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Functional, Aesthetic and Symbolic Requalification of Polyamide and Elastane Textile Waste: Contributions to Sustainable Design

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Summary

This article explores two possibilities for the functional, aesthetic, and symbolic requalification of synthetic textile waste, specifically composed of polyamide and elastane, through material-based approaches in the fields of design and materials science. Considering the thermoplastic nature of polyamide, the waste was processed by fusion to produce two types of materials: plates made from pure waste and blends with virgin polyamide (PA6), developed in artisanal and semi-industrial contexts, respectively. The resulting materials were characterized in terms of their properties (chemical, thermal, morphological, and mechanical) and compared with materials widely used in product design based on characteristics reported by other authors. Some applications were developed using the material produced in the artisanal context. The results reveal the functional, aesthetic, and symbolic potential of both materials for applications in accessories, informational objects, and utilitarian products. The research contributes to discussions on circularity in design, waste valorization, and experimentation with unconventional materials as a design strategy.

Keywords

Materials, Waste, Textile, Polyamide, Recycling, Blend

Introduction

The fashion industry plays a significant role in the global economy, accounting for approximately 2% of global GDP (Fashion United, 2022). It meets the need for clothing while also serving as a means of individual expression and identity, driving growing, ongoing demand for textile products, as Pattanayak (2025) notes.

It is also among the planet's most polluting sectors (McKinsey & Company 2022; ABIT 2023) and faces significant challenges in aligning its processes with sustainable development principles. It generates large volumes of pre-consumer waste, post-consumer waste, and *dead stock* (Pattanayak 2025; Lee 2025). In Brazil, textile production reached approximately 8 billion pieces in 2021 (IEMI 2022), implying high waste generation.

A substantial portion of this waste consists of fabric scraps. Pattanayak (2025) notes that, during cutting, an average of 15% of the total fabric becomes waste. Among these, synthetic fabrics stand out.

According to Uddin (2025), synthetic fibers are expected to account for 70% (108 million tons) of total production by 2030.

Although classified as non-hazardous solid waste (ABNT 2024), synthetic fabrics and fibers can undergo chemical or biological decomposition and may cause environmental impacts. In addition to not being biodegradable, their degradation, which requires approximately 30–40 years (Uddin 2025), can release microplastics (Pattanayak 2025; Uddin 2025).

Several techniques can requalify this textile waste: reuse, redesign/remanufacturing, recycling, incineration, and landfilling (Lee 2025). Among them, recycling, the reprocessing of materials to produce new ones, is a viable solution that significantly reduces demand for new materials.

Recycling can occur in (a) a closed loop, with the production of a material/product similar or identical to the original, and (b) an open loop, with the production of a different material/product. Three main strategies can be employed for recycling: (a) mechanical recycling, without significant alteration of the chemical structure and with physical changes to the material; (b) chemical recycling, with significant alteration of the material's chemical structure; and (c) energy recycling, with energy recovery through the combustion of materials.

Only 1% of textile waste worldwide is recycled in a closed loop (into new clothing) and 2% in an open loop (into different applications, generally of lower value) (Phan et al. 2023; Lee 2025), since fiber recycling tends to produce lower-quality fibers. Mechanical recycling accounts for 43% of recycling technologies, likely because it is the simplest and most economical method and relies less on chemical reactions. However, it is not suitable for all synthetic polymers, struggles to recycle blended fabrics, and reduces the material's mechanical quality, resulting in downcycling (Pattanayak 2025; Uddin 20025).

Chen (2021) points to mixing new fibers with recycled fibers as a possible solution to balance quality and sustainability. This process produces composites or blends. The use of blends with virgin polymer has been a viable strategy for meeting minimum performance requirements in the mechanical recycling of fabrics (Soomro et al. 2025).

Most fabrics are composed of multiple fiber types, which makes recycling even more complex (Boschmeier et al. 2023; Baloyi et al. 2024; Lee 2025), mainly because separating the fibers is difficult. Fiber identification is also hindered because disposal often mixes all waste together, without indicating composition or separating by type. These factors limit the efficiency of recycling systems.

Segments such as beachwear, fitness apparel, and underwear, which are widely representative in the Brazilian context, rely heavily on blended synthetic fabrics composed of polyamide and elastane (the object of study of this research). Polyamide, a semicrystalline thermoplastic polymer, is recognized for its mechanical performance and versatility, although its processing and recycling present limitations (Lesko 2012; Kula et al. 2012). Elastane, generally composed of 85% segmented polyurethane, is valued for its elasticity but is difficult to reuse because of its hybrid structure (Fangin 2015; Xie et al. 2019).

This scenario demonstrates the requalification of this waste as a strategic opportunity for various fields, such as design, not only as material reuse, but also as functional, aesthetic, and symbolic reconversion. Despite this potential, few studies have focused on valorizing textile waste containing polyamide and elastane. Some pioneering studies, such as those by Brasil et al. (2016) and Wanderley et

al. (2019; 2022), explored artisanal recycling of this waste using household equipment, without adding chemical compounds or pretreatment stages, resulting in rigid plastic panels.

Given this context, this research proposes the requalification of textile waste composed of polyamide and elastane through (a) mechanical recycling via a melting process, (b) in an open loop, (c) the reprocessing of pure waste, and (d) the production of blends with virgin PA6 and textile waste without the use of new materials. It will involve two contexts: (a) artisanal, using household tools and equipment, and (b) semi-industrial, using laboratory equipment.

Therefore, this approach considers the principles of the circular economy, sustainability, and design, addressing three contexts: environmental, economic, and social (Sachs, 2009, 2009; Abramovay, 2012; Xavier; Corrêa, 2013), as well as the three properties of objects: functionality, aesthetics, and symbolism (Löbach, 2001). It also employs some of their guidelines: (a) raw materials with low negative impact (Papanek, 1971; Pessôa, 2016); (b) mono-material (Salcedo, 2014); (c) minimization of resource use (Abramovay, 2012; Pessôa, 2016); (d) waste management policy (generation and reapplication) (Salcedo, 2014; Pessôa, 2016); (e) durable, repairable, recyclable, and adjustable products (Salcedo, 2014; Pessôa, 2016); (f) products with multiple applications and diverse target audiences (Salcedo, 2014; Pessôa, 2016); (g) a flexible, uncomplicated, and replicable production context (artisanal and semi-industrial contexts) (Capra, 2006; Pessôa, 2016); (h) accessible production activities (raw materials, equipment, tools, and processes; acquisition and use) (Sachs, 2009; Xavier; Corrêa, 2013); and (i) production activities with representativeness (raw material and process – aesthetic and symbolic) (Sachs, 2009; Salcedo, 2014).

This research adopts an interdisciplinary approach between design and materials science, using experimental and comparative methods to characterize and analyze potential applications. It follows the guidelines of the National Solid Waste Policy (Brasil 2010) and the United Nations Sustainable Development Goals (SDGs) (UN 2015), particularly SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production). Finally, by proposing new pathways for waste use, it seeks to support more circular, accessible, and sustainable practices.

Materials and Methods

This section describes the materials, characterization techniques, and processes for transforming waste into new materials. The methodological choices integrate materials engineering foundations with exploratory design procedures, enabling an integrated understanding of physicochemical performance and design possibilities. This research is structured into three stages: (1) exploratory study, (2) experimental study, and (3) analytical study. These stages involve: (a) material characterization, (b) material processing, and (c) material applications.

Materials Used

Two main types of materials were employed in this study: (a) virgin polyamide 6, referred to in this study as PA6, and (b) synthetic fabric scraps from industrial waste, referred to as RT. The PA6 was acquired from the company *Thathi Polímeros*, under the reference PA Thathi B300C, presenting the following properties: melting point of 220 °C, density of 1.13 g/cm³ and melt flow index (MFI) of 2.7 ±

0.02 g/10 min. The textile waste (RT) was kindly donated by the company *Confecção Camboriú*, located in Santa Cruz do Capibaribe (PE). This waste consist of two types of fabrics with a predominance of polyamide and variable concentration of elastane, both widely used in the swimwear, underwear and sportswear industry: RT8020: composed of 80% polyamide and 20% elastane, commercially known as thin lycra, referred to in this study by the acronym BF (for "thin base"); and RT8515: composed of 85% polyamide and 15% elastane, known commercially as *lycra lisa*, is referred to in this study by the acronym BL (for "flat base"). The selection of these materials sought to represent typical compositions of fabric residues with potential for reprocessing, considering both their technical properties and their availability in the regional production context.

Characterization of Materials

A comprehensive understanding of the thermal and mechanical properties of the residues and formulated blends was essential to assessing their feasibility in applications in the design field.

Thermal Analysis: The thermal characterization of the materials was conducted through Differential Scanning Calorimetry (DSC) and Thermogravimetry Analysis (TGA), aiming to understand their thermal stability and the main physical transitions involved in fusion processing.

Polymeric materials, such as those studied in this research, can be reprocessed through heating, provided their thermal properties allow this transformation. For this, three fundamental temperatures must be known: the crystallization temperature (Tc), associated with the transition from a liquid to a solid state through the formation of organized structures (crystals); the glass transition temperature (Tg), the point at which the material shifts from a rigid to a more flexible state, with increased molecular mobility; and the melting temperature (Tm), the at which the breaking of the bonds between molecular chains occurs, leading to material fusion. In addition, the percentage of crystallinity was evaluated as an indicator of the molecular organization, a factor directly related to the mechanical and thermal properties of the materials.

Thermal stability, the ability of the material to resist physicochemical changes over time under heating, was evaluated using TGA. This technique allows the beginning of thermal degradation observation, a process in which polymeric chains break down forming residues or by-products. Materials exhibiting higher decomposition temperatures and lower amounts of final residue are considered more thermally stable.

The analyses were conducted under the following experimental conditions: DSC: heating from 20 °C to 300 °C in two stages, followed by cooling to 20 °C; TGA: temperature range from 30 °C to 300 °C, heating rate of 10 °C/min, under nitrogen atmosphere (50 mL/min).

These parameters are fundamental to guiding the reuse of polymeric textile materials through fusion-based mechanical processes, contributing to the appropriate selection of compositions and processing conditions within the context of sustainable material design.

Mechanical Analysis: In an artisanal setting, we produced boards in various thicknesses and ran empirical experiments to understand their physical behavior and workability. We assessed flexibility through manual bending, load-bearing capacity by placing weights on boards supported on sawhorses,

and impact resistance by striking the boards with a hammer. We analyzed molding potential by making holes, cuts, and sanding marks using household tools.

We performed standardized tensile tests on the materials in a semi-industrial setting. Tensile tests provided essential data on the strength and deformability of materials, aspects that are essential to evaluate their suitability for different design applications.

Under stress, solid materials exhibit two distinct behaviors: elastic and plastic (Calister 2011; Lesko 2012). In the elastic phase, the deformation is reversible, whereas in the plastic phase, it becomes permanent. The tensile test, which subjects the material to opposing forces until rupture, enabled the evaluation of ultimate tensile strength, Young modulus, and elongation at break.

Ultimate tensile strength is the maximum stress a material can withstand before rupture. Higher values indicate stronger and, in many cases, more ductile materials. Meanwhile, Young modulus is the ratio of applied stress to elastic deformation in the elastic phase, and it indicates material rigidity: the higher the modulus, the more rigid (and less malleable) the material. On the other hand, elongation at break expresses the total deformation the specimen undergoes until rupture, characterizing ductility. Materials with greater elongation tend to be more ductile and less fragile.

Therefore, the rigidity refers to the ability of a material to resist elastic deformation, in contrast to malleability, which denotes the material capacity to undergo surface deformations. Ductility refers to the ability of a material to deform plastically, by elongation or shaping, without breaking, with fragility as opposite characteristic.

The tensile test was conducted using a 1KN load cell and a speed of 12.5 mm/min, according to ASTM D638, type V. The experimental protocol included prior hydration of the tested specimens in tepid water (approximately 30 °C) for five minutes, followed by tensile testing of the specimens in a universal test equipment, with the speed adjusted between 30 and 50 mm/min.

Processing of Textile Waste

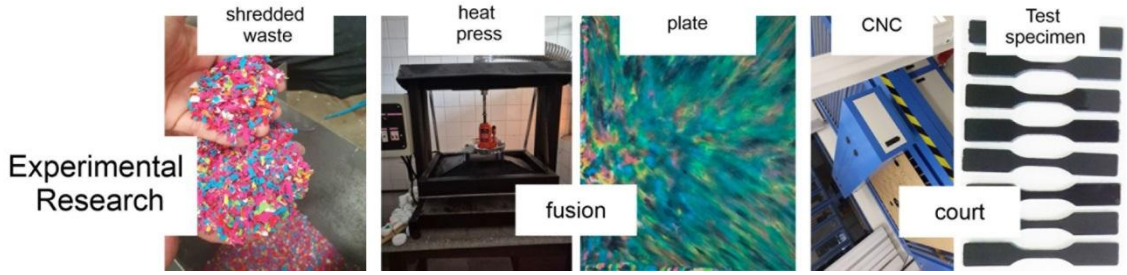
The artisanal processing of textile waste was carried out during the exploratory phase of the research, as shown in Figure 1. The procedure involved grinding the original scraps in a mill, reducing them to fragments approximately 3 to 5 mm long and wide. Then, 200 g of shredded waste were weighed on a digital scale. The material was then evenly distributed on an aluminum foil-covered tray and subjected to melting in a domestic oven, operating at 220 °C for 20 minutes. After heating, the plates formed were cooled to room temperature and removed.

Fig.1 Representation of the artisanal processing of residues



In the experimental stage of the research, the waste was also processed in semi-industrial conditions, as presented in Figure 2. The procedure began with the grinding of the textile scraps following the same approach as the artisanal process, producing fragments of 3 to 5 mm. Subsequently, 200 g of the material were weighed and distributed in a cast-iron mold, previously coated with silicone release agent. The melting process was carried out in a Precious Plastic hot press *at* 220 °C, applied simultaneously to the upper and lower plates for 30 minutes, under constant pressure of 3 tons. Cooling occurred in the switched off press, maintaining the pressure for another 2 hours. Finally, the obtained plates were cut into specimens according to the ASTM D638 standard - type V, using an industrial laser cutting machine.

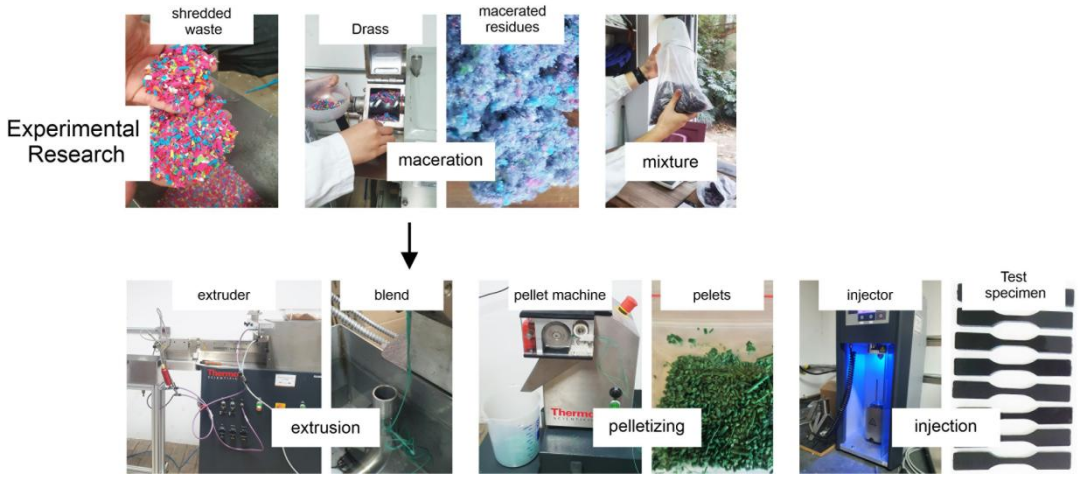
Fig.2 Representation of the semi-industrial processing of residues



Development of PA/RT Polymeric Blends

The processing of blends was carried out during the experimental phase of this research, using virgin polyamide 6 (PA6) pellets as the matrix and recycled textile residues (RTs). The textile residues act both as a physical reinforcement and as modifiers of the mechanical and aesthetic properties of the polymeric matrix. This process comprised five main stages: preparation of base materials, weighing, mixing, fusion, and specimen conformation, as illustrated in Figure 3.

Fig.3 Schematization of the processing of PA/RT blends



Initially, the textile waste was ground in a mill until it reached fragments with approximately 3 to 5 mm in length and width. Then, they were subjected to maceration in a thermokinetic mixing

homogenizer (DRAIS model) for two minutes, operating at minimum and maximum rotations. For moisture removal, both the waste and the PA6 pellets were dried in an oven at 80 °C for eight hours.

After this step, the materials were weighed on a digital scale and manually homogenized in Ziplock plastic bags. Six different compositions were formulated, with an approximate mass of 200 g each, with three different proportions (PA/RT: 60/40, 50/50 and 40/60) for each type of waste (RT8020 and RT8515).

The mixture obtained was processed in a twin-screw extruder. In this process, the materials are introduced through the feed hopper and driven into the cylinder. With the simultaneous action of the electrical resistances and the rotation of the screws, the melting, compression, homogenization, and transport of the material to the head occur (Lima, 2006; Kula et al., 2012). The operating conditions adopted were feed rate of 6%, increasing temperature profile from 220 °C to 250 °C along ten heating zones, average screw rotation speed of 31 rpm, and average pressure of 2.5 bar. The extruded material was subsequently cooled and pelletized in an appropriate granulator.

Finally, the pellets were submitted to the molding process by injection according to ASTM D638 – type V. The material was introduced into the injection molding machine's feeding chamber, melted by electrical resistance means, and injected at high pressure into the metal mold (Kula et al., 2012). Injection conditions included injection temperature of 220 °C, mold temperature of 85 °C, injection pressure of 700 bar, injection time of 10 seconds, driving pressure of 720 bar and settling time of 5 seconds.

Criteria for Material Selection and Identification of Applications

Material selection is a key stage in product development, as the qualifications of materials guide their most suitable applications. According to Ashby and Johnson (2013, p. 5), materials play two overlapping roles in the product: (a) technical functionality, associated with material properties, and (b) personality, related to immaterial attributes. These intangible properties can be classified as: (a) associative, linked to collective or personal contexts; (b) aesthetic, related to visual, tactile and auditory sensations; (c) perceived, which involves the user's reaction; and (d) emotional, which evoke affective sensations.

Lima (2006) proposes five fundamental parameters for the selection of materials: (a) functioning, considering technical performance and exposure to specific conditions of use; (b) use, related to interaction with the user, including ergonomic and symbolic aspects; (c) manufacturing and commercialization, with a focus on production feasibility; (d) ecological aspects, referring to the environmental impact of materials, including their origin and disposal; and (e) compliance with standards and legislation. Complementing these aspects, Baraúna et al. (2015) also highlight metaphysical qualifications – such as market demands, cultural trends, fashion, consumption and reputation – as relevant factors in the decision-making process.

Therefore, to identify possible applications for the materials developed in this research, (a) materials commonly used in design artifacts and (b) specific objects themselves were related to (c) the materials developed in this study. Based on a literature review, some reference materials were selected and characterized, including: (a) glass, (b) cellulose acetate, (c) wood, (d) iron, (e) aluminium, (f) polyethylene, (g) polypropylene, (h) acrylic, (i) ABS, (j) PVC, and (l) polyamide 6 itself. Fundamental

requirements for some applications (objects) were also identified: (a) accessories (necklace, earring, bracelet, and ring), (b) glasses, (c) handbag, (d) suitcase, (e) baskets/pitchers/trash cans, (f) trays, (g) shelves, (h) chair/stools, and (i) tables.

. These references were then compared with the materials developed in this research: (a) reprocessed pure textile waste and (b) blends of polyamide 6 (PA6) with textile waste containing polyamide and elastane, in different proportions. Finally, we identified applications for the materials developed in this research. Some of these applications were produced (specifically in the artisanal context) and critically analyzed.

The materials were characterized for technical properties, including tensile strength, stiffness (Young's modulus), elasticity (elongation at break), resistance to moisture and UV radiation, thermal conductivity, among others. For the objects, the focus was on basic functionality and their physical requirements. The study then linked these two groups of information to the materials developed in the research. The objective was to assess the potential of recycled materials for use in design artifacts within the context of the circular economy and the revalorization of textile waste.

Exploratory Study: Processing Potential of Textile Waste

Characterization of Pure Polyamide and Textile Waste

Thermal analyses allowed the identification of the main physical transitions and thermal stability of textile waste (RTs), fundamental to evaluate their feasibility in melt-based thermal recycling processes. The results obtained through Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA) are presented in Tables 1 and 2, respectively.

Table 1 Thermal transition and crystallinity properties of textile waste (RTs)

Specimen	Tg (°C	TM (°C)	Crystallinity (%)
Polyamide 6 (PA6)	*68*	185/220	35
RT8020	60	219/226	20
RT8515	68	210 / 220 / 223	17

Thermal analysis made the identification of the main transitions of the materials possible, which are fundamental for their application in requalification processes by melting. Melting temperatures (Tm) close to 220 °C indicate that both materials can be safely processed in this temperature range. However, the difference in glass transition temperatures (Tg) reveals that each residue acquires greater flexibility in distinct ranges, which may influence its tactile response and malleability in specific uses. The low crystallinity points to less ordered structures, facilitating conformation in artisanal and semi-industrial contexts.

Table 2 Thermal stability and degradation residues of textile waste (RTs)

Sample	To (°C)	Tpeak (°C)	Tf (°C	Δm (%)	Residue (%)
Polyamide 6 (PA6)	412	474	450	97	2
RT8020	396	443	468	95	5

RT8515	401	450	467	92	4

The materials presented high thermal resistance, starting the degradation process only above 390 °C. This allows them to be heated and reprocessed at significantly lower temperatures, without compromising their integrity. The low amount of residue after burning (4-5%) confirms the predominance of polymeric components, with no relevant presence of mineral fillers. These data reinforce the suitability of RTs for experiments based on thermal transformation in the context of material design, with the potential to generate surfaces or products with new aesthetic and functional meanings.

Processing of Textile Waste

Artisanal processing of textile waste produced plastic plates. They are characterized by: (a) a smooth texture on one side (the side in direct contact with the mold) and a heterogeneous texture (the side not in direct contact with the mold), (b) darkening, but without color mixing, and (c) internal porosity. The images in Figure 4 illustrate the visual aspect, textures, and imperfections resulting from the artisanal processing methodology: (a) the original textile waste, (b) the plate obtained after the melting process, and (c) the internal bubbles visible in cutting.

Fig.4 Stages and results of the artisanal processing of textile waste. (a) shredded textile waste; (b) plate formed by thermal fusion in a domestic oven; (c) detail of the air bubbles generated during the process, visible in the inner section of the plate

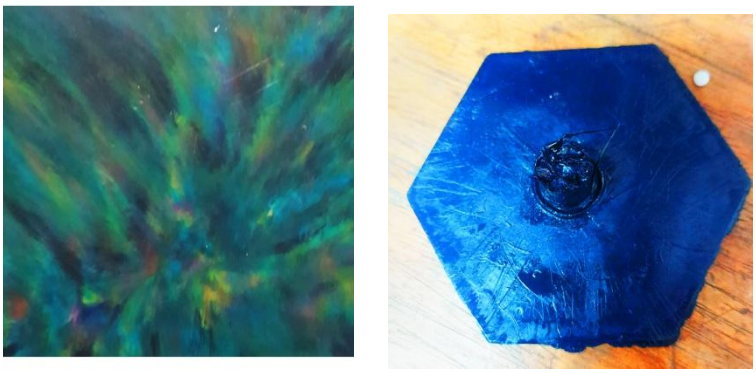


Images created by the researchers themselves

They can also be processed using semi-industrial equipment (hot press, extruder, or injection molding machine) to produce plastic sheets, extrudates, and molded products, respectively (Figure 5). While extrusion and injection molding with RTs are possible, these processes are complex and difficult to replicate consistently because RTs tend to clog the equipment.

The plastic sheets produced by the hot press exhibit: (a) a smooth texture on both sides, (b) darkened colors with a tendency to blend, and (c) little to no internal porosity (Figure 5a). The extrudate and the injection-molded object (Figures 5b) have a homogeneous appearance with a single blended color, a smooth texture, and solid compaction and shaping , but their processing is not yet efficient or scalable

Fig.5 Results of processing the RTs in the press, extruder, and injection molding machine, respectively



(a) (b)

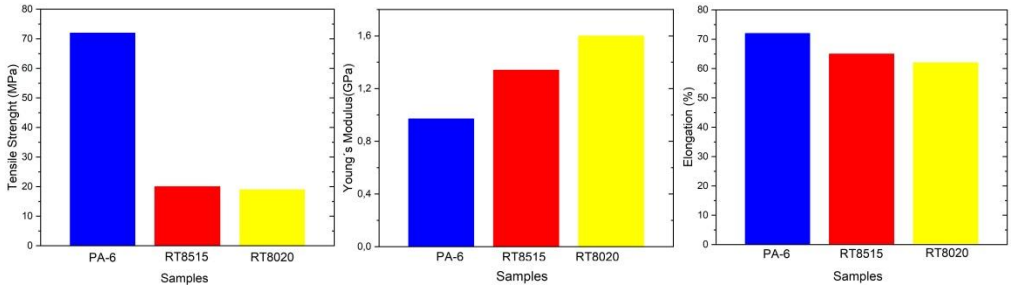
Images created by the researchers themselves

Mechanical Characterizations of Pure Polyamide and Textile Waste

Empirical tests: The tests indicated that the thinner plates presented greater flexibility, while the thicker plates provided greater structural stability. Regardless of thickness, all plates demonstrated good impact resistance and allowed for subsequent mechanical manipulation. These experiments offered valuable insights to evaluate the potential use of the material, especially in design contexts in which visual, tactile and symbolic qualities intersect with rigorous technical performance.

Standardized tensile test: The tensile tests compared the mechanical performance of PA6, recycled textile waste (RTs). The data presented in Figures 6 include maximum tensile force, Young modulus, and elongation at break.

Fig.6 Mechanical properties of RT8020 and RT8515 textile waste compared to polyamide PA6: (a) tensile strength, (b) Young modulus, and (c) elongation at break



(a) (b) (c)

Figure 6 shows that RTs show significantly lower tensile strength than PA6, reaching only about a quarter of the strength of the virgin polymer. Despite this, the RTs showed greater rigidity, evidenced by the higher Young modulus, which decreases as the proportion of PA6 increases. The elongation at break was also lower in RTs, indicating lower ductility compared to PA6. Therefore, the residues have

lower strength and ductility in relation to PA6, but greater rigidity, which may indicate specific applications in contexts that require greater dimensional stability.

Experimental Study: Processing Potential of Blends

Thermal Characterization of PA/RT Blends

Thermal analysis of the blends revealed two endothermic peaks in all samples, indicating multiple melting events. The average melting temperature (Tm) remained around 220 °C, reinforcing the feasibility of thermal processing under conditions like those of pure materials.

The glass transition temperatures (Tg) of the blends were similar to each other, but significantly different from the Tg of PA6, evidencing the impact of incorporating textile residues on the structural properties of the material. A trend of increasing crystallinity was also observed among the blends, although the presence of elastane, especially in the BL samples, led to higher thermal transition temperatures and a reduced crystallinity, suggesting a direct influence on the organization of polymer chains.

Table 3 presents the data from the thermogravimetric analysis (TGA), indicating the initial (To), final (Tf) and maximum (Tpeak) degradation temperatures, as well as the mass variation (Δm) and the percentage of residue after degradation.

Table 3 Thermal parameters of PA6 blends with textile waste (RTs)

Specimen	To (°C)	Tpeak (°C)	Tf (°C	Δm (%)	Residue (%)
Polyamide (PA6)	412	474	450	97	2
BF6040	411	474	465	98	2
BF5050	325 / 413	489	456	95	1
BF4060	373 / 425	461	461	94	1
BL6040	404	447	466	91	4
BL5050	419	478	449 / 455	90	1
BL4060	409	479	456 / 458	90	2

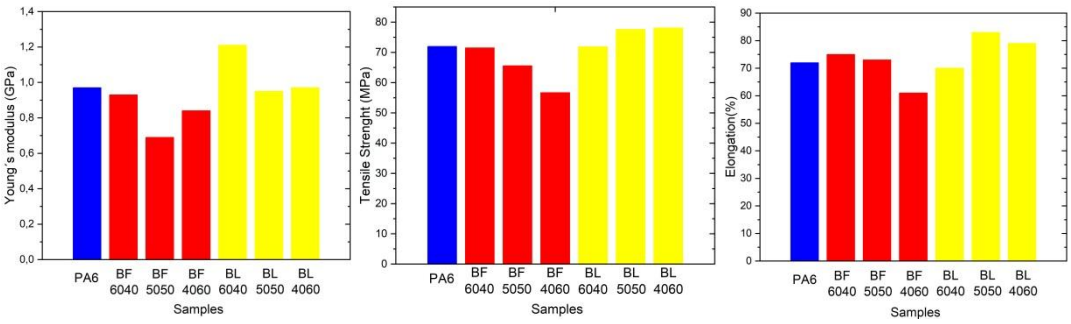
The degradation temperatures of blends generally ranged from 400 °C to 489 °C, which indicates sufficient thermal stability for thermal transformation processes applied on an artisanal or semi-industrial scale. Most blends showed higher Tpeak values than pure PA6, reflecting changes in thermal stability induced by the incorporation of residues. Moreover, the BL and BF blends in the 60:40 ratio showed lower To and Tf compared to PA6, but with higher Tpeak, suggesting a complex and possibly biphasic degradative behavior.

The mass variation (Δm) in the BF blends was similar to that of PA6, whereas BLs blends showed greater losses. The final residue remained low in all formulations, except for the BL6040 blend, whose higher residual value indicates the possible presence of less volatile components or partial carbonization. Overall, the TGA analysis shows that blends can be safely reprocessed under controlled thermal conditions, which expands their application possibilities in the field of sustainable materials design.

Mechanical Characterizations of Pure Polyamide and Textile Waste

The data presented in Figures 7 include maximum tensile force, Young modulus, and elongation at break.

Fig.7 Mechanical properties of PA6 blends with RT8020 (BF) and RT8515 (BL) textile waste: (a) tensile strength, (b) Young modulus, and (c) elongation at break



(a) (b) (c)

In Figure 7, the results of the blends reveal distinct behaviors between the formulations with RT8020 (BFs) and with RT8515 (BLs). In BFs, the traction force decreases as the proportion of waste increases, confirming the loss of strength with the increase of the recycled material. In BLs, there is a gain in resistance, with values that exceed or equal those of PA6. This suggests a possible synergy between PA6 and RT8515 in this type of formulation. LFs show gradual loss of strength and rigidity with increasing residue content. BLs, on the other hand, demonstrate gains in strength and, in some cases, ductility, indicating potential for use in products that require higher mechanical performance combined with waste reuse.

Young modulus varies among specimens. BL6040 stands out as the most rigid in relation to PA6, while BFs and BL5050 showed lower rigidity, indicating greater malleability, a characteristic that may be desirable in applications that require flexibility.

Regarding the elongation at break, the BFs maintain similar values to or slightly higher than those of the PA6, except in the formulation with higher residue content, which presents a sharp decrease. BLs exhibit nonlinear behavior, with BL5050 showing a significant gain in ductility. These results indicate that the mechanical properties of recycled materials and blends can be adjusted according to the proportion and type of textile waste used, opening possibilities for different applications in product design.

Analytical Study: Indication of Possible Applications in Design

One of the actions of design is artifact development (ideation, design, and materialization), whose characteristics and performance are directly related to the properties of the raw materials used. Therefore, selecting these raw materials is fundamental to the object's functional, aesthetic, and symbolic effectiveness.

Characterization and Comparison of the Materials

Based on several authors (Titow 1984; Barra, 2000; Lima 2006; Le Bourhis, 2007; Ashby & Johnson 2011; Kula & Ternaux 2012; Lesko 2012; Ashby 2013; Nurul et al. 2013; Baraúna et al. 2015; Gu et al. 2015; Metu et al. 2016; Khatri et al. 2018; Rynkowska et al. 2018; Melo Júnior et al. 2019; Calister and Rethwisch, 2020; Mezzomo and Moraes, 2020; Silva and Gemelli, 2020; Nation Glass; Wimolmala et al. 2021; Guzzi et al. 2023; Giang et al. 2024; O'Driscoll et al. 2024), Tables 4, 5, and 6 present a synthesis of some technical properties of traditional materials used in design, as well as of the textile waste (RTs) and the blends developed in this research.

Table 4. Properties of certain metals (iron and aluminum) and ceramic materials (glass)

Properties / Materials	**Iron**	**Aluminium**	**Glass**
Tensile strength (MPa)	250-500	310	30-90
Young´s modulus (GPa)	210	69	50-90
Elongation at break (%)	7.3	10	0.2
Moisture sensitivity	resistant	resistant	sensitive
UV sensitivity	resistant	resistant	sensitive
Thermal conductor	good	good	poor
Chemically resistance	Moderate	Good	Good
Impact resistance	High	Good	Low
Scratch and stain resistance	Good	Moderate	Good
Compression resistance	Good	Good	Good
Flexural resistance	Good	Good	Low
Biologic resistance	Good	Good	Good
Recyclability	Good	Good	Good

Table 5. Properties of certain synthetic (PE, PP, Acrylic, ABS, PVC e PA)

Properties / Materials	**PE**	**PP**	**Acrylic**	**ABS**	**PVC**	**PA**
Tensile strength (MPa)	20-40	34	65	30	40-60	72
Young´s modulus (GPa)	0.2-1	0,1	3	1,1	3.4	0,97
Elongation at break (%)	600	7,5	2,4	1.5-100	80	72
Moisture sensitivity	resistant	resistant	sensitive	resistant	resistant	sensitive
UV sensitivity	sensitive	sensitive	sensitive	sensitive	sensitive	sensitive
Thermal conductor	Good	poor	poor	poor	poor	poor
Chemically resistance	Good	Good	Moderate	Moderate	Good	Good
Impact resistance	High	Good	Moderate	High	Variable	Good/alta
Scratch and stain resistance	Low	Low – Moderate	Low – Moderate	Low	Good	Good
Compression	Moderate	Moderate	Good	Good	Good	Good

resistance						
Flexural resistance	Good	Good	Moderate	Good	Good	Good
Biologic resistance	High	High	High	High	High	Good
Recyclability	High	High	Limited	Limited	Limited	Good

Table 6. Properties of certain natural materials (Cellulose acetate and Wood)

Properties / Materials	**Cellulose acetate**	**Wood**
Tensile strength (MPa)	5	40-100
Young´s modulus (GPa)	1.2	5-10
Elongation at break (%)	50	4
Moisture sensitivity	sensitive	sensitive
UV sensitivity	sensitive	resistant
Thermal conductor	poor	good
Chemically resistance	sensitive	variable
Impact resistance	moderate	good
Scratch and stain resistance	low - moderate	variable
Compression resistance	good	good
Flexural resistance	moderate	good
Biologic resistance	moderate	variable
Recyclability	limited	limited
Other properties	renewable resource	renewable resource

Both the RTs and the blends exhibit lower tensile strength than iron, approximately 92% to 96% lower and 69% to 89% lower, respectively. They also show significantly lower stiffness, approximately 99% lower than iron. In contrast, they exhibit considerably higher deformation capacities (RTs: 749% to 790% higher; blends: 736% to 1,037% higher) than iron. In addition, iron and PA6 (and probably the RTs and blends) are generally considered mechanically resistant in impact, compression, and flexural resistance, while PA6 tends to be more resistant to chemical agents.

The tensile strengths of the RTs and blends are significantly lower than those of aluminium, approximately 94% lower for the RTs and 75% to 82% lower for the blends. They also exhibit considerably lower stiffness, approximately 98% lower for the RTs and 98% to 99% lower for the blends. In contrast, they show much higher deformation capacity (RTs: 520% to 550%; blends: 510% to 730%) than aluminum. In addition, aluminum and PA6 (and probably the RTs and blends) show significant mechanical resistance, with aluminum being more susceptible to surface damage (scratches and stains).

The RTs exhibit lower tensile strength than glass, with values approximately 33% to 79% lower. The blends, in turn, exhibit tensile strength within the glass range, toward the upper end. Both the RTs and the blends exhibit considerably lower stiffness than glass, approximately 97% to 99% and 98% to 99% lower, respectively. In contrast, both exhibit much higher deformation capacities than glass. Unlike PA6 (and probably the RTs and blends), glass does not exhibit impact or flexural resistance, but it is resistant to chemical and biological agents, compression, and surface alterations (scratches and stains).

Pure RTs exhibit lower tensile strength than wood, while the blends fall within the range reported for wood. Wood is considerably stiffer and deforms much less before rupture than the RTs and blends. Wood benefits from being a renewable resource and is resistant to UV radiation, although it is susceptible to moisture and fungal and bacterial attack, unlike polyamide (and probably the RTs and blends).

The RTs exhibit significantly higher tensile strength than cellulose acetate (280% to 300% higher), greater stiffness (12% to 33% higher), and greater deformation capacity before rupture (24% to 30% higher). The blends also exhibit considerably higher tensile strength and greater deformation capacity before rupture (22% to 66% higher). Regarding stiffness, the blends show values close to or lower than cellulose acetate, ranging from about 43% below to 1% above. Cellulose acetate and PA6 (and probably the RTs and blends) share good compression resistance and sensitivity to moisture and UV radiation, but differ in that PA6 (and probably the RTs and blends) exhibits greater chemical and biological resistance, impact and flexural resistance, and, particularly, recyclability (although complex).

The blends exhibit higher tensile strength than PE, exceeding the upper limit of the reported PE range by approximately 42% to 95%. Regarding stiffness, the blends partially overlap PE values, although some compositions reach higher values. The RTs, in turn, show tensile strength near the lower end of the PE range but greater stiffness. However, PE is considerably more ductile than both materials. PE and PA6 (and probably the RTs and blends) are generally considered mechanically resistant materials, but they differ mainly in PE's low resistance to surface alterations (scratches and stains).

The blends exhibit higher tensile strength than PP, ranging from approximately 67% to 130% above that material. They also exhibit considerably greater stiffness, ranging from 590% to 1,110% higher. The blends exhibit much greater ductility/deformability than PP. The RTs, in turn, have tensile strength approximately 41% to 44% lower than PP. However, the RTs are considerably stiffer and exhibit approximately 727% to 767% greater deformation capacity/ductility than PP. Regarding the other characteristics, PP and PA6 (and probably the RTs and blends) are described as mechanically resistant, with PP being less resistant to surface alterations (scratches and stains).

The RTs exhibit tensile strength approximately 69% to 71% lower than that of acrylic. The blends, in turn, show values close to or higher than acrylic, ranging from about 13% below to 20% above. Acrylic is considerably stiffer, approximately 88% to 124% stiffer than the RTs and 148% to 335% stiffer than the blends. In contrast, it shows much lower ductility/deformability, about 96% lower than the RTs and 96% to 97% lower than the blends. All the materials are impact resistant. Acrylic is less mechanically resistant than PA6 (and probably than the RTs and blends) and, in particular, has limited recyclability.

The RTs exhibit tensile strength approximately 33% to 37% lower than that of ABS, but are 22% to 45% stiffer. The blends, in turn, exhibit tensile strength approximately 89% to 160% higher than ABS and stiffness values close to ABS, ranging from approximately 37% below to 10% above. The ductility/deformability of the RTs and blends falls within the upper range reported for ABS, although it does not exceed its maximum value. ABS and PA6 (and probably the RTs and blends) are described as impact resistant. ABS, however, is indicated as being sensitive to abrasion and having limited recyclability, unlike PA6 (and probably the RTs and blends).

The RTs exhibit tensile strength approximately 50% to 68% lower, stiffness 53% to 61% lower, and ductility approximately 19% to 23% lower than the range reported for PVC. The blends exhibit tensile strength ranging from the upper end of the PVC range to values above it (30%) and ductile behavior close to PVC, ranging from 61% to 83%, compared with 80% for PVC. They also exhibit stiffness approximately 64% to 80% lower than that of PVC. PVC and PA6 (and probably the RTs and blends) are indicated as mechanically and chemically resistant, although PVC has limited recyclability.

The blends very significantly exceed the tensile strength of the pure textile waste. Some blends (BL5050 and BL4060) show tensile performance and elongation capacity superior to PA6.

The pure textile waste (RTs) shows low tensile strength compared with most materials analyzed, with values near the lower end of the polyethylene (PE) range and only slightly higher than cellulose acetate. In terms of stiffness, RTs show higher values than PE, PP, ABS, PA6, and cellulose acetate, but significantly lower than wood, glass, iron, aluminum, acrylic, and PVC. In terms of deformation capacity, the RTs show high elongation values, lower than PE, PVC, and PA6, but higher than PP, acrylic, cellulose acetate, wood, glass, iron, and aluminum.

The blends, in turn, exhibit higher tensile strength than the RTs, with performance comparable to that of PA6 and within the ranges observed for wood and glass. Regarding stiffness, they show values close to PA6, ABS, and cellulose acetate, but are considerably less stiff than acrylic, PVC, wood, glass, aluminum, and iron. Regarding deformation capacity, the blends exhibit high elongation values, significantly higher than those of PP, acrylic, cellulose acetate, wood, glass, iron, and aluminum and, depending on the composition, close to or higher than those of PA6 and PVC, but much lower than those of PE.

Based on the characterization and comparison performed, the RTs and blends exhibit mechanical behavior considerably different from that of iron and aluminum, particularly in terms of tensile strength, stiffness, and deformation capacity before rupture, consequently indicating different fields of application when these properties constitute determining requirements. In contrast, the RTs and blends tend to share certain mechanical behavior characteristics with materials such as PP, PE, PVC, and wood, although at different performance levels, indicating potential for applications in similar categories of artifacts, provided that the specific requirements of each product are met. For cellulose acetate, acrylic, and, to a lesser extent, ABS, relevant differences were observed in the analyzed mechanical properties, making a more in-depth assessment of performance requirements necessary to determine the feasibility of replacing these materials with RTs or blends in artifact manufacturing.

Application Experimentation

Based on various authors (MATWEB 2026; ANSYS 2026; Calister Jr. and Rethwisch 2018; Ashby 2016; Ashby and Johnson 2014; Lesko 2012) and technical standards (ABNT NBR 13962, NBR 13966, NBR 14006, NBR 14488, NBR 14564, NBR 14776, and ISO 7170, ISO 7173, ISO 12870, and ISO 19682), Table 7 presents (a) the main requirements for the selected products.

Table 7. Requirements of Selected Artifacts and Some of Their Raw Materials

Artifacts	Requirements
Accessories	Low weight; resistance to tension and bending; resistance to moisture and UV radiation; durability; good surface finish; possibility of coloring and forming.
Eyeglasses	Low weight; stiffness; resistance to bending, tension, impact, and fatigue; dimensional stability; resistance to moisture and UV radiation; scratch resistance; comfort; transparency when applicable.
Bags	Low weight; flexibility; high elongation; resistance to tension, tearing, bending, and abrasion; resistance to moisture and UV radiation; durability; resistance to microorganisms; ease of forming/sewing.
Suitcase	Low weight; stiffness; toughness; resistance to impact, compression, bending, and abrasion; resistance to moisture and UV radiation; dimensional stability; durability.
Baskets / pitchers / trash collector	Low weight; stiffness; resistance to bending, compression, and impact; resistance to moisture; resistance to chemicals and microorganisms; ease of cleaning.
Trays	Low weight; stiffness; resistance to bending, compression, and impact; dimensional stability; resistance to moisture; low thermal conductivity when necessary; ease of cleaning; resistance to microorganisms; thermal resistance depending on the application.
Shelves	High stiffness (Young's modulus); resistance to bending and compression; dimensional stability; low deformation/creep under load; resistance to moisture depending on the environment; wear resistance and durability.
Chair/stools	Low weight; high structural rigidity; resistance to bending, compression, impact, and fatigue; controlled deformability; stability; durability; moisture and UV resistance suited to the environment.
Table	High stiffness; resistance to bending, compression, and impact; dimensional stability; resistance to moisture and wear; surface hardness; scratch resistance; durability; ease of cleaning.

Pure waste, due to its low apparent density (large volume but low mass) and the empty spaces between particles, should be processed in an artisanal context or by hot pressing, since the equipment requires simple feeding into a large space and does not require the transport of material through its interior. Objects without highly strict and controlled requirements, and with significant aesthetic appeal, are indicated as applications.

Blends, because they involve combining materials, require greater control over material properties, and need greater mixture homogenization, are better suited to semi-industrial processing, where equipment supports the execution and management of these stages. Because their production

processes and results are more complex, their application is recommended for products with more controlled and proven requirements (such as mechanical properties), greater uniformity among parts, and production at scale.

Accessories, due to their versatile forms and lack of high mechanical requirements, are better suited to production from pure waste in thin plates (up to 0.5 mm), either in an artisanal context or by pressing. This base material is lightweight, easy to form, has a good surface finish, and offers basic tensile and flexural resistance. Figure 8 presents two necklaces produced with pure waste by artisanal processing and by pressing, respectively, and cut using a CNC machine.

Fig.8 Necklaces produced with pure waste by artisanal processing and pressing, respectively



Images created by the researchers themselves

Bags that require dimensional stability and basic flexural resistance can be produced from thin or medium-thickness plates (depending on the bag type) using pure waste, either in the artisanal context or by pressing, as well as using pressed and extruded blends. These base materials are lightweight and have low to moderate mechanical resistance, durability, and ease of forming and shaping. Figure 9 shows one bag produced with pure waste in the artisanal context.

Fig.9 Bag produced with pure waste in the artisanal context



Images created by the researchers themselves

Trays, plates, and other artifacts with the function of holding and transporting, due to their need for dimensional stability and flexural resistance, can be produced from medium-thickness plates (around 1 cm) using pressed or injection-molded blends (higher cost and a more complex production process) and, particularly, pressed pure waste (lower cost and a less complex production process). These plates are characterized by low weight, moderate stiffness, ease of forming, and moderate mechanical resistance.

Shelves, tabletops, chair and stool backrests, and seats, because they require dimensional stability and high mechanical resistance (such as flexural, abrasion, and compression resistance), are best produced from medium to thick plates (from 2 cm) using pressed pure waste or pressed or extruded blends. These plates are characterized by mechanical, chemical, and biological resistance, moisture resistance, and ease of forming and shaping. Figure 10 presents a shelf, a tabletop, a chair seat, and stool seats produced with pure waste and cut using a household machine. None of these artifacts were produced using the blends.

Fig.10 Shelf, tabletop, and stool seats produced with pure waste



Images created by the researchers themselves

Other applications can be indicated based on the mechanical, thermal, aesthetic, and symbolic characteristics of the materials. In an artisanal context, pure waste can be used for decorative objects because of its considerable versatility. Pure waste and blends pressed into thin- to medium-thickness plates can be applied to signage artifacts, as they are lightweight, have basic mechanical resistance, are easy to manipulate (particularly for cutting and recessing), and allow simple fastening. None of these artifacts were produced using these materials.

Eyeglasses, which mainly require moderate mechanical resistance, dimensional stability, and tactile comfort, can be made from pressed pure waste or blends. The pressed plates have basic stiffness, easy formability, and sufficient tensile and flexural resistance. The blends are easy to form and have good mechanical resistance. Both, due to their tactile homogeneity and light weight, provide comfort. Eyeglass production using these materials has not yet been tested, but their feasibility in both production and commercial contexts is evident.

Suitcases, given their need for moderate to high mechanical resistance and moderate dimensional stability, can be produced using extruded and/or injection-molded blends. These blends are homogeneous and easy to form, with high mechanical resistance (tensile, flexural, compression, and abrasion resistance). Although suitcases using these blends have not yet been produced, their feasibility in production and commercial contexts is already evident.

Conclusions

This research presented strategies for requalifying synthetic textile waste composed of polyamide 6 and elastane, both in its pure form and in blends, through mechanical recycling via melting in an open-loop context. The applicability of each material varied according to its properties and the use requirements of different design artifacts.

The waste and blends exhibited structural and thermal behavior similar to polyamide 6, with a melting temperature of about 220 °C. The waste was more brittle, stiffer, and less deformable than PA6. The blends showed higher tensile strength, lower stiffness, and high deformation capacity, approaching or, in some compositions, exceeding PA6 performance.

RT85/15 exhibited the best performance in its pure form, with greater thermal and mechanical stability, lower mass variation, lower final residue, and greater elastic and plastic deformation capacity. The blends combine higher tensile strength with lower stiffness and high deformation capacity, offering more balanced behavior for certain applications.

Incorporating virgin PA6 substantially improves the tensile performance of the waste. This increase in strength does not necessarily result in increased stiffness, since the blends are relatively less stiff (lower Young's moduli). The presence of the waste does not necessarily imply a loss of performance compared with the virgin raw material, since incorporating the waste into PA6 did not reduce the matrix properties, with tensile strength and deformation capacity equivalent to or greater than those of pure PA6.

The results also indicate that no simple linear relationship exists between the amount of virgin PA6 and mechanical performance. Possible influencing factors include: (a) waste/PA6 ratio, (b) processing conditions, (c) distribution, (d) interaction between the phases, among others. A more

homogeneous distribution, favorable interaction between the materials, and a waste/PA6 ratio that favors stress transfer may improve tensile strength.

The artisanal context is recommended for processing pure waste because it is accessible (lower cost, simpler process, and lower production capacity). Semi-industrial processing, using an extruder and injection molding machine, proved more suitable for the blends because it is more complex, mainly due to the waste's low density and the difficulty of transporting it internally through the equipment. The press, in turn, was effective for both material types.

The pure waste proved more suitable for accessories, decorative artifacts, and communication products because of its light weight, ease of forming, and aesthetic appeal. The blends, in turn, demonstrated mechanical strength and versatility, making them suitable for household utensils and furniture.

The proposed requalification of synthetic textile waste proved technically feasible, economically interesting, socially significant, and culturally representative. It was aligned with the principles of sustainability: (a) use of residual or recycled raw material (pre-consumer synthetic textile waste); (b) minimization of the use of new materials/chemical elements (only virgin PA6, which is already present in the waste); (c) minimization of resource use (only electrical energy); (d) generation of waste, but with its reapplication as raw material (reprocessing of the waste within the same activity); (e) raw material representative of the locality (production activities of the local fashion cluster); (f) accessible tools and equipment in the artisanal context (household equipment: easy to obtain and use, and low cost); (g) material (result) with a tendency toward unique pieces; (h) material (result) with multiple applications (in an open loop), for diverse target audiences, with its own aesthetics and symbolism; (i) recyclable, adjustable, repairable, and durable material (result) (reprocessable for up to seven cycles, according to [reference]); (j) flexible production context (artisanal and semi-industrial contexts); and (l) an uncomplicated and replicable process (mechanical recycling and melting: easy to understand and perform).

Declarations

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Data Availability All data gathered or analysed during this study are included in this published article.

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CLSL analyzed the data. RGW drafted the initial version of the text. CRM reviewed the manuscript. RGW edited the manuscript. All authors approved the final version of the article

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