properties it displays present new possibilities. . Many objects can be made out of it with the goal of playing with light.
	B	
	C	

So, in conclusion for this chapter, it is obvious that the experimental work was fundamental in obtaining and developing this material. The epoxy resin experiment was valid in order to determine that coffee waste can, in fact, be mixed with other substances to achieve a composite material. It didn't work however, because it is not safe for food contact and is not biodegradable. Starch showed some promising results at the beginning, but with time it revealed great negative characteristics, with the appearance of mold on all samples. It also couldn't withstand contact with cold water, being therefore discarded. Pine resin displayed very weak results, because it couldn't be homogenised with coffee waste, not even with the addition of wax.

PLA exceeded the initial expectations. It is biodegradable and the experiments showed very good results, with different formulas, permitting its use in different areas of interest. It is also FDA approved, allowing for food contact. The final material is not, however, perfect or completely developed. It does not withstand high temperatures like hot beverages (coffee). There is, for that reason, room for improvement.

CHAPTER V

DESIGN PROPOSAL

The objective with this chapter is to demonstrate different ways of using the developed material.

The design proposal is divided into four sections. The first section is where the main project is presented. Section number two addresses the creation of a prototype that validates the main project. On section three, other design possibilities are proposed in an attempt to show the various areas that the composite material can be used. Finally, on the fourth section, a construction proposal by means of injection moulding is presented.

Injection moulding involves melting a thermoplastic by extrusion, injecting the polymer melt into a mold, cooling the part, and finally ejecting the part. Most polymers can be injection moulded so long as they can flow and fill the mold cavity easily (Majid Jamshidian 2010). This is the most common method of producing parts made of plastic. The process includes the injection or forcing of heated molten plastic into a mold which is in the form of the part to be made. Upon cooling and solidification, the part is ejected and the process continues. The injection moulding process is capable of producing an infinite variety of part designs containing an equally infinite variety of details such as threads, springs, and hinges, and all in a single moulding operation (Engineers).

5.1. Main Project

The first goal of the main design project would be to create a cup with the capacity of withstanding hot coffee temperatures. However, throughout this study, it was realized that this would not be possible at this stage. The project stays the same, but its function adapted to its physical characteristics.

It is a tray with capacity for 6 cups. The cups are made out of our composite (preferably 40% coffee grounds waste), as well as the two side bases/handles. The tray platform is made out of light wood to introduce some contrast to the set (Figure 40).

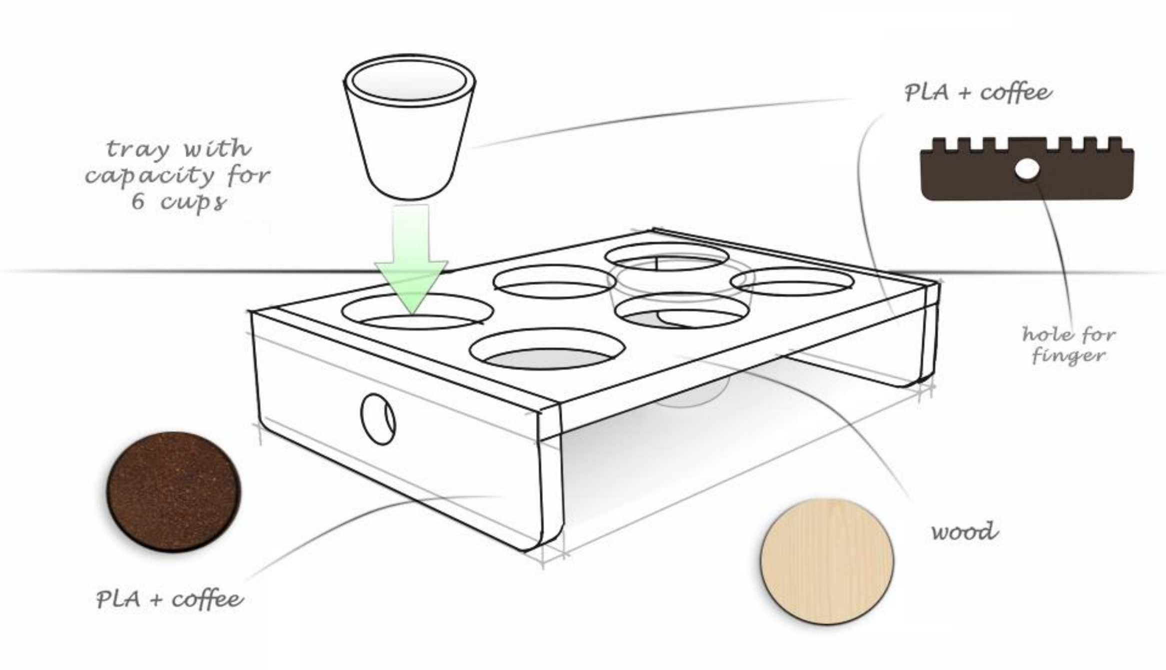


Figure 40 - Explanatory sketch for the main design project.

This project was set within the discipline of Industrial Design from the Master's degree in Product and Industrial Design's first year from the Faculties of Engineering and Fine Arts from the University of Porto. The main objective was the creation of one or more objects from the reuse of wasted materials in the municipality of Matosinhos, in Porto, Portugal. It was also necessary to take into account the low cost of creations in an attempt to generate profit for the poorest communities in the region.

As recognized previously, on chapter four, PLA is an FDA approved material. Therefore, it is safe for food use and is well known as a food packaging material. For this reason, it was decided to maintain the project as it was, because further uses for the cups were seen, other than the capacity to withstand hot liquids, as can be seen on Figure 41.

The cups may, then, be used for all kinds of cold beverages, desserts, condiments, spices, jams. The list goes on and on, as long as it's nothing hot (temperature wise).

Figure 41 - 3D renderization of the main project. Proposed use.

The two side legs/handles are simple structural pieces with an orifice to facilitate handling. These were made to try to demonstrate other uses for the created material, with a higher thickness.

The wooden tray has 6 holes for the cups and some geometric cuts at each end to make the joinery with the legs/handles.

Figure 42 - 3D renderization of the main project.

5.2. Prototype

With the main project idealized, it was time to try and validate it with the construction of a prototype. Table 21 describes the process used for this task.

Table 21 - Prototype creation description.

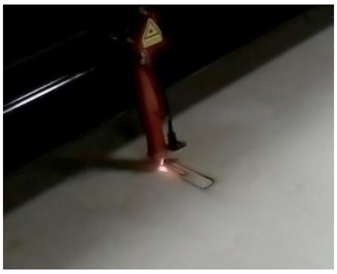
Action	Procedure
	The first step was to create the 3D printed cup, in the same way the earlier version was created, as can be seen on chapter four.
	From the 3D printed object, a silicone mould was produced.
	Next, our formula of 40% coffee waste and PLA was poured into the mould.
	After about 15 to 20 minutes the material was dry and the mould could be opened.

These steps were repeated at least 6 times, to produce the cups for the prototype.

For the base legs/handles, again a 3D printed piece was produced.

From that piece, a silicone mould was created.

And following the same process as with the previous objects, the intended part was formed.



For the wooden part, the chosen method was by laser cutting, as it was the fastest and most precise method.

For the laser cut, the CAD part was converted to DWG (2D) and from that, an operative programmed a laser cutting machine to cut a wooden board with the aid of software. The machine used for this task is from Hanma Laser, as is the software that programmes it.

The initial 3D printed pieces were all produced at FEUP on one of their printers, the moulds were created in INEGI with the aid of their staff and the wooden part was cut at Manuel, Ferreira & Augusto, Lda. The only assemblage necessary was to glue the legs/handles to the wooden tray.

Figure 43 - Prototype parts.

Figure 44 - Prototype

General Dimensions

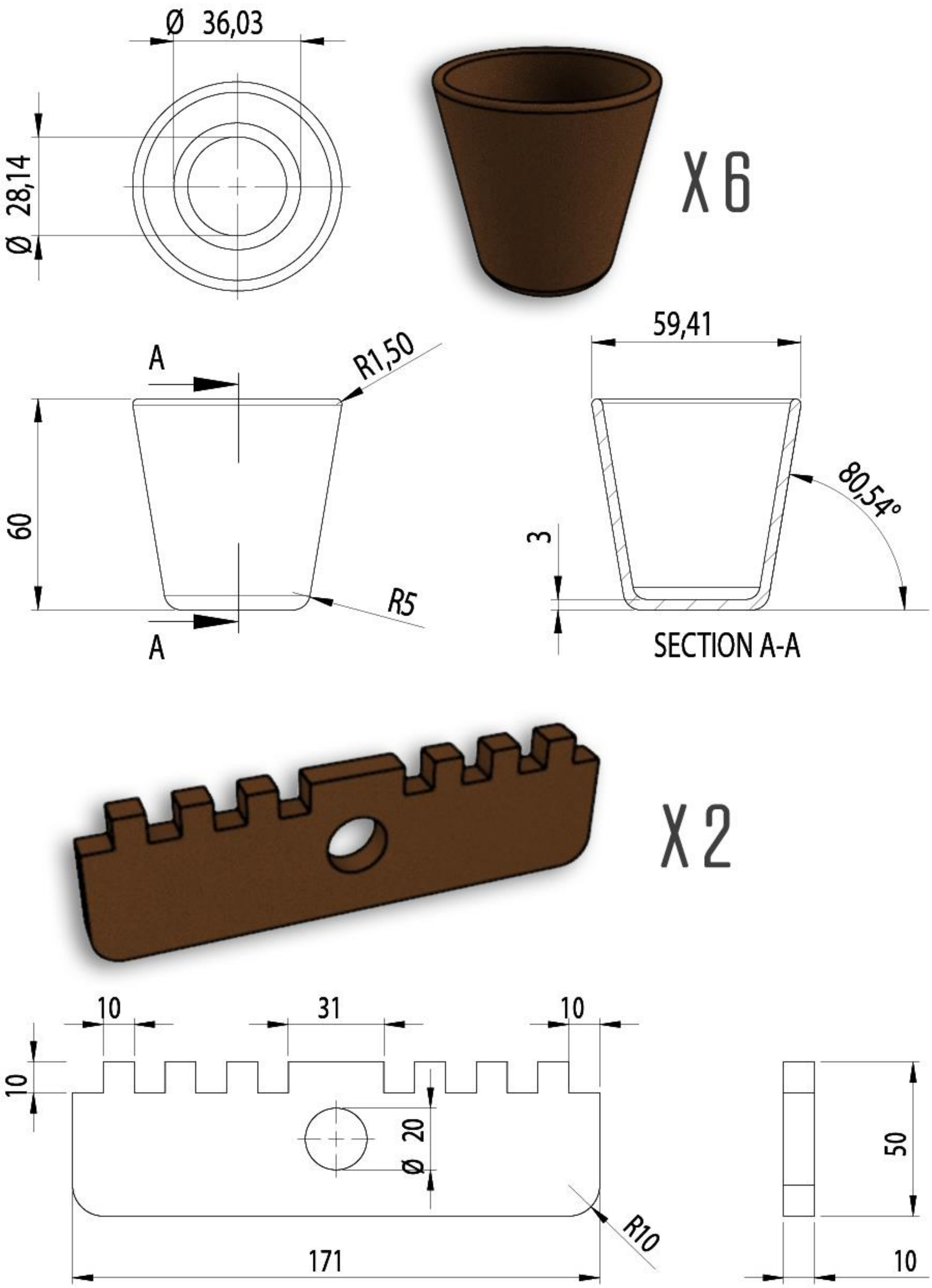


Figure 45 - General dimensions for the cup and legs/handles parts.

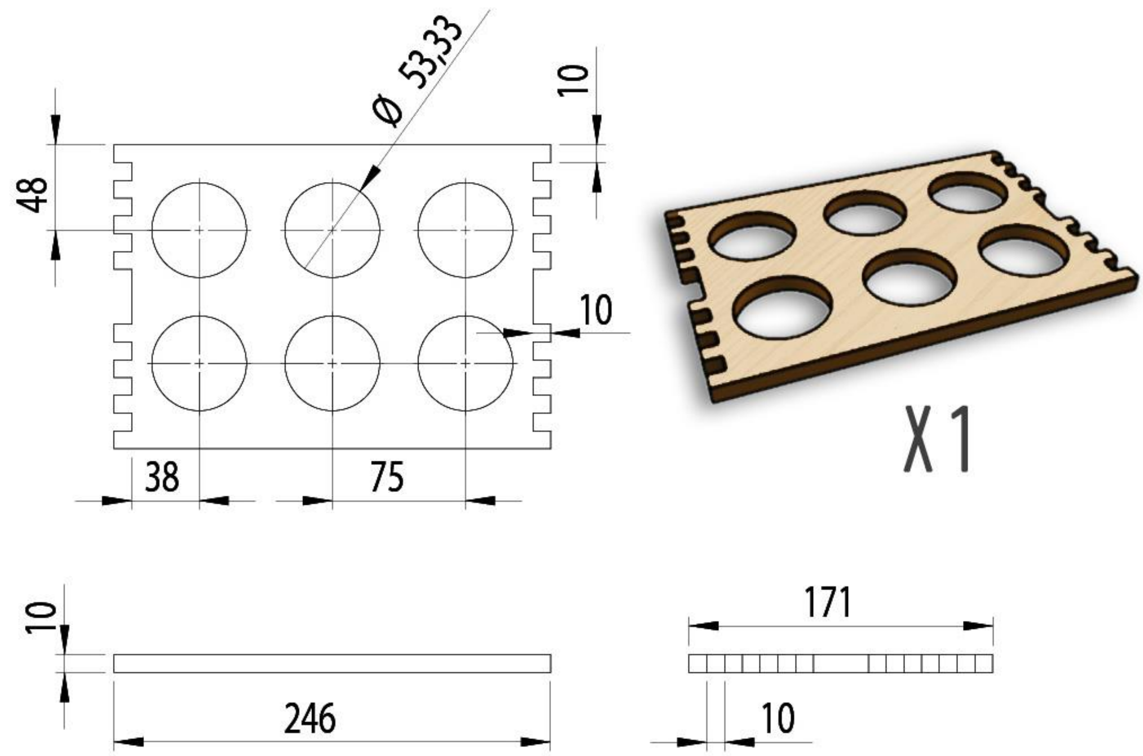


Figure 46 - General dimensions for the wooden tray.

For the Design process, many software programs were used to obtain the final images presented in each step, in order to properly communicate the products. The main 3D modelling program was Solidworks, although 3DS Max was also used at times to achieve the desired results. For the rendering part of the process, Keyshot and VRay were used for the primary images and Photoshop appeared to complement them as an image editor software. For the technical drawings of the parts, Solidworks was again used as a base and then Adobe Illustrator, to turn them into vector images.

5.3. Other Design Possibilities

Because the experimental work presented such positive results in terms of formulas between coffee waste and PLA, with so many different visual and physical effects, other design possibilities (besides the main project) were thought of.

Figure 47 illustrates the creative process that allowed for the creation of the products present on this section of the chapter. These products try to embrace the different potentials offered by the material. Some include the contact with food, others the good relation between coffee waste and plants, and even the effect some samples have when placed against a light source.

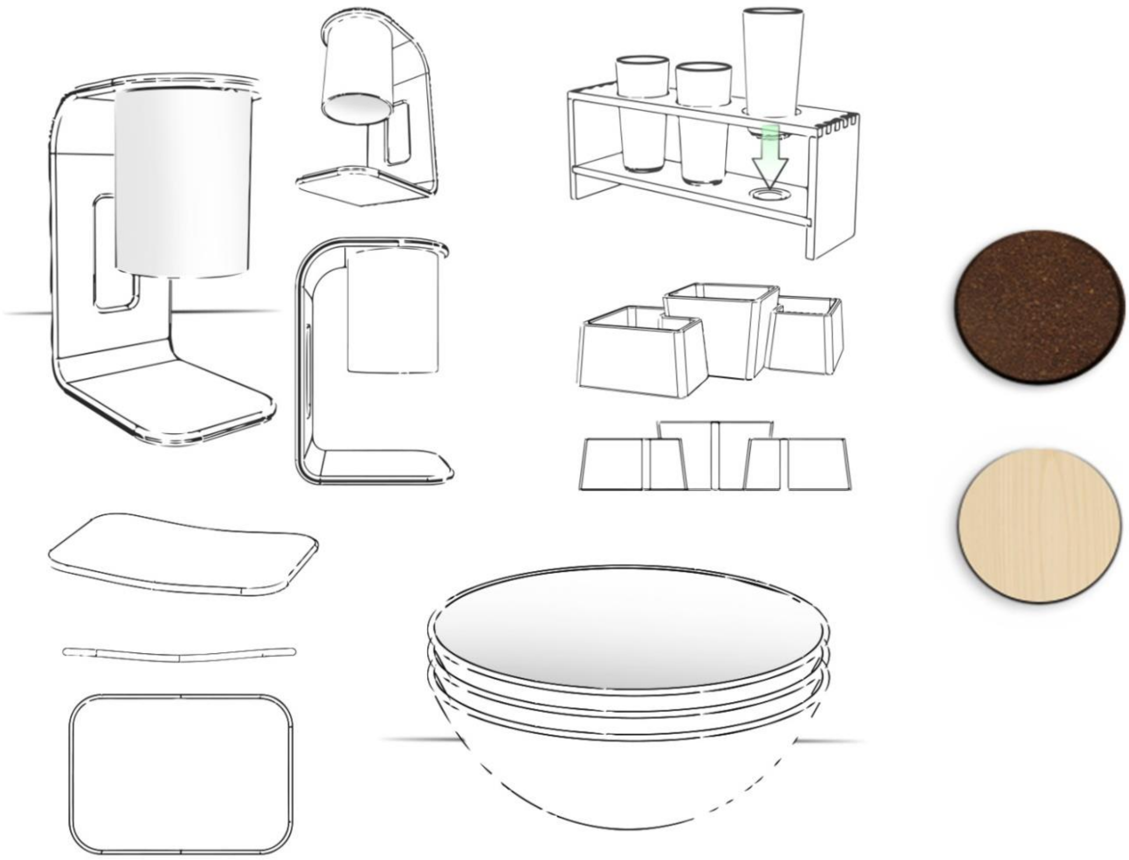


Figure 47 - Other design possibilities creative sketch.

From Figure 48 to Figure 55 these possibilities for the produced material can be seen, other than the main project. They all have into account the sui-generis characteristics of the mixture, studied through the process of experimentation.

Figure 48 and Figure 49 depict the possibility of creating some kind of object to interact with plants. As indicated before, on chapter three, coffee is already being used with this purpose and from the tests on point 3.4 from chapter three, the mixture between PLA and coffee left overs is biodegradable. Consequently, this is an instant option for the use of this material.

On Figures 50, 51 and 52 there's an attempt to demonstrate, from a design point of view, how well the composite would look in contact with food. This is not a problem from the health and safety standpoint, since it is by now well established that PLA is in no way a hazardous substance for this. So anything like dessert plates, cups for cold beverages, bowls for salads or fruit and even containers for appetizers could be a possibility.

Figures 53 and 54 should be accompanied by Table 20 for further understanding of the concept. Basically at smaller percentages of coffee, the mixture becomes considerably transparent, allowing for light to pass through it. With this in mind, the idea of conceiving a lamp emerged. The material itself might work as a shade for the lamp, if the conditions are right. What is meant by this is that the shade should never be in contact with the hot bulb and preferably this would be an LED (light-emitting diode).

On lifx.com there's an article explaining how hot LEDs really are. In development and testing, they found that the heatsink of a fully lit LED bulb was around 60°C-100°C (140°F-212°F) depending on the make and model of the LED bulb, room temperature, and airflow (Alexander 2014). But you can only feel how really hot they are, if you touch them directly. Because of this, it is almost certain that the material at the right distance from the bulb, would withstand the temperature.

The list of design possibilities could go on with the visual properties and surface finishes this material offers, it really feels like the sky is the limit, as long as the material's true properties and characteristics are understood.

Perhaps in the future even more possibilities could emerge, for its use in several areas.

Figure 48 - Plant pots possibility.

Figure 49 - Plant pots possibility with plants.

Figure 50 - Containers for appetizers and cup for cold beverages.

Figure 51 - Different sized bowls and plates for various purposes.

Figure 52 - Proposal for the plates.

Figure 53 - Possibility for using the material as a shade.

Figure 54 - Aspect of the shade against a light source.

Figure 55 - Set of all the design proposals for the developed material.

5.4. Construction Proposal

The proposed method for construction of parts using this material, from an Industrial Designer's point of view, has to be by Injection moulding. Figure 56 illustrates an injection moulding machine. Injection moulding machines consist of a material hopper, screw type plunger or an injection ram and a heating unit. It holds the mould tool to get the required shape of the components. In which the amount of clamping force that the machine can exert in terms of in tonnage. The plastic material requires more injection pressure to fill the mould and this more clamp tonnage is required to hold the mould closed (N. Sreenivasulu 2013).

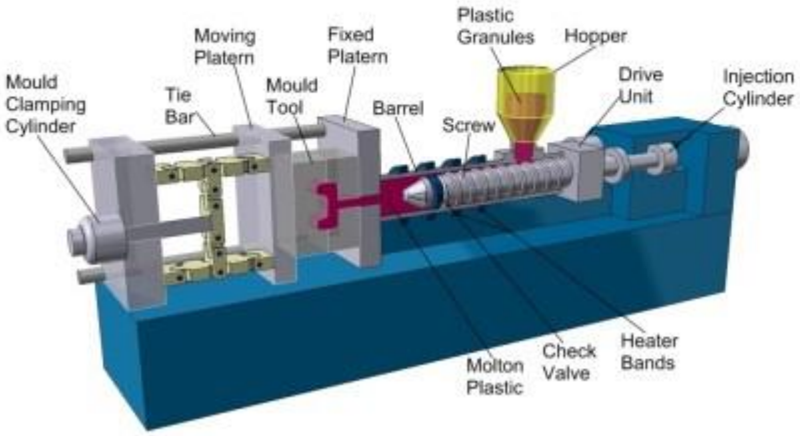


Figure 56 - Injection Moulding Machine (N. Sreenivasulu 2013).

If Appendixes three and four are consulted, relative to PLA, as well as point 4.5 from chapter four, it becomes clear that this method is in accordance with the selected material. For the developed substance in conjunction with coffee powder, there would, nonetheless, be the need to first mix the two materials. This could be done on a machine similar to the one seen on Table 22. The machine would heat the materials and constantly mix them to create the desired paste. From this paste, plates or even pallets could be done, and those parts could then integrate the normal process of injection moulding.

On Figure 57 it is possible to have a glimpse at what a mould for a cup, similar to the one created in the main project, could look like. So, there would be the nozzle, from which the material would be injected and then the liquid substance would go through the distribution channels of the two-main-part mould and stay lodged there. After it cooled down, the cavity would be lifted and then the striper plate would lift our finished part. This is just a simulation, as this could be made in various different ways.

Table 22 - Plastic industrial Colour Mixer 300kg Blender Machine (Jiangmen Xiecheng Machinery Co.).

Model N°	XC-HL300
Mixer type	Powder Mixer
Job	High Speed Mixer
Agitation type	Spiral
Application	Liquid with solids in suspension, powder, viscous fluid, liquid, granules

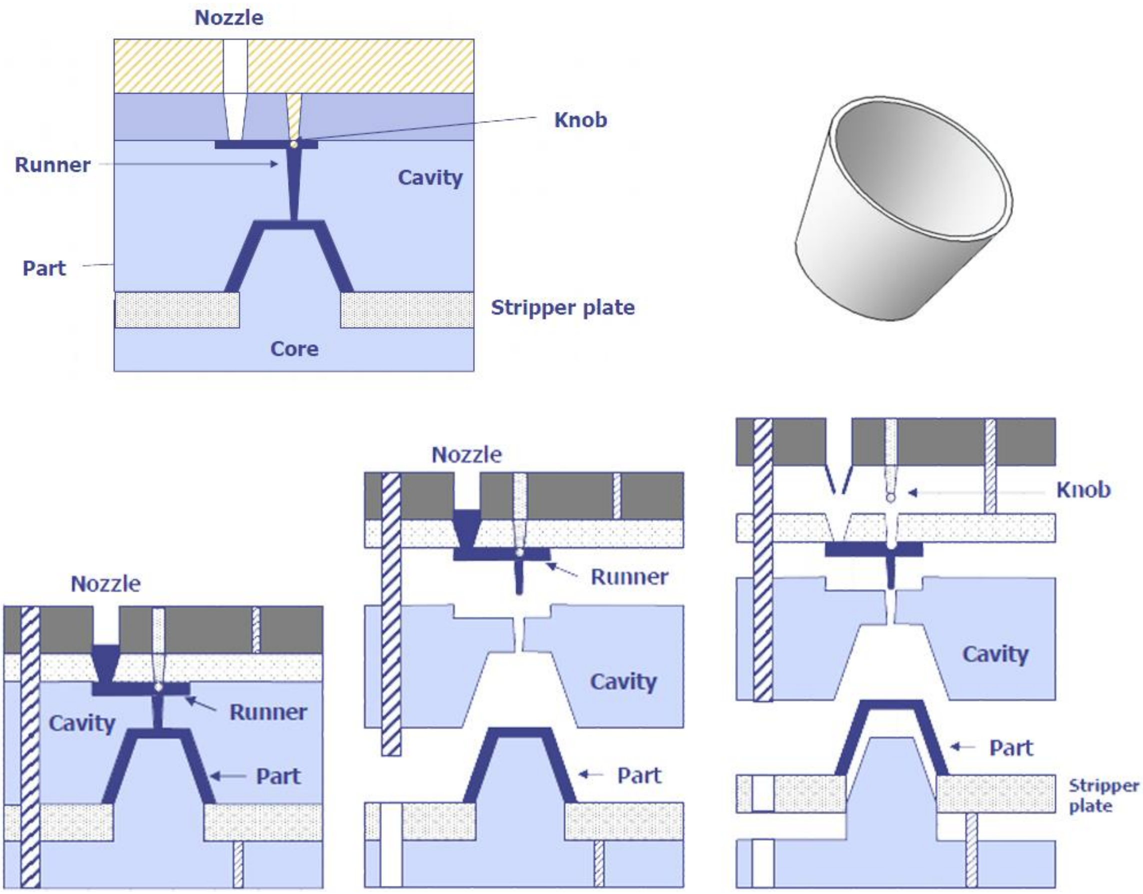


Figure 57 - Tooling for a plastic cup (Gutowski).

A cost simulation for the cup has also been conducted, with the aid of Solidworks (software). This simulation predicts the creation of 100 000 cups, on an industrial mould with capacity for 64 units. The estimated cost per unit amounted to 3.46 US dollars (Table 23). However, this study only provides results for the use of PLA alone. If it would be mixed with 40% of other substance like coffee, which is normally free after used, this value could descend to almost half. The complete simulation can be consulted on Appendix six of this document.

Table 23 - Cost Simulation

Manufacturing Method: Plastics	
Material:	PLA
Stock weight:	0.03 kg
Mold Type:	Hot Runner Mold
Maximum Wall Thickness:	4.00 mm
Material cost/weight:	2.54 USD/kg
Shop Rate:	N/A

Quantity to Produce	
Total Number of Parts:	100 000
Number of cavities:	64
Estimated Cost per Part	3.46 USD

And if in previous years, the most negative point of PLA was its price in comparison with petrochemical-based polymers, today, by using other sources of dextrose, optimizing lactic acid production processes and its costs, substituting electricity energy by wind and solar energy for PLA production, optimizing PLA production processes, and increasing PLA demands, reduction of its price can be attained. The present PLA price is much lower than in previous years, but it is not fixed and it even will be considerably lower in the future because, according to expert forecasts, beyond 2010 the global demand for biodegradable plastics will continue to increase by 30% each year and PLA will take a large part of this market because of its valuable properties (Majid Jamshidian 2010).

For what can be seen on this chapter, the design proposal might be considered a success, having in mind that most of the initial goals were achieved and some have even exceeded expectations. Several proposals were made for the material and the creation of a prototype became a reality.

CHAPTER VI

CLOSING REMARKS

6.1. Conclusions

From chapter two, it can be concluded that waste in general is growing and there are no predictions for this growth to slow down. And although there are already waste treatment strategies in place, if it could be reused, this problem might not exist in a near future. Also, the use of most wastage materials allow for a no cost approach, making this an unrivalled advantage. For this reason, it becomes apparent that coffee waste really is a good choice for a substance to be reused as a material on the creation of design products. It is also obvious that its abundance will continue to exist and designers should see this as an opportunity.

Chapter three demonstrates that it is safe to recognize that coffee grounds waste is and has been studied for its characteristics in order for it to be reused in the most various ways and on different areas of interest. Moreover, there are already attempts to use coffee waste in additive manufacturing, with some being more successful than others. Additionally, it can be concluded that much has been done in relation to coffee waste reuse in several areas, from agriculture to product design, and even the transformation of raw materials into fuel. However, it is also clear that many of these technologies are at the beginning of their existence and much more can still be done. It also shows that there is already research being done in order to aggregate coffee waste to other substances as a way to turn it into a composite material.

With chapter four, it can be concluded that PLA exceeded the initial expectations. It is biodegradable and the experiments showed very good results, with different formulas, permitting its use in different areas of interest. It is also FDA approved, allowing for food contact. The final material is not, however, perfect or completely developed. It does not withstand high temperatures like hot beverages (coffee) or washing machines. There is, for that reason, room for improvement to create an ideal material, but the forecasts are quite positive. Taking into account that it is a mouldable material, the creation of shapes is only limited by the imagination.

However, it is certain that the developed composite allows for coffee waste to be reused in the universe of Product and Industrial Design. There is still some way to go to improve this technology, but at this time one can already realize that coffee does not need to be just another piece of trash, it can be turned in to a building material, very efficient and applicable to a large number of areas.

6.2. Future Perspectives

For the future, much more could still be done. I, personally, do not believe that a new material can be developed in its entirety within one year, by only one person, so it would be needed either more time for development or a team of researchers. The next steps regarding the composite itself would be to try to improve it in order to withstand higher temperatures, through further experimentation. Perhaps adding some other substance to the mixture could solve this problem.

Another aspect that would improve the final result in the future would probably be to test the various formulas on FEUP's and INEGI's laboratories to try to achieve greater physical properties.

Finally, it would also be interesting to create some products by means of injection, to confirm, or not, if this is the best way for part construction.

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Tooling & Composites

Product Data Sheet
Version 04 / 2016

Biresin® CR83
Composite resin system

Product Description

Biresin® CR83 is an epoxy resin system with extremely low viscosity designed specifically for the infusion process for the production of high performance fibre reinforced composites parts and moulds. The system has thermal properties up to 80°C. Biresin® CR83 epoxy resin has a low tendency to crystallise.

Application Areas

Biresin® CR83 is especially suited to the infusion and injection processes due to its low viscosity range. It can be used in the marine and general industrial composite areas. Due to its good wetting properties it is particularly suited for use with carbon fibre reinforcement.

Features / Advantages

- 3 hardeners (B) give a wide range of processing times
- The reactivity can be adapted by mixing the hardeners
- Fast infusion and good wet-out of fabrics and non-wovens due to low viscosity and good wetting characteristics even at low temperatures
- All systems Germanischer Lloyd approved, Certificate No. WP 1420017 HH (attached)
- Glass transition temperatures up to 80°C dependent on curing conditions
- Carbon fibres are wet out well by all of the resin systems
- Biresin® CR83 resin (A) has a low tendency to crystallise

Physical Data		Resin (A)	Hardener (B)		
Individual Components		**Biresin® CR83**	**Biresin® CH83-2**	**Biresin® CH83-6**	**Biresin® CH83-10**
Mixing ratio, parts by	**weight**	100	30		
Mixing ratio, parts by	**volume**	100	36		
Colour		translucent	colourless to yellowish		
Viscosity, 25°C	mPa.s	~610	<10	<10	< 10
Density, 25°C	g/ml	1.14	0.95	0.94	0.95
				Mixture	
Potlife, 100 g / RT, approx. values	min		60	180	300
Mixed viscosity, 25°C, approx. values	mPa.s		155	170	155

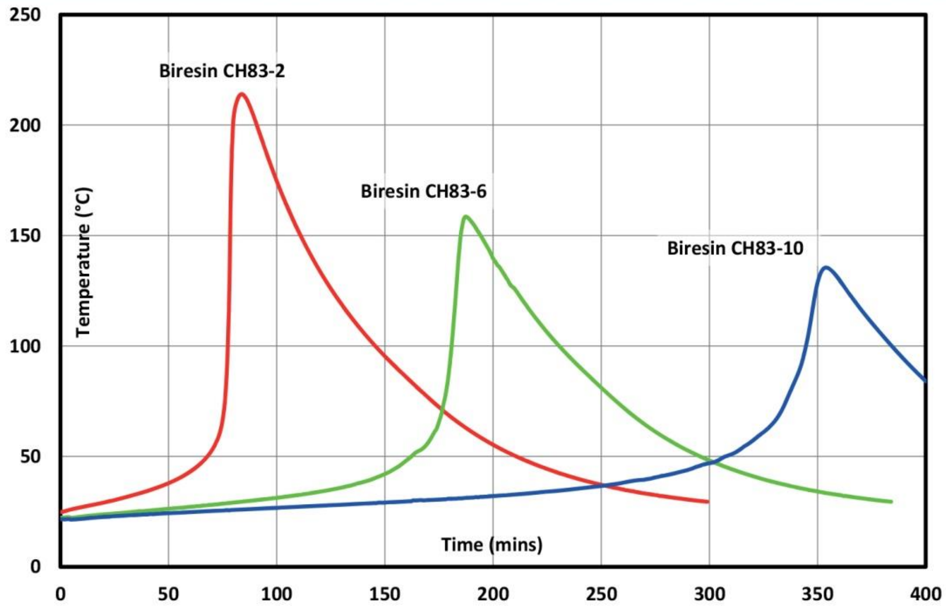
Processing

- The material and processing temperatures should be in the range 18 - 35°C.
- The mixing ratio must be followed accurately to obtain best results. Deviating from the correct mix ratio will lead to lower performance.
- The final mechanical and thermal values are dependent on the applied postcuring cycles.
- It is recommended to clean brushes or tools immediately after use with Sika Reinigungsmittel 5.
- Additional information is available in “Processing Instructions for Composite Resins”.

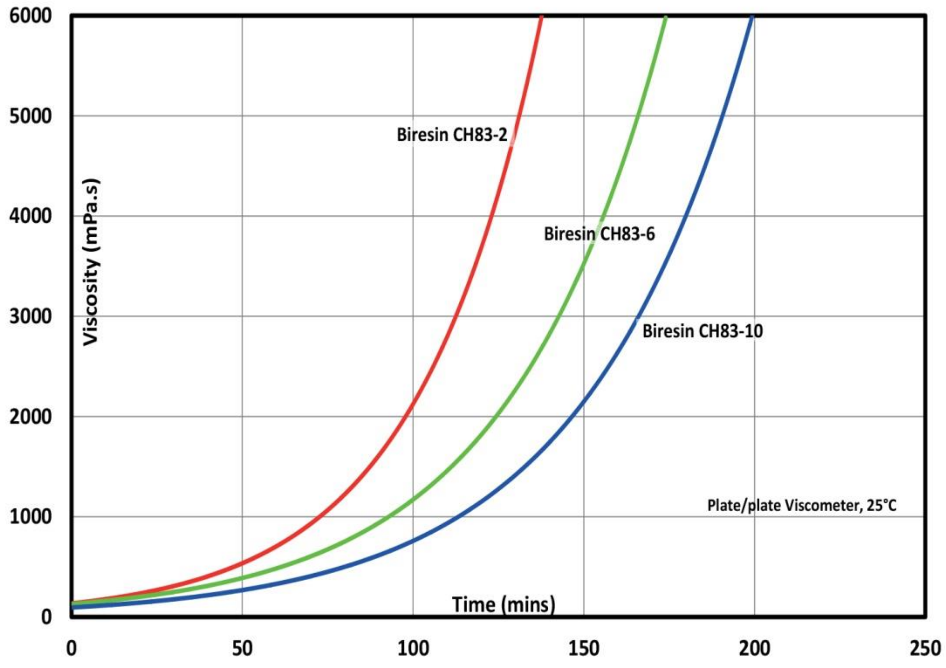
Biresin® CR83 1 / 4

Axson BUILDING TRUST Sika®

Development of Exotherm of Biresin® CR83-Resin (A)-Hardener (B)-Mixtures, 100g / RT, insulated



Development of Viscosity of Biresin® CR83 (A)-Resin-Hardener (B)-Mixtures, 25°C

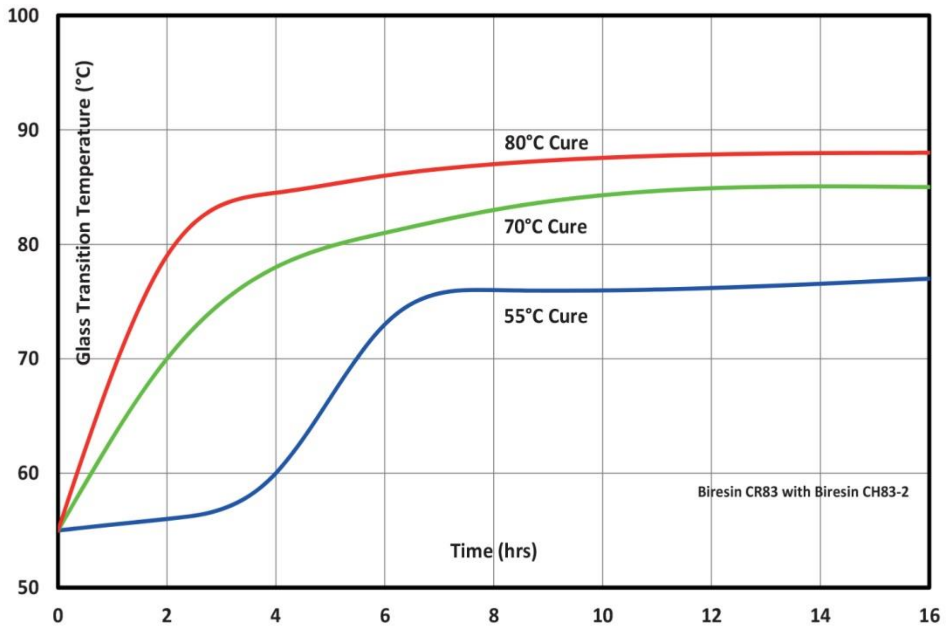


BUILDING TRUST

Typical Mechanical Properties of Fully Cured Neat Resin					
Biresin® CR83 resin (A)	with hardener (B) **Biresin®**		**CH83-2**	**CH83-6**	**CH83-10**
Tensile strength	ISO 527	MPa	84	91	86
Tensile E-Modulus	ISO 527	MPa	2,960	3,200	3,100
Elongation at break	ISO 527	%	6.7	8.4	7.9
Flexural strength	ISO 178	MPa	129	134	131
Flexural E-Modulus	ISO 178	MPa	3,125	3,360	3,340
Compressive strength	ISO 604	N/mm²	107	111	109
Density	ISO 1183	g/cm³	1.15	1.15	1.15
Shore-hardness	ISO 868		D 85	D 85	D 85
Impact resistance	ISO 179	kJ/m²	93	84	83

Typical Thermal Properties of Fully Cured Neat Resin					
Biresin® CR83 resin (A)	with hardener (B) **Biresin®**		**CH83-2**	**CH83-6**	**CH83-10**
Heat distortion temperature	ISO 75B	°C	79	79	78
Glass transition temperature	ISO 11357	°C	84	80	81

Glass Transition Temperature vs. Cure Cycle



When curing a composite part, the whole of the part (including the very middle of the laminate) needs to see the cure temperature.

Biresin® CR83 3 / 4

BUILDING TRUST

Packaging (net weight, kg)

Biresin® CR83 resin (A)	1,000	200		10
Biresin® CH83-2 hardener (B)		180	20	3.0
Biresin® CH83-6 hardener (B)		180	20	3.0
Biresin® CH83-10 hardener (B)		180	20	3.0

Storage

- Minimum shelf life of Biresin® CR83 resin (A) is 24 month and of Biresin® CH83-2, CH83-6 and CH83-10 hardeners (B) is 12 month under room conditions (18 - 25°C), when stored in original unopened containers.
- The tendency to of crystallise with this system is very low. However, if crystallisation of the resin (A) component appears, it can be easily removed by warming up the resin for a sufficient time to at least 60°C.
- Containers must be closed tightly immediately after use. The residual material needs to be used up as soon as possible.

Health and Safety Information

For information and advice on the safe handling, storage and disposal of chemical products, users shall refer to the most recent Safety Data Sheet (SDS) containing physical, ecological, toxicological and other safety related data.

Disposal considerations

Product Recommendations: Must be disposed of in a special waste disposal unit in accordance with the corresponding regulations.
Packaging Recommendations: Completely emptied packagings can be given for recycling. Packaging that cannot be cleaned should be disposed of as product waste.

Value Bases

All technical data stated in this Product Data Sheet are based on laboratory tests. Actual measured data may vary due to circumstances beyond our control.

Legal Notice

The information, and, in particular, the recommendations relating to the application and end-use of Sika products, are given in good faith based on Sika's current knowledge and experience of the products when properly stored, handled and applied under normal conditions in accordance with Sika's recommendations. In practice, the differences in materials, substrates and actual site conditions are such that no warranty in respect of merchantability or of fitness for a particular purpose, nor any liability arising out of any legal relationship whatsoever, can be inferred either from this information, or from any written recommendations, or from any other advice offered. The user of the product must test the product's suitability for the intended application and purpose. Sika reserves the right to change the properties of its products. The proprietary rights of third parties must be observed. All orders are accepted subject to our current terms of sale and delivery. Users must always refer to the most recent issue of the local Product Data Sheet for the product concerned, copies of which will be supplied on request.

Further information available at:

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BUILDING TRUST

APPENDIX II / PINE RESIN YT321 DATA SHEET

YSER

Ficha Técnica

YT 321

Descrição do Produto

YT 321 é um éster de pentaeritritol e colofónia estabilizado de forma a garantir uma boa estabilidade térmica e uma boa resistência à oxidação.

Características

Sólido de cor amarelada.

É compatível com os polímeros usuais, tais como:

- Polímeros EVA, SIS, SBS, SBR, borracha natural, borracha butílica, neopreno e outros polímeros;
- Resinas de hidrocarboneto e terpénicas.

É solúvel em:

- Solventes aromáticos e alifáticos;
- Ésteres e cetonas.

É insolúvel em:

- Álcool e água.

Especificações de Produto[1]

	Especificação Produto	Propriedades Típicas	Unidades
Índice de Acidez	20 máx	15	mg KOH/g
Ponto de amolecimento (R&B)	95-100	97	ºC
Cor *Gardner* (50%, Tolueno)	4 máx	3	-------
Viscosidade (*Brookfield*) (@150°C;160°C;170°C;180°C)	-------	1200;670;300;180	mPa.s

Regulamentação

Conforme com os requisitos do "*Code Federal Regulation, Title 21*" nas secções seguintes:

- 175.105 Adesivos

Aplicações

É especialmente recomendado como *tackifier* em *hot melts* de base EVA, por ter:

- Excelente resistência térmica;
- Boa compatibilidade com ceras;
- Compatibilidade total com polímeros EVA;
- Excelente coesão interna;
- Boa resistência à oxidação devido ao baixo teor em ácido abiético.

Também pode ser usado em adesivos sensíveis à pressão (PSA), compósitos de borracha, revestimentos e outras aplicações.

Formas de Fornecimento

Flakes: em sacos de 25 kg;

Bloco: em tambores de 225 kg.

Prazo de Validade

Até seis meses em condições normais de armazenagem.

28 – 11 – 2012

[1]Métodos analíticos disponibilizados a pedido do cliente.

A informação contida nesta ficha técnica é, tanto quanto sabemos, verdadeira e correcta. No entanto, devido às condições de uso fora do nosso controlo, não podemos dar garantias implícitas ou explícitas no que respeita à informação aqui prestada. Nós estamos permanentemente a estudar as aplicações específicas dos produtos dos nossos clientes, nos quais os nossos produtos fazem parte da sua composição, de modo a que possam tornar-se cada vez mais eficazes

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APPENDIX III / PLA INGEO 3251D DATA SHEET

NatureWorks

Ingeo™ Biopolymer 3251D Technical Data Sheet

Injection Molding Process Guide

Ingeo biopolymer 3251D is designed for injection molding applications. This polymer grade has a higher melt flow capability than other Ingeo resin grades currently in the marketplace. The higher flow capability allows for easier molding of thin-walled parts. It is designed for injection molding applications, both clear and opaque, requiring high gloss, UV resistance and stiffness.

Typical Material & Application Properties		
Physical Properties	**Ingeo 3251D**	**ASTM Method**
Specific Gravity	1.24	D792
MFR, g/10 min (210°C, 2.16kg)	80	D1238
MFR, g/10 min (190°C, 2.16kg)	35	D1238
Relative Viscosity	2.5	
Crystalline Melt Temperature (ºC)	155-170	D3418
Glass Transition Temperature (ºC)	55-60	D3418
Clarity	Transparent	
Mechanical Properties		
Tensile Yield Strength, psi (MPa)	9,000 (62)	D638
Tensile Elongation, %	3.5	D638
Notched Izod Impact, ft-lb/in (J/m)	0.3 (16)	D256
Flexural Strength (MPa)	15,700 (108)	D790
Notched Izod Impact, ft-lb/in (J/m)	0.3 (16)	D256
Heat Distortion Temperate (ºC)	55	E2092

Note: These are starting points and may need to be optimized.

Processing Information

Ingeo biopolymer 3251D can be processed on conventional injection molding equipment. The material is stable in the molten state, provided that the drying procedures are followed. Mold flow is highly dependent on melt temperature. In order to control melt temperature, it is recommended to balance screw speed, back pressure, and process temperature. Injection speed should be medium to fast.

Processing Temperature Profile		
Melt Temp.	370-410ºF	188-210ºC
Feed Throat	70ºF	20ºC
Feed Temp.	330-350ºF	166-177ºC
Compression Section	360-380ºF	182-193ºC
Metering Section	370-400ºF	188-205ºC
Nozzle	370-400ºF	188-205ºC
Mold	75ºF	25ºC
Screw Speed	100-200 rpm	
Back Pressure	50-100 psi	
Mold Shrinkage	.004 in/in. +/-.001	

Process Details

Startup and Shutdown

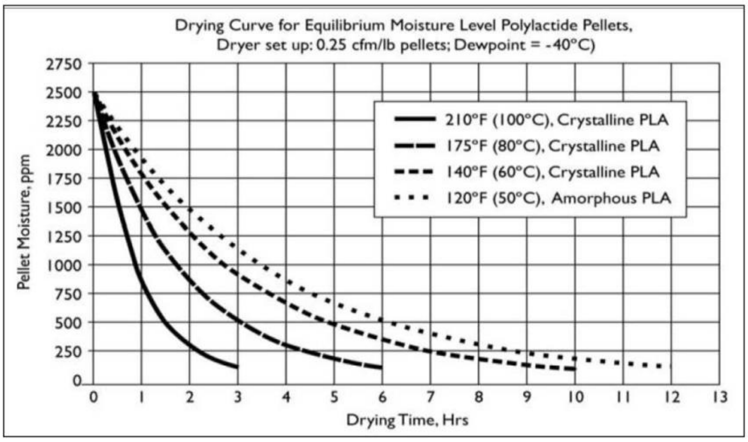
Ingeo biopolymer 3251D is not compatible with a wide variety of other resins, and special purging sequences should be followed:

1. Clean extruder and bring temperatures to steady state with low viscosity, general purpose polystyrene or polypropylene.
2. Vacuum out hopper system to avoid contamination.
3. Introduce Ingeo biopolymer into the extruder at the operating conditions used in step one.
4. Once Ingeo biopolymer has purged, reduce barrel temperatures to desired set points.
5. At shutdown, purge machine with high viscosity polystyrene or polypropylene.

Drying

Inline drying is recommended for Ingeo biopolymers. A moisture content of less than 0.010% (100 ppm) is recommended to prevent viscosity degradation. Polymer is supplied in foil-lined boxes or bags dried to<250 ppm. The resin should not be exposed to atmospheric conditions after drying. Keep the package sealed until ready to use and promptly dry and reseal any unused material. The drying curves for both amorphous and crystalline resins are shown to the right.

Note: Amorphous polymer must be dried below 120F (50C).



Food Packaging Status

U.S. Status

On January 3, 2002 FCN 000178 submitted by NatureWorks LLC to FDA became effective. This effective notification is part of list currently maintained on FDA's website at

http://www.fda.gov/food/ingredientspackaginglabeling/packagingfcs/notifications/default.htm

This grade of Ingeo biopolymer may therefore be used in food packaging materials and, as such, is a permitted component of such materials pursuant to section 201(s) of the Federal, Drug, and Cosmetic Act, and Parts 182, 184, and 186 of the Food Additive Regulations. All additives and adjuncts contained in the referenced Ingeo biopolymer formulation meet the applicable sections of the Federal Food, Drug, and Cosmetic Act. The finished polymer is approved for all food types and B-H use conditions. We urge all of our customers to perform GMP (Good Manufacturing Procedures) when constructing a package so that it is suitable for the end use.

European Status

This grade of Ingeo biopolymer complies with Plastics Regulation 10/2011 as amended. No SML's for the above referenced grade exist in Plastics Regulation 10/2011 as amended. NatureWorks LLC would like to draw your attention to the fact that the EU- Plastics Regulation 10/2011, which applies to all EU-Member States, includes a limit of 10 mg/dm^2 of the overall migration from finished plastic articles into food. In accordance with Plastics Regulation 10/2011 the migration should be measured on finished articles placed into contact with the foodstuff or appropriate food simulants for a period and at a temperature which are chosen by reference to the contact conditions in actual use, according to the rules laid down in Plastics Regulation 10/2011.

Please note that it is the responsibility of both the manufacturers of finished food contact articles as well as the industrial food packers to make sure that these articles in their actual use are in compliance with the imposed specific and overall migration requirements.

This grade as supplied meets European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste heavy metal content as described in Article 11.

Should you need further clarification, contact NatureWorks LLC.

Bulk Storage Recommendations

The resin silos recommended and used by NatureWorks LLC are designed to maintain dry air in the silo and to be isolated from the outside air. This design would be in contrast to an open, vented to atmosphere system that we understand to be a typical polystyrene resin silo. Key features that are added to a typical (example: polystyrene) resin silo to achieve this objective include a cyclone and rotary valve loading system and some pressure vessel relief valves. The dry air put to the system is sized to the resin flow rate out of the silo. Not too much dry air would be needed and there may be excess instrument air (-30°F dew point) available in the plant to meet the needs for dry air. Our estimate is 10 scfm for a 20,000 lb/hr rate resin usage. Typically, resin manufacturers specify aluminum or stainless steel silos for their own use and avoid epoxy-lined steel.

Safety and Handling Considerations

Safety Data Sheets (SDS) for Ingeo biopolymers are available from NatureWorks. SDS's are provided to help customers satisfy their own handling, safety, and disposal needs, and those that may be required by locally applicable health and safety regulations. SDS's are updated regularly; therefore, please request and review the most current SDS's before handling or using any product.

The following comments apply only to Ingeo biopolymers; additives and processing aids used in fabrication and other materials used in finishing steps have their own safe-use profile and must be investigated separately.

Hazards and Handling Precautions

Ingeo biopolymers have a very low degree of toxicity and, under normal conditions of use, should pose no unusual problems from incidental ingestion or eye and skin contact. However, caution is advised when handling, storing, using, or disposing of these resins, and good housekeeping and controlling of dusts are necessary for safe handling of product. Pellets or beads may present a slipping hazard.

No other precautions other than clean, body-covering clothing should be needed for handling Ingeo biopolymers. Use gloves with insulation for thermal protection when exposure to the melt is localized. Workers should be protected from the possibility of contact with molten resin during fabrication.

Handling and fabrication of resins can result in the generation of vapors and dusts that may cause irritation to eyes and the upper respiratory tract. In dusty atmospheres, use an approved dust respirator.

Good general ventilation of the polymer processing area is recommended. At temperatures exceeding the polymer melt temperature (typically 175ºC), polymer can release fumes, which may contain fragments of the polymer, creating a potential to irritate eyes and mucous membranes. Good general ventilation should be sufficient for most conditions. Local exhaust ventilation is recommended for melt operations. Use safety glasses (or goggles) to prevent exposure to particles, which could cause mechanical injury to the eye. If vapor exposure causes eye discomfort, improve localized fume exhausting methods or use a full-face respirator.

The primary thermal decomposition product of PLA is acetaldehyde, a material also produced during the thermal degradation of PET. Thermal decomposition products also include carbon monoxide and hexanal, all of which exist as gases at normal room conditions. These species are highly flammable, easily ignited by spark or flame, and can also auto ignite. For polyesters such as PLA, thermal decomposition producing flammable vapors containing acetaldehyde and carbon monoxide can occur in almost any process equipment maintaining PLA at high temperature over longer residence times than typically experienced in extruders, fiber spinning lines, injection molding machines, accumulators, pipe lines and adapters. As a rough guideline based upon some practical experience, significant decomposition of PLA will occur if polymer residues are held at temperatures above the melting point for prolonged periods, e.g., in excess of 24 hours at 175°C, although this will vary significantly with temperature.

Combustibility

Ingeo biopolymers will burn. Clear to white smoke is produced when product burns. Toxic fumes are released under conditions of incomplete combustion. Do not permit dust to accumulate. Dust layers can be ignited by spontaneous combustion or other ignition sources. When suspended in air, dust can pose an explosion hazard. Firefighters should wear positive-pressure, self-contained breathing apparatuses and full protective equipment. Water or water fog is the preferred extinguishing medium. Foam, alcohol-resistant foam, carbon dioxide or dry chemicals may also be used. Soak thoroughly with water to cool and prevent re-ignition.

Disposal

DO NOT DUMP INTO ANY SEWERS, ON THE GROUND, OR INTO ANY BODY OF WATER. For unused or uncontaminated material, the preferred option is to recycle into the process otherwise, send to an incinerator or other thermal destruction device. For used or contaminated material, the disposal options remain the same, although additional evaluation is required. Disposal must be in compliance with Federal, State/Provincial, and local laws and regulations.

Environmental Concerns

Generally speaking, lost pellets, while undesirable, are benign in terms of their physical environmental impact, but if ingested by wildlife, they may mechanically cause adverse effects. Spills should be minimized, and they should be cleaned up when they happen. Plastics should not be discarded into the environment.

Product Stewardship

NatureWorks has a fundamental duty to all those that use our products, and for the environment in which we live. This duty is the basis for our Product Stewardship philosophy, by which we assess the health and environmental information on our products and their intended use, and then take appropriate steps to protect the environment and the health of our employees and the public.

Customer Notice

NatureWorks encourages its customers and potential users of its products to review their applications from the standpoint of human health and environmental quality. To help ensure our products are not used in ways for which they were not intended or tested, our personnel will assist customers in dealing with ecological and product safety considerations. Your sales representative can arrange the proper contacts. NatureWorks literature should be consulted prior to the use of the company's products.

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For additional information please contact NatureWorks via our website on the tab called FAQ's or by clicking here.

NatureWorks
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APPENDIX IV / PLA DESCRIPTION CES EDUPACK 2016

Polylactide (PLA)

Description

Image

Caption

Polylactide food packaging. © Cargill Dow

The material

Polylactide, PLA, is a biodegradable thermoplastic derived from natural lactic acid from corn, maize or milk. It resembles clear polystyrene, provides good aesthetics (gloss and clarity), but it is stiff and brittle and needs modification using plasticizers for most practical applications. It can be processed like most thermoplastics into fibers, films, thermoformed or injection molded.

General properties				
Density	1,24e3			kg/m^3
Price	* 1,65	-	1,98	EUR/kg
Date first used	1993			
Mechanical properties				
Young's modulus	3,3	-	3,6	GPa
Shear modulus	* 1,2	-	1,29	GPa
Bulk modulus	* 5,7	-	6,3	GPa
Poisson's ratio	* 0,38	-	0,4	
Yield strength (elastic limit)	55	-	72	MPa
Tensile strength	47	-	70	MPa
Compressive strength	66	-	86	MPa
Elongation	3	-	6	% strain
Hardness - Vickers	* 17	-	22	HV
Fatigue strength at 10^7 cycles	* 22,2	-	27,7	MPa
Fracture toughness	* 3	-	5	MPa.m^0.5
Mechanical loss coefficient (tan delta)	0,06	-	0,09	
Thermal properties				
Melting point	145	-	177	°C
Glass temperature	52	-	60	°C
Maximum service temperature	* 45	-	55	°C
Minimum service temperature	-20	-	-10	°C
Thermal conductor or insulator?	Good insulator			
Thermal conductivity	0,13	-	0,16	W/m.°C
Specific heat capacity	1,18e3	-	1,21e3	J/kg.°C

Thermal expansion coefficient	* 126 - 145	µstrain/°C
Electrical properties		
Electrical conductor or insulator?	Good insulator	
Electrical resistivity	* 3e17 - 6e17	µohm.cm
Dielectric constant (relative permittivity)	* 3 - 3,5	
Dissipation factor (dielectric loss tangent)	* 0,001 - 0,02	
Dielectric strength (dielectric breakdown)	* 15 - 17	1000000 V/m
Optical properties		
Transparency	Transparent	
Refractive index	* 1,4 - 1,48	
Processability		
Moldability	4 - 5	
Formability	* 4 - 5	
Machinability	* 4 - 5	
Weldability	* 3 - 4	
Eco properties		
Embodied energy, primary production	* 49 - 54,2	MJ/kg
CO2 footprint, primary production	* 3,43 - 3,79	kg/kg
Recycle	True	

Recycle mark

7 Other

Supporting information

Design guidelines

PLA is a biopolymer that can be molded, thermoformed and extruded, much like any other thermoplastic. It is transparent and has FDA approval for food packaging. PLA film and sheet can be printed and laminated. Biopolymers are, however, expensive, costing 2 to 6 times as much as commodity plastics like polypropylene.

Technical notes

PLA is a thermoplastic derived primarily from annually renewable resources (maize, corn or milk). It is available in a number of grades, designed for ease of processing. In-line drying may be needed to reduce water content for extrusion and molding. The recommended molding temperature is 165 - 170 C.

Typical uses

Food packaging, plastic bags, plant pots, diapers, bottles, cold drink cups, sheet and film.

Tradenames

NatureWorks PLA, BOPLA

Further reading

See Reference link and Producer website.

Links

Reference

ProcessUniverse

Producers

Values marked * are estimates.

No warranty is given for the accuracy of this data

APPENDIX V / SILICONE RUBBER VTX 950 DATA SHEET

Data sheet: silicone rubber VTX 950

Description		**Low viscosity, extended mould life**				
Features		**Tough, good release properties**				
Suitable for		**Vacuum casting / wax casting**				
Cured properties		**High tear strength**				
Colour		Colourless				
Transparency		Transparent				
Catalyst		**CAT 950 (dry)**	**CAT 951 (oil bleed)**	**CAT 952 (0.2 %)***	**CAT 952 (0.3 %)***	**Test / ISO standard where applicable**
Shore hardness	At 23 °C At 60 °C At 80 °C	40 A - -	40 A - -	40 A - -	40 A - -	
Tensile strength		6.7 N/mm²	-	-	-	
Elongation at break		390 %	390 %	390 %	390 %	
Tear strength		27 N/mm²	-	-	-	
Coefficient of expansion		2.5×10^{-4} mm/mm/K	2.5×10^{-4} mm/mm/K	2.5×10^{-4} mm/mm/K	2.5×10^{-4} mm/mm/K	
Processing information						
Viscosity (at 25 °C)	Part A Part B	42000 cPs -	42000 cPs -	42000 cPs -	42000 cPs -	
Specific gravity (at 25 °C)	Part A Part B	1.10 1.00	1.10 1.00	1.10 1.00	1.10 1.00	
Mix ratio A:B (by weight)		100:10	100:10	0.2*	0.3*	
Curing time	At 25 °C At 40 °C At 60 °C	12 hr 6 hr to 8 hr 2 hr to 6 hr	12 hr 6 hr to 8 hr 2 hr to 6 hr	18 hr 12 hr to 14 hr 4 hr to 8 hr	26 hr 18 hr to 20 hr 5 hr to 10 hr	
Pot life (100 g at 25 °C)		80 min	80 min	150 min	180 min	
Typical shrinkage		0.1 %	0.1 %	0.1 %	0.1 %	

***CAT 952 (long pot life)**
CAT 952 is added to the base material (VTX 950) in the ratio shown above. E.g. 10 kg VTX 950 + 1 kg CAT 950 + 0.2 kg or 0.3 kg CAT 952. Add CAT 952 shortly before mixing.

Handling procedure

Mixing procedure

- Weigh the silicone and catalyst to the ratio indicated overleaf.
- Combine the two components and blend well, scraping the sides and bottom of the container to ensure that there are no unmixed pockets of material.
- Start the vacuum process to extract all excess air out of the mixed silicone. This usually takes around 10 min to 15 min.
- Ensure that enough volume remains in the container to accommodate the action of the material as the air is extracted from the mix. Silicone rubber may expand up to 7 times its original volume in the process of air extraction under vacuum.
- Pour the mixed material into the mould frame in a slow steady stream and allow to flow freely around and over the model.

Special notes

- It is recommended to use a Renishaw vacuum mixer for this work.
- It is important that a clean dry container and mixing paddle is used to avoid adding dirt or contaminants to the mix.
- If a Renishaw vacuum mixer is not available then the mixed material should be left in the container and placed into a Renishaw vacuum casting machine.
- Cure of the mixed silicone material may be inhibited by amines or products with a high sulfur content such as latex rubber.
- Patch testing is advisable prior to use to avoid inhibition.

Product information

Secondary degassing is recommended once pouring of the mould is completed. This is to eliminate voids around or under the model if air has been trapped while pouring. It is important to ensure that the whole degassing process is carried out well within the working time of the mixed silicone.

Please follow the correct procedure for use of your vacuum casting system, as set out in its operating instructions.

Always follow the instructions in the Product Safety Data Sheets and always work in accordance with the safety instructions of the materials manufacturer. Product Safety Data Sheets can be found at www.renishaw.com.

Wear suitable respiratory protection, safety gloves and safety goggles during the entire filling procedure in accordance with the Product Safety Data Sheets.

H-5800-0050-01-A
Issued 1012 Part no. H-5800-0050-01-A

APPENDIX VI / COST REPORT SIMULATION

SOLIDWORKS Costing Report

Model Name: CUP

Date and time of report:	21/08/2016 18:32:29

Manufacturing Method: Plastics

Material:	PLA
Stock weight:	0.03 kg
Mold Type:	Hot Runner Mold
Maximum Wall Thickness:	4.00 mm
Material cost/weight:	2.54 USD/kg
Shop Rate:	N/A

Quantity to Produce

Total number of parts:	100000
Number of cavities:	64

Estimated cost per part: 3.46 USD

Costing template used:	machiningtemplate_default(metric).sldctm
Costing mode used:	Manufacturing Process Recognition
Comparison:	100% Current 3.46 USD

Cost Breakdown

Material:	0.08 USD	2%
Manufacturing:	3.33 USD	96%
Markup:	0.00 USD	0%
Mold:	0.05 USD	1%

Estimated time per part: 00:05:00

Setups:	00:05:00
Operations:	00:00:00

1

SOLIDWORKS

Cost Report

Model Name:	CUP 01.07.16 14h30m	Material:	PLA	Material cost: Manufacturing cost: Markup:	0.08 USD 3.33 USD 0.00 USD	Total cost /part: Total time /part:	**3.46 USD** **00:05:00**

Manufacturing Cost Breakdown

Load and Unload Setups	Time (hh:mm:ss)	Cost (USD / Part)
Setup Operation 1	00:05:00	3.33
Total	**00:05:00**	**3.33**

Mold Operation	Time (hh:mm:ss)	Manufacturing Cost(USD / Part)	Mold Cost(USD / Part)
Plastic Injection Molding	00:00:00	0.00	0.05

2

SOLIDWORKS

APPENDIX VII / ICO DATA TABLES

Total production by all exporting countries
In thousand 60kg bags

Crop year		2010/11	2011/12	2012/13	2013/14	2014/15
April group		**64 494**	**59 701**	**71 294**	**67 953**	**60 342**
Angola	(R/A)	35	29	33	35	39
Bolivia	(A)	130	143	115	128	106
Brazil	(A/R)	48 095	43 484	50 826	49 152	45 342
Burundi	(A)	353	204	406	163	252
Ecuador	(A/R)	854	825	828	666	644
Indonesia	(R/A)	9 129	7 288	13 048	11 667	9 350
Madagascar	(R)	530	585	500	588	518
Malawi	(A)	17	26	23	27	16
Papua New Guinea	(A/R)	870	1 414	717	828	798
Paraguay	(A)	20	21	22	20	20
Peru	(A)	4 069	5 373	4 453	4 338	2 883
Rwanda	(A)	323	251	259	254	258
Timor-Leste	(A)	60	50	59	79	104
Zimbabwe	(A)	10	9	7	8	12
July group		**1 887**	**1 678**	**2 222**	**1 886**	**2 086**
Congo, Rep. of	(R)	3	3	3	3	3
Cuba	(A)	108	100	88	107	100
Dominican Republic	(A)	378	491	488	425	400
Haiti	(A)	350	349	350	345	350
Philippines	(R/A)	189	180	177	186	200
Tanzania	(A/R)	846	544	1 109	809	1 030
Zambia	(A)	13	11	5	11	3
October group		**67 258**	**75 192**	**74 077**	**76 963**	**78 753**
Benin	(R)	0	0	0	0	0
Cameroon	(R/A)	503	574	366	413	475
Central African Republic	(R)	78	91	23	90	95
Colombia	(A)	8 523	7 652	9 927	12 124	12 500
Congo, Dem. Rep. of	(R/A)	305	357	334	347	335
Costa Rica	(A)	1 392	1 462	1 571	1 444	1 508
Côte d'Ivoire	(R)	982	1 966	2 072	2 107	2 175
El Salvador	(A)	1 814	1 152	1 235	537	680
Equatorial Guinea	(R)	0	0	0	0	0
Ethiopia	(A)	7 500	6 798	6 233	6 527	6 625
Gabon	(R)	2	1	1	0	1
Ghana	(R)	92	94	82	45	40
Guatemala	(A/R)	3 950	3 840	3 743	3 159	3 500
Guinea	(R)	386	385	233	158	150
Guyana	(R)	1	1	1	1	1
Honduras	(A)	4 331	5 903	4 537	4 568	5 400
India	(R/A)	4 728	4 921	4 977	5 075	5 517
Jamaica	(A)	21	24	24	20	20
Kenya	(A)	641	757	875	838	850
Lao, People's Dem. Rep. of	(R)	544	512	542	544	500
Liberia	(R)	10	10	10	6	10
Mexico	(A)	4 001	4 563	4 327	3 916	3 900
Nepal	(A)	3	2	2	1	2
Nicaragua	(A)	1 638	2 193	1 991	1 941	2 050
Nigeria	(R)	42	47	41	41	40
Panama	(A)	114	106	116	110	95
Sierra Leone	(R)	33	78	61	32	50
Sri Lanka	(R)	37	36	35	36	36
Thailand	(R/A)	828	831	608	638	494
Togo	(R)	160	162	78	135	100
Trinidad & Tobago	(R)	10	11	12	12	10
Uganda	(R/A)	3 223	3 075	3 878	3 602	3 800
Venezuela	(A)	1 202	902	952	805	660
Vietnam	(R/A)	20 000	26 500	25 000	27 500	27 500
Yemen	(A)	161	185	190	191	185
Total		**133 640**	**136 572**	**147 593**	**146 801**	**141 732**

Domestic consumption by all exporting countries
In thousand 60kg bags

Crop year		2010/11	2011/12	2012/13	2013/14	2014/15
April group		**23 455**	**24 023**	**24 947**	**25 187**	**26 082**
Angola	(R/A)	30	30	30	30	30
Bolivia	(A)	60	60	60	60	60
Brazil	(A/R)	19 132	19 720	20 330	20 085	21 000
Burundi	(A)	2	2	2	2	2
Ecuador	(A/R)	150	150	150	155	155
Indonesia	(R/A)	3 333	3 333	3 667	4 167	4 167
Madagascar	(R)	467	450	430	410	390
Malawi	(A)	1	1	1	1	1
Papua New Guinea	(A/R)	4	1	2	2	2
Paraguay	(A)	20	20	20	20	20
Peru	(A)	250	250	250	250	250
Rwanda	(A)	1	1	1	1	1
Timor-Leste	(A)	0	0	0	0	0
Zimbabwe	(A)	4	4	4	4	4
July group		**3 113**	**3 163**	**3 163**	**3 168**	**3 168**
Congo, Rep. of	(R)	3	3	3	3	3
Cuba	(A)	220	220	220	220	220
Dominican Republic	(A)	378	378	378	383	383
Haiti	(A)	340	340	340	340	340
Philippines	(R/A)	2 125	2 175	2 175	2 175	2 175
Tanzania	(A/R)	47	47	47	47	47
Zambia	(A)	0	0	0	0	0
October group		**15 609**	**16 249**	**16 521**	**17 067**	**17 268**
Benin	(R)	0	0	0	0	0
Cameroon	(R/A)	69	69	69	69	69
Central African Republic	(R)	10	13	17	20	20
Colombia	(A)	1 308	1 439	1 441	1 558	1 570
Congo, Dem. Rep. of	(R/A)	200	200	200	200	200
Costa Rica	(A)	282	270	298	217	226
Côte d'Ivoire	(R)	317	317	317	317	317
El Salvador	(A)	275	271	275	275	275
Equatorial Guinea	(R)	0	0	0	0	0
Ethiopia	(A)	3 383	3 383	3 400	3 650	3 675
Gabon	(R)	1	1	1	1	1
Ghana	(R)	2	2	2	2	2
Guatemala	(A/R)	340	340	340	340	340
Guinea	(R)	50	50	50	50	50
Guyana	(R)	0	0	0	0	0
Honduras	(A)	345	345	345	345	345
India	(R/A)	1 800	1 917	1 917	1 917	1 917
Jamaica	(A)	9	9	9	9	9
Kenya	(A)	50	50	50	50	50
Lao, People's Dem. Rep. of	(R)	150	150	150	150	150
Liberia	(R)	5	5	5	5	5
Mexico	(A)	2 354	2 354	2 354	2 354	2 354
Nepal	(A)	0	0	0	0	0
Nicaragua	(A)	203	205	207	210	204
Nigeria	(R)	40	40	40	40	40
Panama	(A)	67	67	67	67	67
Sierra Leone	(R)	5	5	5	5	5
Sri Lanka	(R)	35	35	35	35	35
Thailand	(R/A)	775	1 100	1 130	1 200	1 250
Togo	(R)	2	2	2	2	2
Trinidad & Tobago	(R)	10	10	10	10	10
Uganda	(R/A)	160	170	180	190	200
Venezuela	(A)	1 650	1 650	1 650	1 650	1 650
Vietnam	(R/A)	1 583	1 650	1 825	2 000	2 100
Yemen	(A)	130	130	130	130	130
Total		**42 177**	**43 435**	**44 632**	**45 423**	**46 519**

Disappearance (consumption) in selected importing countries

In thousand 60kg bags

Calendar years	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
European Union	**41 743**	**39 877**	**41 586**	**41 141**	**40 700**	**40 042**	**41 207**	**40 765**	**41 018**	**41 875**	**41 648**
Austria	996	772	612	847	908	886	903	1 117	1 269	1 249	
Belgium	1 396	1 158	1 537	1 103	650	934	871	934	915	1 245	
Belgium/Luxembourg											
Bulgaria	364	430	420	364	445	409	395	360	376	419	
Croatia	370	374	386	386	377	366	370	367	360	387	
Cyprus	60	70	55	69	77	75	74	81	85	89	
Czech Republic	605	656	631	679	621	525	470	572	685	637	
Denmark	849	795	822	794	688	676	806	762	800	822	
Estonia	129	145	167	101	154	123	105	67	104	120	
Finland	1 034	1 102	1 047	1 057	1 115	1 058	1 080	1 093	1 082	1 095	
France	4 929	4 787	5 278	5 628	5 152	5 677	5 713	5 962	5 790	5 707	
Germany	10 445	8 665	9 151	8 627	9 535	8 897	9 292	9 460	8 830	9 378	
Greece	871	870	857	1 015	978	974	994	1 023	1 076	1 101	
Hungary	708	570	598	522	494	445	376	180	252	177	
Ireland	225	223	203	244	115	134	160	179	214	196	
Italy	5 469	5 552	5 593	5 821	5 892	5 806	5 781	5 689	5 710	5 646	
Latvia	155	144	181	131	115	88	99	101	101	95	
Lithuania	197	193	213	230	204	210	223	180	193	197	
Luxembourg	221	227	233	251	239	222	232	215	212	241	
Malta	16	16	29	16	23	14	12	16	21	22	
Netherlands	1 978	1 927	2 129	2 292	1 324	898	1 347	909	1 382	1 625	
Poland	2 281	2 267	1 993	1 554	1 681	2 001	2 156	2 034	1 936	1 669	
Portugal	763	744	768	769	747	731	824	868	867	850	
Romania	818	857	835	824	807	775	796	802	849	891	
Slovakia	283	293	281	356	341	213	337	388	201	328	
Slovenia	185	181	176	195	194	198	205	208	185	184	
Spain	2 705	3 007	3 017	3 198	3 485	3 352	3 232	3 149	3 435	3 501	
Sweden	1 234	1 170	1 315	1 244	1 272	1 133	1 221	1 125	1 159	1 175	
United Kingdom	2 458	2 680	3 059	2 824	3 067	3 220	3 134	2 925	2 926	2 828	
Japan	7 117	7 128	7 268	7 282	7 065	7 130	7 192	7 015	7 131	7 435	7 494
Norway	709	743	721	771	715	715	746	785	723	763	729
Switzerland	722	1 099	932	989	1 149	966	1 012	1 035	1 047	1 123	1 028
Tunisia	263	190	200	253	317	289	301	415	421	429	460
Turkey	403	464	497	516	484	521	610	633	681	789	929
USA	20 973	20 998	20 667	21 033	21 652	21 436	21 783	22 044	22 232	23 417	23 761
Total	**71 930**	**70 499**	**71 872**	**71 986**	**72 082**	**71 098**	**72 851**	**72 693**	**73 252**	**75 832**	**76 049**

World coffee consumption
In thousand 60kg bags

Calendar years	2011	2012	2013	2014	CAGR
World total	**139 483**	**143 140**	**147 113**	**149 823**	**2.4%**
Africa	9 170	10 081	10 624	10 809	5.6%
Asia & Oceania	26 452	28 014	29 159	30 446	4.8%
Central America & Mexico	4 974	5 035	5 030	4 979	0.0%
Europe	49 311	49 461	50 493	51 109	1.2%
North America	25 618	25 730	26 931	27 674	2.6%
South America	23 958	24 820	24 875	24 807	1.2%
Exporting countries	***42 788***	***44 196***	***44 929***	***45 558***	***2.1%***
Brazil	19 573	20 178	20 146	20 271	1.2%
Indonesia	3 333	3 584	4 042	4 167	7.7%
Ethiopia	3 383	3 387	3 463	3 656	2.6%
Mexico	2 354	2 354	2 354	2 354	0.0%
Philippines	2 150	2 175	2 175	2 175	0.4%
Vietnam	1 600	1 694	1 869	2 025	8.2%
India	1 829	1 917	1 917	1 917	1.6%
Venezuela	1 650	1 650	1 650	1 650	0.0%
Colombia	1 341	1 439	1 448	1 475	3.2%
Thailand	856	1 108	1 148	1 213	12.3%
Madagascar	454	435	415	395	-4.6%
Dominican Republic	378	378	381	383	0.5%
Honduras	345	345	345	345	0.0%
Guatemala	340	340	340	340	0.0%
Haiti	340	340	340	340	0.0%
Côte d'Ivoire	317	317	317	317	0.0%
El Salvador	274	272	275	275	0.1%
Peru	250	250	250	250	0.0%
Cuba	220	220	220	220	0.0%
Costa Rica	279	277	278	219	-7.7%
Others	1 522	1 538	1 557	1 571	1.1%
Importing countries	***96 695***	***98 944***	***102 185***	***104 265***	***2.5%***
European Union	40 765	41 018	41 875	42 442	1.4%
USA	22 044	22 232	23 417	23 761	2.5%
Japan	7 015	7 131	7 435	7 494	2.2%
Russian Federation	3 695	3 696	3 648	4 021	2.9%
Canada	3 574	3 498	3 514	3 913	3.1%
Algeria	1 942	2 117	2 125	2 154	3.5%
South Korea	1 801	1 714	1 760	1 910	2.0%
Australia	1 407	1 631	1 542	1 543	3.1%
Saudi Arabia	1 000	1 186	1 279	1 279	8.6%
Ukraine	1 324	1 238	1 338	1 215	-2.8%
Switzerland	1 035	1 047	1 123	1 028	-0.2%
Turkey	633	681	789	929	13.6%
Israel	472	556	585	777	18.1%
Sudan	572	675	758	758	9.8%
Norway	785	723	763	729	-2.4%
Egypt	67	452	726	726	120.9%
Lebanon	407	418	613	580	12.5%
Argentina	587	756	800	558	-1.6%
Morocco	464	633	635	546	5.6%
South Africa	538	504	493	525	-0.8%
Others	6 568	7 039	6 967	7 377	3.9%