Upcycling of denim discard for development of new material

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ABSTRACT: This study proposes to incorporate the process of upcycling textile discards by moulding polymers with denim fabric within the polymer matrix. This research seeks to develop a solid material that can be used in the development of new products. This paper is the result of the experimental phase, where the compression moulding process was applied to denim waste composed of cotton, elastane and polyethylene incorporating polymeric waste. Thermoplastic polymers such as polypropylene, high density polymer and low-density polymer were used in the process. One of the objectives of the study was to process the material as little as possible, using waste without felting. The result is that a layer of polymer interspersed with the denim and a compression temperature of 165ºC is required for better adhesion. A compact material with different levels of malleability were achieved and the next phase of the study will be the material characterization step.

1 INTRODUCTION

Increasingly, companies are investing in the development of products that have the least environmental impact possible. Climate change brings a growing alert involving the impacts of the industry on the environment. Therefore, there are growing studies on creating sustainable materials, as well as researches about the reuse of materials. Finding reuse of waste prevents discarded products from reaching landfills and contributes to reducing the extraction of natural resources for the manufacture of new products. The reuse of materials is a way to mitigate the damage already done.

This research proposes to incorporate the recycling process by upcycling textile discards, this study links sustainable design and the circular economy through the upcycling process once upcycling seeks an appreciation of the discarded material, an appreciation attributed again to the material preventing the discard (Moraes 2013). In sustainable design, the environmental aspects are addressed, aiming to develop more products and services with ever-decreasing use of resources as well as waste generation (Manzini 2008). According to Manzini, the design acts, in the same way, on the function and form of an object and with the awareness that they are independent and with importance capable of interacting with each other (Manzini 2015).

Ellen MacArthur Foundation, which seeks for accelerating the transition to a Circular Economy, wants to encourage brands and consumers to rethink and slow down to create a more circular economy. Circular Economy requires businesses and consumers to be able to reflect on their actions and the consequences for the environment and take care of the preservation and the resources available for future generations (Ellen MacArthur Foundation 2019).

The United Nations has proposed the so-called "SDGs" - "Sustainable Development Goals" to ensure sustainable development while maintaining balance between the 3 pillars - environmental, social and economic. There are 17 goals stipulated by the UN whose presence in the 2030 Agenda for Sustainable Development has the mission of achieving a better and more sustainable future for all by 2030 (United Nations 2021).

The 2030 Agenda, approved in 2015, seeks to create a new global model to end poverty, promote prosperity and provide well-being for all, as well as protect the environment and combat climate change (BCSD 2021).

This study is based on the circular economy and seeks a new material involving the reuse of discarded textiles that would have garbage as their final destination, this research is directed to the recycling of denim waste from both manufacturing waste from the production chain, but mainly from the recycling of post-consumer denim discard (denim discarded by consumers at the end of life) that has as its main destination the landfills. Ellen MacArthur Foundation, in their 2019 report, reports that 73% of post-consumer textile clothing is incinerated or landfilled, that only 12% is recycled in a process that waste is incorporated into items of lesser value and only 1% is related to reuse to through the production of the same type of item (Ellen MacArthur Foundation 2019).

Denim is a textile widely used by the fashion industry, is a resistant material and produced on a large scale, is a textile that even after disposal can serve as raw material for various types of products. This resistant property is due to its composition's interweaving of the weft and warp yarns (Chataignier 2007). Denim discards can be reused in different ways, highlighted for redistribution in second-hand stores, for use in crafts, for recycling to develop new yarns or for upcycling in the development of new material which is the focus of this research.

The method developed in this second phase of studies paper begins with an analysis that was made of the materials to be considered for testing, which includes discarded denim and polymers disposal. The Ellen MacArthur Foundation is concerned about the amount of plastic waste too, for that reason Plastics Pact Network is globally aligned with the problem of plastic waste and pollution. The Portuguese Plastics Pact was launched in February 2020, it is led by Smart Waste Portugal, with the support of the Ministry of Environment and General Directorate of Economy and seeks to reduce plastic waste (Ellen MacArthur Foundation 2022). In 2020, Breaking the Plastic Wave was launched and a study of plastics in the ocean shows that plastic pollution is outstripping efforts to stop it. The study predicts that, if nothing is done, by 2040 the volume of plastic on the market will double, increasing the annual volume of plastic entering the oceans, proving the 2016 analysis, which revealed that by 2050 there could be more plastic than fish in the ocean (Ellen MacArthur Foundation 2020).

This research seeks to creating material for furniture and fashion development, looks for a solid material, resistant and good aesthetic appeal. One of the objectives of the study is to process the material as little as possible, avoiding the felting process. This research seeks to develop products taking into consideration materials already extracted from nature, which have been used and even after being discarded have potential use for new product development.

From this, the upcycling of plastic and denim began, where combinations of materials and important process details of the process were determined in search of new materials.

2 MATERIALS AND METHODS

This research proposes to incorporate the process of upcycling textile discards by moulding polymers with denim fabric within the polymer matrix. This study seeks to develop a solid material with appealing visual grammar that can be applied in various fields of production.

The second research phase, described in this paper, began after the stages of the first phase have been completed, which encompassed the main literature review and the study of some important concepts related to the theme such as Circular Economy, Sustainable Design and Upcycling. In the first phase was made the theoretical study and the analysis of what has already been explored on the subject in question.

The methodological structure applied in this second research phase, presented in this article, is practical/experimental. In this practical phase of laboratory work, experiments were carried out with the combinations of materials selected in the first phase of studies, and the method to be improved and characterized was chosen. In the next phase, after this material is created and characterized, depending on its properties, it will then be applied in the development of new furniture, fashion products and interior design.

The objective is to take advantage of existing denim waste, with methods and techniques for reusing pre and post-consumption waste for the elaboration of new materials and products. This

research is based on the Circular Economy, which proposes economic growth disconnected from the exploitation of natural resources, through the creation of closed production cycles without waste generation and presenting a systemic look at the evaluation of new forms of production and consumption. The Circular Economy is allied with Sustainable Design seeking to develop products taking into consideration materials already extracted from nature, which have been used and even after being discarded have potential use for new product development. Ellen MacArthur Foundation argues that adopting a circular economy approach could reduce global CO2 emissions from major industry materials by 40% or 3.7 billion tons by 2050 (Ellen MacArthur Foundation 2019). To start this second phase were selected the materials: denim and polymer disposal. The denim that will be combined with other materials is a result of discarded by consumers, they are post-consumer products with wear and tear. The denim can be fabric made of 100% cotton (which is a natural polymer) or in combination with other synthetic fibres such as elastane and/or polyester. Firstly, the material was separated and manipulated in laboratory to find the sample size appropriated to the compressing process.

Most of the collected denim presents a mixture of materials, and most of them present elastane in its composition, so the first experiment was to do the compressing process using only the denim without the addition of extra polymer. The objective was to see the comportment only of the denim in this compression moulding process (COM).

Compression moulding (COM) is the processing techniques to develop the material which compresses and uses the heated mould cavity and was selected as the technique to be used in this phase of testing. The compression machine used was the model Fontijne Presses BV – Model LabManual 300. The material was used with whole fibres, the denim disposal was used without the pieces being shredded, they were used whole just adapting the pieces to the size of the mould. The material was prepared and transferred to the hot press machine between sheets of Teflon paper to prevent the matrix material from sticking to the machine. In the first experiment, without the addition of extra polymer, four (4) layers of denim are placed on top of each other. Three (3) samples were tested, the first one with layers of denim composed of cotton (98%) and elastane (2%); the second one with cotton (80%), polyester (15%) and elastane (5%) and the third one to mix both denim material (in the same proportions). All three samples with denim scraps were subjected to first compression, 200ºC in 10 minutes and the pressure applied was 30N. The melting point of polyester and elastane is concentrated between 260ºC and 270ºC. After this compression, in a second moment, the same 3 samples were again subjected to another 10 minutes of the same compression, but this time at 270ºC.

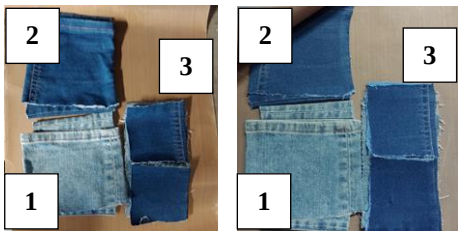
Then, the hot press process began with samples containing discarded denim and polymer waste. There were made several tests with different layers (denim and polymers), different temperatures and compressing. Tests were performed with non-woven polymer industrial residue (polypropylene (PP) pre-consumer) usually applicated to medical products (hospital clothing, masks) and discarded plastic bags (high density polyethylene – HDPE and low-density polypropylene - LDPE).

Polymers are made up of synthetic macromolecules, in this work, thermoplastics polymers were used, which are materials with the characteristic that can be processed many times, present advantages in mechanical and physical characteristics concerning thermosetting matrices, as well as better impact resistance (Pereira 2017).

Samples with the disposal of denim and polymers waste were made, in these samples were tested the interference of the: use of double and single polymers layer, the use of patchwork or whole pieces of denim and the temperature required for the melting point. The polypropylene has the fusion point between 130ºC e 171ºC and the cotton can start the degradation after 200ºC. During the hot press process, the production temperature was adjusted between 150ºC and 170ºC until find the ideal temperature. The compression time was established in 10 minutes in all tests and the compression was modified considering the number of layers used, ranging from 30 Newtons (at the beginning of the tests) to 200N until find the ideal compression. The polymers used were concentrated in non-woven fabric waste and plastic bag disposal, and no material used in this study was reprocessed or crushed. The denim was stacked in layers and different amounts of layers of denim were tested to check the thickness and hardness of the material after compressed.

3 RESULTS

In the analysis, it was observed that the denim discarded material in its great majority is not made of 100% cotton, usually the denim present combinations of cotton with elastane and/or polyester. In the first step, after the compression process without extra polymer (sample 1, 2 and 3), the materials were yellowish and presents few adherences, Figure 1. The test with a temperature lower than 200ºC didn't show results.



a) b)

Figure 1. a) Samples before compression; b) Samples after the compression

Then, when the same 3 samples were subjected at 270ºC, the result was a bit more stuck material, but the cotton was burned, changing their colouration and the material with more elastane presented cuts, Figure 2.

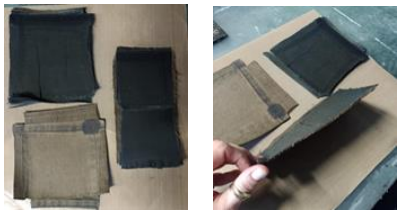


Figure 2. Samples after second compression, 270ºC.

After these firsts results, the hot press process began with samples containing discarded denim and polymer waste. The results with Polypropylene (PP), high density polyethylene (HDPE) and low-density polypropylene (LDPE) show that it was possible to obtain a compact material without burning or damaging the denim, Figure 3.

a) b) c) d)

Figure 3. a) Samples with non-woven before compression; b) Samples with non-woven after compression; c) Samples with plastic bags (HDPE) before compression; d) Samples with plastic bags (HDPE) after compression.

At the end of these tests and after using different numbers of denim layers it was possible to achieve a good fusion, a compact material, with different levels of malleability and appearance, Figure 4. Samples with about 4 layers of denim results in 1 mm of compact material, a caliper was used to measure the thickness of the composite material.

a) b)

Figure 4. a) Samples with non-woven (PP); b) Samples with plastic bags (LDPE).

However, all these perceptions about the consistency of this material can only be evaluated after the next phase, which consists of the material characterization step.

4 DISCUSSION

Because this phase of tests was concluded, after all the work made and analysed, some relevant considerations to this experimental phase of the studies were made. From the consistency of the material obtained, it seems that a good combination of polymer, rein-forcing fibre and manufacturing process, may lead to an application with better properties related to strength, weight, and adherence, among others. It is present in the literature that there are several reports on the thermal and acoustic properties of recycled composite panels (Sezgin et al 2021).

In this phase of studies were tested combinations of materials involving discarded denim, aiming to find an alternative way for the development of new fashion and furniture products with denim waste by means of a polymeric matrix. The literature review indicates that cotton fibers obtained from waste denim fabrics have been used as the reinforcement material (Sezgin et al 2021).

Researches involving textile waste were the starting point for the development of this material. It is present in the literature that polypropylene (PP) is a cost-effective thermoplastic matrix material, which can be reinforced with the waste denim fibres to manufacture the composites by compression moulding (Wang et al 2022).

Discarded thermoplastic polymers were selected as materials to be added, the choice of this material with denim discards because they were also considered to have a great polluting potential as well as textile waste, with the need for both to be recycled and removed from the environment.

Plastic is not biodegradable and often single-use which leads to an accumulation of waste deposited in the environment without being recycled. This kind of material, like textile disposal, is considered one big threat to the environment. About 80% to 85% of marine litter in the EU is plastic, 50% of which is single-use plastics and 27% fishing-related items (CGD 2022).

For pollution from the use of polymers could be minimized a set of actions is necessary, among them, the development of new biodegradable materials and the reuse of the existing polymers, they must be recycling and taken from the environment.

It's necessary much care about the treatment of disposal, the management and disposal of waste can have serious environmental impacts. The residual discarded, besides occupying land space can still cause air, water and soil pollution, and incineration can result in emissions of atmospheric pollutants (Eurostat 2021).

This research seeks to creating material for furniture and fashion development, looks for a solid material, resistant and good aesthetic appeal. For this, the thermoplastic polymeric matrix seems is the most appropriate option to tested, considering that this material can present a solid physical state, impact resistance, good durability outdoors, and recyclability.

Is it known in the literature that compression moulding (COM) is a well-suited and highly used method for resin (Temmink et al 2018).

The processing technique for the material used in this phase was compression moulding, was made several samples to analyse the better use of the material. It was verified that the denim

needs of the layer polymer between the layer's denim. Tests were performed without polymer between all denim layers, and it was observed that it is always necessary to have at least one polymer layer interspersed with the denim for adhesion.

It was observed the need for a polymer layer between the denim for adhesion, but there was no change if the polymer layer is double or if it is placed in patches or whole.

The temperature must be at least 160ºC for the fusion without degradation of the cotton, having been considered ideal temperature 165ºC. The results of the material obtained with 165ºC (melting, appearance and consistency) were considered more satisfactory than those pressed at 160ºC. The applied pressure ranged from 30N to 200N and it was been observed that compression at 100N results in satisfactory compression without damaging the material. The compression time of 10 minutes was maintained since the beginning of the tests.

One of the objectives of the study is to process the material as little as possible, all residues were used only adapting the size to the space of the compression machine available for the tests, avoiding the process analysed in other studies, in which denim felting is mandatory.

5 CONCLUSIONS

Solid waste management is an important focus worldwide, vast quantities of textile and plastic waste are generated daily. In this study, the main goal was to develop material to be used as alternative materials for the development of products. This research seeks to develop products with materials already extracted from nature, which have been used and even after being discarded have potential use for development of new materials.

Once this phase of the investigation is concluded, it is considered that a solid material has been produced from the upcycling of denim and polymers wastes, with different thicknesses and malleability, as well as good aesthetic appeal. The objective of developing the material without crushing was achieved, the material was obtained without the pieces having been shredded or felting.

At this stage, was possible to find a solid material made from denim waste, with good fusion and ability to go on to the next stage of testing, which is the characterization of the material is for application in the development of new furniture and fashion products. The next phase will be tests such as water permeability, stiffness and strength, among others.

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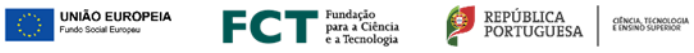

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