DEVELOPMENT OF A MATERIAL WITH ELASTOMER WASTE

DESENVOLVIMENTO DE MATERIAL COM RESÍDUOS DE ELASTÔMEROS

DESARROLLO DE MATERIAL CON ELASTÓMEROS DE DESECHO

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ABSTRACT
Elastomers for industrial use are mostly thermosetting polymers, which are difficult to recycle. Thus, this material is commonly used for energy recovery, wasting most of its potential. One of the alternatives to the reuse of this residue is its use in composite materials. There are reports in the literature on the development and applications of composites reinforced with plant fibers or industrial waste. The aim of this paper is to present the development of a composite using elastomers waste generated in the company MicroJuntas Ltda., located in Joinville/SC. This article is an excerpt from a Professional Master's in Design project, structured according to the Design Science Research methodology. The proposal is to use a particulate rubber residue as a reinforcement phase in different proportions in a composite based on biodegradable vegetable polyurethane (PUR). Visual and empirical evaluations indicate that the proportion of 70% of residue presents the best properties of cohesion, texture, and uniformity. It is concluded that the material developed has potential for application in products, especially those formed by compression, a process that facilitates the cohesion and uniformity of the artifact. Therefore, it is possible to use this by-product in new artifacts with added value, reducing the impacts of its disposal on the environment.

KEYWORDS
Elastomers; industrial waste; Design for sustainability; vegetable oil polyurethane; composite materials.

RESUMO
Elastômeros de uso industrial são majoritariamente materiais poliméricos termofixos, de difícil reciclagem. Assim, esse material é comumente destinado à recuperação energética, desperdiçando suas potencialidades. Uma das alternativas ao reuso desse resíduo é o seu aproveitamento em materiais compostos, os compósitos. Há relatos em literatura sobre o desenvolvimento e aplicações de compósitos reforçados com fibras vegetais ou resíduos da indústria. O objetivo deste artigo é apresentar o desenvolvimento de um compósito utilizando os resíduos de elastômeros gerados na empresa MicroJuntas Ind. e Com. Ltda., localizada em Joinville/SC. Esse artigo se constitui de um recorte de um projeto de Mestrado Profissional em Design, estruturado segundo a metodologia Design Science Research. Foi proposto o uso de um resíduo particulado de borracha como reforço em diferentes proporções em um compósito à base de poliuretano vegetal biodegradável (PUR). Análises visuais e empíricas indicam que a proporção de 70% de resíduo apresenta as melhores propriedades de coesão, textura e uniformidade. Conclui-se que o material desenvolvido tem potencial para aplicação em produtos, principalmente aqueles formados a partir de compressão, processo que facilita a coesão e uniformidade do artefato. Com isso, é possível utilizar esse subproduto em novos produtos com valor agregado, reduzindo os impactos do

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seu descarte no meio ambiente.

PALAVRAS-CHAVE
Elastômeros; resíduos industriais; Design para a sustentabilidade; poliuretano vegetal; compósitos.

RESUMEN
Los elastómeros de uso industrial son principalmente materiales poliméricos termoestables de difícil reciclaje. Por lo tanto, este material suele destinarse a la recuperación de energía, desaprovechando su potencial. Una de las alternativas para reutilizar este residuo es su utilización en materiales compuestos, los compuestos. Existen informes en la literatura sobre el desarrollo y las aplicaciones de compuestos reforzados con fibras vegetales o residuos de la industria. El objetivo de este artículo es presentar el desarrollo de un compuesto utilizando los residuos de elastómeros generados en la empresa MicroJuntas Ind. e Com. Ltda., Joinville/SC. Este artículo forma parte de un proyecto de Maestría Profesional en Diseño, estructurado según la metodología de Investigación en Ciencias del Diseño. Se propuso utilizar un residuo de goma particulado como refuerzo en diferentes proporciones en un compuesto a base de poliuretano vegetal biodegradable (PUR). Análisis visuales y empíricos indican que la proporción del 70% de residuos presenta las mejores propiedades de cohesión, textura y uniformidad. Se concluye que el material desarrollado tiene potencial para su aplicación en productos, especialmente aquellos formados por compresión, un proceso que facilita la cohesión y uniformidad del artefacto. De esta manera, es posible utilizar este subproducto en nuevos productos con valor agregado, reduciendo el impacto de su eliminación en el medio ambiente.

PALABRAS CLAVE
Elastómeros; residuos industriales; diseño para la sostenibilidad; poliuretano a base de aceite vegetal; materiales compuestos.

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1. INTRODUCTION

Polymers, popularly known as plastics, are widely consumed materials today in several markets. Among the polymers are the elastomers, also known as rubbers, which have the ability of their length to be elongated several times and then return to their original length (LESKO, 2012).

Like other types of polymers, elastomers are also commonly discarded improperly after use. Most of the elastomeric polymers used in industry are difficult to reuse or recycle because they are thermosetting materials. This is due to its chemical structure with cross-links between molecules, making it difficult to reshape by heating. In addition, they are materials that are difficult to decompose.

Due to this difficulty, Andrietta (2002) states that elastomeric waste is almost always deposited in inappropriate places, that is, when they are not sent to industrial landfills, they are incinerated or discarded directly into the environment. This causes a series of problems such as the silting up of rivers, the proliferation of venomous insects and the release of polluting gases when burned. Thus, a more suitable option for the environment would be the reuse of this material by the productive sector itself.

This article specifically addresses the problem related to waste generated in the production process of elastomeric components of a company in Joinville/SC. This company produces rubber products and gaskets with different compositions and formats, generating around 40 tons of waste monthly.

Currently, this company sends this waste to the specialized collection, which is subsequently co-processed through energy recovery (burning), mainly in the cement industry. Although it is a destination superior to a landfill, it still does not take advantage of the potential of this material, which often has excellent physical and chemical characteristics.

With this, the objective of this work is to report the development of a composite material from the elastomeric waste of this company. This development makes it possible to reintroduce waste into a new life cycle since design artifacts can be produced from the material.

This work is also a part of a master's in Design project, in which it is possible to find more complete and detailed information on the development (ANDREZZO, 2022). The methodology used to structure the entire proposal was Design Science Research (DRESH; LACERDA; ANTUNES, 2015).

In this article, a theoretical review and empirical development of the material are presented. Preliminary analyses and considerations are also presented on the use of the material developed to support future applications in product design.

2. THEORETICAL REVIEW

2.1. Elastomers

Polymers are formed by the union of smaller molecules (monomers) in long chains in a process called polymerization, generating rigid or flexible materials. Its industrialization happened quickly, becoming one of the symbols of the consumer society (KULA; TERNAUX, 2012).

Elastomers are polymers with great elasticity, that is, they can be stretched and return to their original shape with tension relief. According to Lesko (2012), in addition to withstanding elongation, elastomers are characterized by their resistance to abrasion, good retention of properties when exposed to heat, oxidation and ozone, good electrical properties and excellent impermeability to gases.

They are commonly formed by more than one monomer and, for the most part, are thermosetting, that is, they cannot be heated and remolded. Cross-links between molecules act as anchors, which prevent the material from melting (MARKL; LACKNER, 2020).

Natural rubber is a well-known example of this group of materials. It is produced from the sap of the rubber tree (latex) and still occupies a considerable part of the elastomers used. Virgin rubber goes through the vulcanization process, which is the addition of sulfur to the rubber, under heating and with the use of catalysts (THOMPSON, 2015).

According to Paulo and Saron (2009), the chemical structure of the material is what gives elastomers their elastic properties. Elastomers are formed by long polymeric chains that, when vulcanized, become entangled, forming crosslinks (Figure 01) that elongate more under tension, resulting in a reduction in the entropy of the system. Because it is not a spontaneous process, the polymeric chains return to the entangled condition

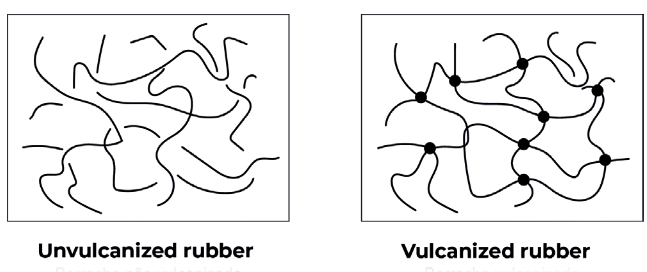

Figure 01: Cross-links of vulcanized rubber.
Source: adapted from Brito (2009, p. 18).

when the tension is removed from the material, causing its contraction.

2.1.1. Processes of reuse of elastomers

The high purchase cost of natural rubber has been a stimulus for recycling since the product's growth in the industry. With records dating back to 1909, in Germany, crushing and separation of rubber were already carried out, which made the by-product available to the industries that produced rubber products. With the lack of investment and technology at the time, interest in carrying out this recycling was lost (LAGARINHOS; TENÓRIO, 2008).

There are several studies on the recycling of elastomers and therefore different processes can be applied. These processes have been studied in thermomechanical, chemical, ultrasound-based, microwave-assisted, and biological devulcanization methods, among others (MARKL; LACKNER, 2020).

Thermal processes are those in which high temperature is applied in an autoclave. To carry out this procedure, first, the residues are turned into crumbs or powder to better adhere to the solvent and reagents. Then, the residues and solvents and reagents are placed in the autoclave, which is sealed and then heated at 180 °C for 1 h. In this process, it is even possible to reach devulcanization levels of up to 100% for gum rubbers, whereas in composite rubbers the levels obtained are lower (FORREST, 2014).

About this process, when done on a large scale, the devulcanization reaction takes a long time to complete. On the other hand, the process can be used relatively quickly on a small scale, in a controlled manner, being a good resource for investigating and analyzing changes in parameters such as time, temperature and chemical agents to analyze the feasibility of scaling (FORREST, 2014).

The thermal process with chemical reagents follows the same process mentioned above, with the addition of chemical agents seeking a better incorporation of these in the rubber matrix previously impregnated with solvents and achieving the desired properties for the material. Chemical devulcanization can occur by oils and chemical reagents, in which the most used are thiosalicylic acid and diphenyl disulfide, or by organic solvents which are based on the use of alcohols and ketones as agents and finally inorganic compounds used as solvents toluene, naphtha, benzene and cyclohexane (MAGALHÃES, 2015).

One of the alternatives for the mechanical recycling of thermoset elastomers is through microwaves, which can be considered a kind of thermal process, as it uses microwave energy to devulcanize the rubber through heat. A requirement to make use of this technique is that the rubber compound must be polar enough to absorb microwave energy effectively. Thus, the additives present in rubber greatly influence the result (MAGALHÃES, 2015).

Another issue with the process is that it can be difficult to control how fast the temperature of the rubber can rise, requiring a cooling unit to be used at the end of the process to remove heat and reduce the possibility of material degradation (FORREST, 2014).

The mechanical process is when the rubber is subjected to shearing, also at a temperature above that of the environment, but no chemical agent is used. The lack of chemical agents, in turn, can be considered beneficial in several aspects such as reduced cost, reduced odor, health and safety and the environmental point of view (GONZALEZ; SANTANA, 2012).

As with thermal procedures, mechanical processes can add chemical agents to aid the technique. The mechanical process with chemical reagents uses a substance at temperature and pressure above its critical point (supercritical fluid) that is compatible with the rubber being devulcanized. In this, the rubber expands inside the equipment and facilitates devulcanization, increasing the grinding effect. But, unlike the thermal process that is done in an autoclave, in the mechanical one it is more difficult to keep the fluid in a state of high performance due to leaks and loss of pressure (FORREST, 2014).

It is observed that the density of new crosslinks formed during vulcanization after the mechanical devulcanization process with chemical reagents is higher compared to those that were not dissociated during devulcanization (MAGALHÃES, 2015).

Another procedure is that of micronization, in which the elastomer is crushed and is then called a crumb or granule. The process is done by cutting, shearing, or impacting, or a combination of one or more processes. The environment where micronization is carried out can be moisture, ambient, or cryogenic conditions. When the residue is very large, such as tires, before the grinding or fragmentation step, it must be cut. Fragmentation takes place through knives or other types of cutters such as granulators, rotary cutters, and shredders, generating pieces of rubber with sizes ranging from centimeters to millimeters (MAGALHÃES, 2015).

The granules obtained in the process become suitable due to the purity obtained and their relatively high surface area, being a positive point for the devulcanization process when incorporated with other materials. This material is then used as filler in other polymers and reprocessed with rubber by melting and molding. With this, it is possible to generate products such as impact floors, insulation, asphalt paving and the similar products (THOMPSON, 2015).

The ultrasonic process uses the energy captured by ultrasonic waves to break the crosslinks. 50 kHz of ultrasonic waves are applied for 20 minutes to the vulcanized rubber. But, for devulcanization to occur quickly, the breaking of chemical bonds of sulfur atoms (S-S) causes degradation of the polymer chain, decreasing its molecular weight. However, as a result, the rubber devulcanized by ultrasonic energy has a low density of crosslinks, which makes the material fluid and flexible, allowing its use to be reprocessed and vulcanized again. One of the advantages of this process is the fact that it dispenses with the use of chemical agents, which leads to a lower cost and some health and safety factors do not need to be considered, compared to other procedures (FORREST, 2014; MAGALHÃES, 2015).

The microbiological process utilizes chemolithotrophic bacteria (the term refers to organisms that use organic and inorganic chemical compounds, and light energy as an energy source) in an aqueous medium with the assistance of oxygen to selectively promote the scission of the cross-links of the rubber. The process causes biodegradation, using bacteria such as chemolithiotrope and Thiobacillus for devulcanization. The process takes days and reaches more of the outer layers of rubber, making it difficult to reach the inner layers (MAGALHÃES, 2015).

The cryogenic process requires grinding the rubber after it has been cooled close to its glass transition temperature, at which the rubber becomes rigid. As such, the rubber is subjected to impact and shear forces, and the material does not need to be torn apart, resulting in rubber granules between 30 and 120 mesh. Cooling is done using liquefied gases (nitrogen, nitrogen) or just by air (FORREST, 2014).

Another way to fragment rubber is by using high-pressure water. With this technique, it is possible to produce particles with a size below 200 μm. As with the cryogenic process, this technique has the advantage that cutting removes heat from the rubber which reduces material degradation (FORREST, 2014).

Some of the benefits are there is no limitation on the size of the waste, the technique does not require chemical products, the water used in the process can be recycled by 75%, it does not require a lot of energy or tools as it uses water as an energy source. Another point is that during the process the separation of materials already occurs, making it easier to separate the rubber from other materials that are mixed in it (HOLKA; JARZYNA, 2017).

Another rubber fragmentation process is grinding by Cracker Mill. This machine uses a roller with a corrugated surface rotating to one side and the other rollers rotating in the opposite direction and the rubber enters for grinding through a gap between the rollers. Generally, the material is prepared in a crusher before being submitted to the mill and when leaving this the rubber is sieved to separate the granules by size (FORREST, 2014). This process can cause a lot of degradation generated by the friction of the rubber and the particles that stick together even using a separating agent (FORREST, 2014).

The time control of the particles in post-processing is an important resource to avoid their agglomeration. The product obtained is effective in replacing virgin rubber with new rubber compounds (FORREST, 2014). As a result, an example is the use of tire powder, which in mixtures with thermoplastics, has a wide use. It can be used both technologically and scientifically, as it is possible to produce new materials with elastic properties (COSSA; SIRQUEIRA; SOARES, 2009).

From the previously described processes for recycling rubber waste, Table 1 presents each technology addressed and a brief analysis of the advantages and disadvantages analyzed for each one of them.

2.2. Composite materials

Composites are materials composed of two or more inputs insoluble to each other that, when mixed, form a new material with different characteristics when compared to the elements alone (ASM INTERNATIONAL, 1990; BLACK; KOHSER, 2019). Generally, composites are created to achieve certain properties and can be classified as natural or synthetic.

The constituent elements of composites are known as phases. In this sense, there is the matrix phase, or binder, whose function is to unite and distribute the loads in the reinforcement phase, which is generally responsible for supporting the forces and, in some cases, transmitting heat and electricity. There is also the interface between reinforcement and matrix, which corresponds to the region of contact between the previous components. It is at the interface that residual stresses occur due to thermal expansion, fractures, or delamination (BLACK; KOHSER, 2019).

Alves et al. (2007) point out that polymeric matrix composites and reinforcement with particles from renewable sources have been of great interest. The authors state that there is great potential for the development of materials and

Process	Technology	Analysis
Thermal	Heat-Induced Fragmentation	Advantages: A process that does not require so much technological apparatus; Requires an autoclave. Disadvantages: Takes too long on a large scale
Thermal with chemical reagents	Chemical reactions at high temperatures	Advantages: Better results compared to thermal only. Disadvantages: Need chemical agents.
Mechanical	Fragmentation	Advantages: No need for chemical agents. Disadvantages: Fragments can be more clustered.
Mechanical with chemical reagents	Fragmentation with chemical agents	Advantages: Better results compared to the mechanic without reagents. Disadvantages: Fragments can be more clustered.
Ultrasonic	Use of ultrasonic energy	Advantages: Faster process and the rubber can be vulcanized again. Disadvantages: Very specific equipment.
Microwave	Heating with microwave energy	Advantages: A possible alternative. Disadvantages: It cannot be any rubber, it depends on the polarity of the compounds.
Microbiological	Microorganisms	Advantages: Biodegradable agent. Disadvantages: It is difficulty reaching the inner layers of rubber.
Micronization	Transformation into crumbs	Advantages: The resulting material has a relatively high surface area, suitable for incorporation with other materials. Disadvantages: It takes several steps to reach fragmentation.
Cryogenic	Fragmentation with cooled material	Advantages: They do not cluster as in the mechanical process. Disadvantages: The process is expensive due to the use of cryogenic gas.
By water	Shredding with high-pressure water jets	Advantages: Process water can be recycled, and rubber does not degrade Disadvantages: Uses a natural resource essential to life
Cracker mill	Grinding with a cracker mill	Advantages: Output of a very fragmented material. Disadvantages: Need specific machinery.

Table 01: Waste rubber recycling processes.
Source: Andrezzo (2022, p. 34).

respective products. This can be observed in some works, such as that by Oliveira and D'almeida (2014), in which a composite of resin and tururi fiber (derived from the ubuçu palm) used to manufacture a floor was presented. The authors concluded that the developed material performed well.

Marino et al. (2013) used a resin based on vegetable polyurethane as a matrix for bamboo particles. The authors concluded that the reuse of waste by combining it with this resin is feasible and presents good results, both in terms of the material's mechanical performance and in environmental and economic terms.

Oliveira and Novaes (2016) presented a polymeric

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composite reinforced with malt cereal used to manufacture a guitar body. The authors' evaluations demonstrated that the acoustic behavior of the developed product was excellent.

Rajendran and Nagarajan (2021) studied the effect of adding ash resulting from coal combustion (fly ash), peanut shell powder, jute and banana fibers in a polymeric matrix composite based on castor oil. The authors point out that the proposed materials have better mechanical, flame and weather resistance properties than conventional wood-based building materials.

It is important to point out that composites have been widely used in the reuse of waste from different sources. Silva, Cortat, Orlando and Mulinari (2020) created an expanded composite based on castor oil and tire waste. The authors point out that the addition of rubber particles decreased the resistance to compression, flexion, and water absorption. On the other hand, it increased the impact strength, density and thermal stability of the material compared to pure polymer.

In this sense, studies point to the viability of using waste in the elaboration of polymer matrix composites. The use of a matrix from a renewable or biodegradable source can further favor this aspect, since any material developed will also have a life cycle, eventually being destined for recovery.

3. MATERIAL AND METHODS

For this study, a residue that was already in particulate form was selected, and it was obtained from the cryogenic drumming stage of rubber artifacts generated in the company MicroJuntas Ltda. This choice was made due to its availability for testing without the need for specific grinding equipment.

This residue contains a mixture of several different rubber formulations since several products are subjected to this process and there is no separation. A sample of this residue can be seen in Figure 02.

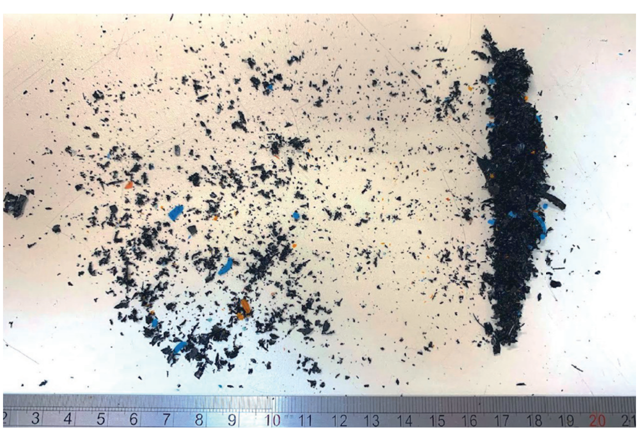

Figure 02: Rubber waste.
Fonte: Andrezzo (2022, p. 42).

Based on reports in the literature, described above, the use of this residue as a reinforcement phase in a polymeric matrix seems to be a valid and promising approach. Also considering sustainability requirements, preference was given to resins from renewable or biodegradable sources. Reports on castor bean-based resin were considered relevant to constitute the composite matrix.

Thus, we opted for resin based on vegetable polyurethane (PUR), Imperveg® AGT 1315 (Figure 03). This PU is a bicomponent, thermoplastic and biodegradable resin based on castor oil. Its preparation is carried out by mixing component A, a prepolymer, and component B, a polyol, to be applied according to the manufacturer, in proportions of 1:1.5. The manufacturer indicates this polymer, among other things, as a matrix in the development of composites (IMPERVEG, 2022).

Figure 03: Resin Imperveg AGT 1315.
Source: adapted from Imperveg (2022).

However, as it was not possible to determine the characteristics of the rubber waste, as it is a mixture, it was necessary to carry out some proportion tests to verify the compatibility between the particles and the resin. Thus, several tests were carried out with different proportions of particles and resin, measured with the aid of a digital scale. Mixing was carried out manually in plastic containers. Table 02 presents the masses of the mixture of components A and B with different masses of rubber waste.

In addition to the different proportions, there was a

Rubber (g)	Comp. A (g)	Comp. B (g)	Total
10	36,0	54,0	100
20	32,0	48,0	100
30	28,0	42,0	100
40	24,0	36,0	100
50	20,0	30,0	100
60	16,0	24,0	100
70	12,0	18,0	100
80	8,0	12,0	100
85	6,0	9,0	100
90	4,0	6,0	100

Table 02: Masses of rubber and resin (A + B).
Source:Adaptado de Andrezzo (2022, p. 47).

preliminary comparison of samples performed with and without the application of pressure. The tests without pressure were carried out in a common plastic mold and allowed to dry at room temperature for 6 hours.

For the pressing tests, an aluminum mold, and clamps (manual pressing) and a hydraulic press were used (Figure 04). As release agents, aerosol silicone, graphite and cellophane with biodegradable detergent were used. The minimum curing time was two hours.

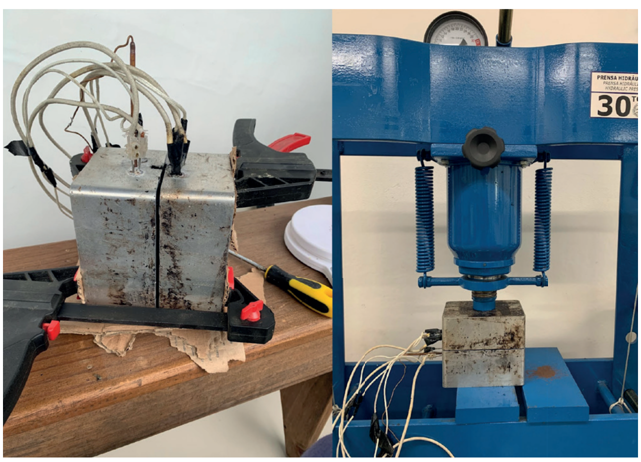

Figure 04: Manual (left) and hydraulic (right) pressing.
Source:Andrezzo (2022, p. 47).

Although mechanical and physical-chemical analyses were carried out, this article only presents preliminary analyses of the material. The relevant aspects at this stage were the appearance, related to the texture, consistency, uniformity, and fragility of the plates. The results of the mechanical and physical-chemical analyses can be consulted in Andrezzo (2022).

4. RESULTS AND DISCUSSION

With the unpressed samples, it was possible to notice that the models with the highest resin concentration formed a block, solid and with a smooth and shiny layer. Samples with less resin and more rubber were more flexible but more fragile. This behavior is mainly visible at the edges, where some rubber particles end up loosening.

Thus, in samples with percentages above 60% of rubber particles, there was not enough adhesion to keep the board cohesive. In Figure 05 it is possible to visualize the samples with their different percentages of resin and rubber particles up to the limit of 60%.

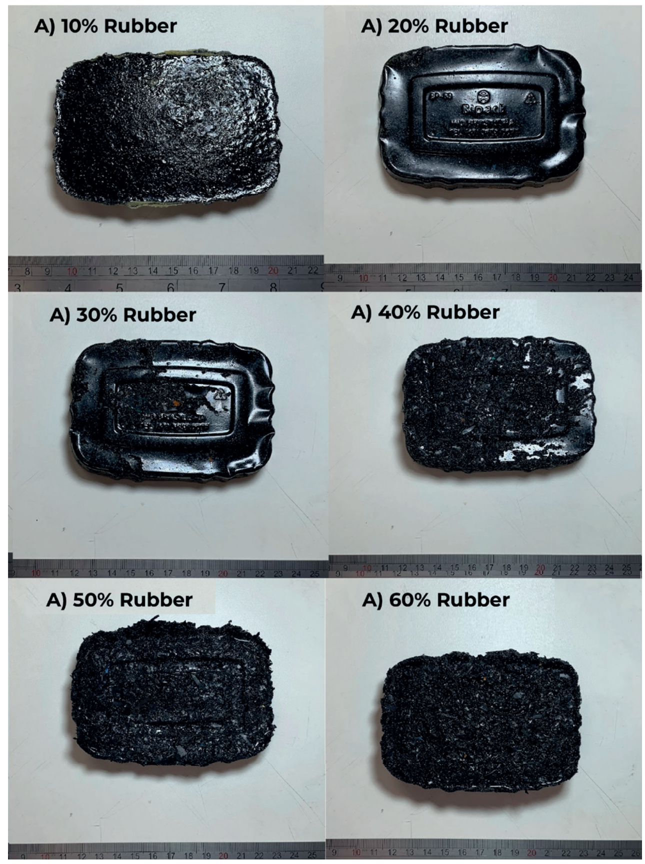

Figure 05: Samples with different percentages without pressure.
Fonte:adapted from Andrezzo (2022, p. 46).

In general, it can be seen from the visual aspect that the increase in the proportion of particles led to a loss of brightness and greater surface roughness. The porosity and flexibility of the sample also increased with increasing particle proportion. However, the fidelity of the shape of the plate to the mold (plastic packaging) decreased.

The samples made with pressing, exhibited a different behavior. Mixtures with higher proportions of resin showed sufficient fluidity to leak at the ends of the matrix, impairing the process. With this, samples with percentages of particles above 60% were made. Figure 06 shows the samples pressed with 60%, 70%, 80% and 90% particulate matter.

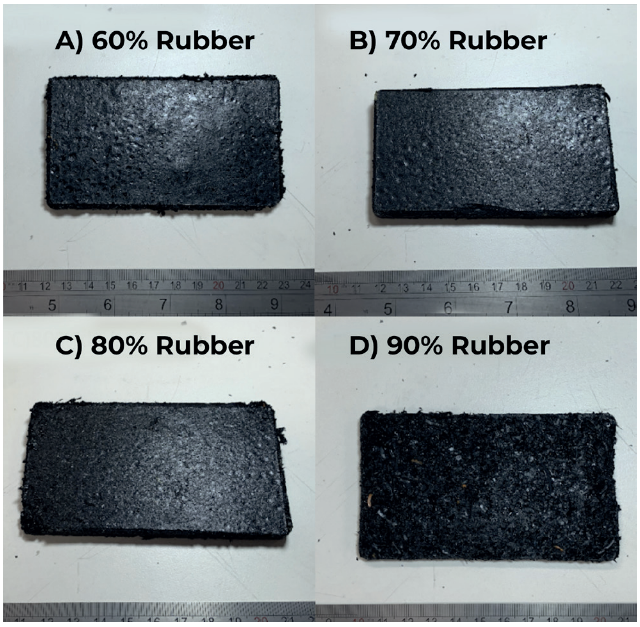

Figure 06: Samples with application of pressure.
Fonte:adapted from Andrezzo (2022, p. 48).

It is understood that applying pressure allowed the resin to flow between the rubber particles and reduced porosity. This resulted in a greater contact area between the particles and better adhesion, even at low resin proportions. As a result, a more solid and uniform material was obtained, even at the ends.

The 60% and 70% samples had very similar behavior, with good flexibility and cohesion. However, in samples above 70%, it was observed that rubber particles came loose at the edges. In this sense, the samples with 70% resin (Figure 07) were the ones that allowed the best use of the residue and resin with a visually solid and compact appearance.

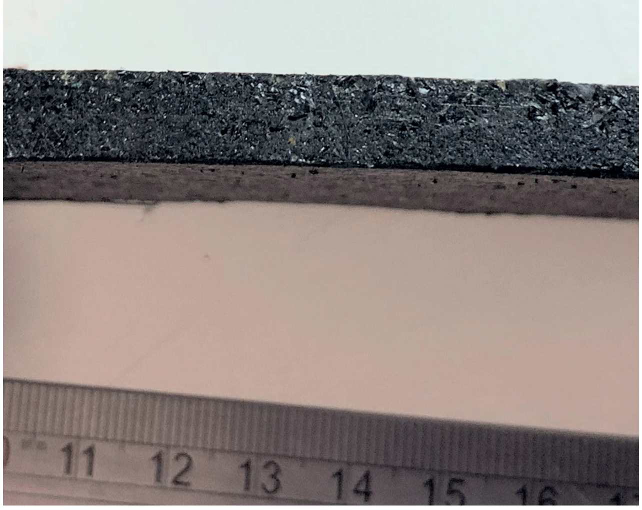

Figure 07: 70% pressed sample.
Source: Andrezzo (2022, p. 50).

It is important to highlight that the samples vary visually according to the composition of the residue. The color is predominantly black but with colored spots depending on which products have gone through the company's process. In this sense, any future developments must consider this feature, exploring it aesthetically. In Figure 8, it is possible to visualize the appearance of some plates produced.

Figure 08: Sample colors.
Source: Andrezzo (2022, p. 50).

The experience of demoulding the samples, especially in the aluminium matrix, was better with cellophane and detergent. In these situations, the demolding happened without difficulties.

5. CONCLUSIONS

This work presents an initiative to reuse rubber waste from a local company. Components manufactured for other industries (gaskets, sealing rings, retainers, hoods, etc.) generate a volume of rubber waste of around 40 tons/month. Although the company sends this waste to an adequate destination according to the legislation, it indicates the demand for reuse in a situation that is less harmful to the environment.

In this sense, structuring the research according to Design Science Research (DRESCH; LACERDA; ANTUNES JÚNIOR, 2015) was essential to provide the scientific basis and structure the research development. This proved to be essential for balancing technical-scientific and practical aspects.

The literature review allowed recognition of the potential of composites in the reuse of different types of materials, both of vegetable and mineral origin. Research on resins has identified that castor bean-based polyurethane resin is very promising for this application since it is of vegetable origin, non-toxic and biodegradable. In this sense, it causes a relatively smaller environmental impact than synthetic resins derived from petroleum.

The development of the material took place in an empirical stage, in which there was the possibility of observing and analyzing the behavior of the different proportions between the particulate material and the resin. It was also possible to analyze aspects of the forming process, by comparing the preparation of samples with or without pressure application.

In general, the proportion of 70% residue with 30% resin provided the best results. This is valid both for the use of residues and resin. The sample exhibited a good combination of strength and flexibility, bringing together two interesting features for product design.

Likewise, it also exhibited adequate texture as well as consistency and uniformity associated with good adhesion between particles. The nature of the waste also conveys a visual aspect that can be explored, since it is predominantly black, but has inclusions of particles of other colors, causing interesting contrasts.

For future developments, the use of this material seems to be suitable for forming processes associated with the application of pressure. Likewise, the possibility of using cellophane and detergent (biodegradable) as release agents is indicated, reducing the need to use industrial chemicals (e.g., silicone products).

It is important to point out that this article presents only an extract of a conclusion work in the professional master's degree in design at the University of Joinville Region – Univille/SC. Mechanical and physicochemical analyses are available in the complete work, as well as must be published separately.

In any case, it is expected that the reports of experiences, limitations and characteristics of the material developed will be useful for future studies of a similar nature. It is also necessary to carry out financial and market analyses, not covered in this study. In addition, the life cycle of the product with the developed compound must be analyzed, since more sustainable uses are sought throughout the value chain.

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NS: conceptualization; data curation; formal analysis; investigation; methodology; supervision; validation; writing – review & editing.
ALMSC: project administration; writing – review & editing.
AO: funding acquisition; investigation; resources; validation.

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