GREEN TRANSITION: RESEARCH AND MANUFACTURE OF COMPOSITES FROM INDUSTRIAL GARMENT SCRAPS USING VIBRATION MOLDING PRINCIPLE

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ABSTRACT

The green transition, aimed at minimizing negative environmental impacts, is a prevailing social trend. The garment and fashion industry currently contributes 20% to global pollution. This study seeks solutions for recycling garment waste into useful materials instead of burning it or sending it to landfills. The study used a vibratory molding engine to combine scrap fabrics with two different substrates (polyester resin at ratios of 19.2%, 23.8% and 31.6% or construction cement at ratios of 9.3%, 12.5% and 15.7%). The experiment produced solid materials with ductile or brittle properties at these ratios. Material samples of different shapes and sizes were tested for tensile and compressive strength. The study noted that the implementation costs and technical specifications varied depending on the type and ratio of the substrate. This is the first step in recycling textile scraps into useful materials, supporting garment manufacturers in reducing landfill waste. Further research is needed to clarify the applicability of these materials in daily life to replace traditional materials such as wood, bricks and plastics. Additionally, the economic aspects of recycling scrap fabric need to be further considered in subsequent studies.

Keywords: Green transition, scrap fabric, composite fabrics, vibration molding.

1. INTRODUCTION

Currently, the garment and fashion industry contributes to 20% of global pollution, generating at least 90 million tons of waste, of which 87% is incinerated or landfilled, and only a small proportion (1%) is recycled into new clothing. Waste is categorized into two types: pre-consumer textile waste, which comes from manufacturing processes and includes scrap fabric, and post-consumer textile waste, which consists of unused or discarded clothing from consumers. This situation underscores the urgent need for sustainable practices in the fashion industry to mitigate environmental impact [1-3].

The fibres used to make clothing are 68% fossil fuels, contributing to the depletion of non-renewable resources and increasing CO_2 emissions into the atmosphere. This makes the textile industry the second largest source of environmental pollution globally, after the oil industry. Textile products consumed in the EU generate 121 million tons of greenhouse gas emissions, equivalent to 270 kg of CO_2 per person. According to Boston Consulting Group (BCG), based on The Global Fashion Market (2022-2028) and Statista research, the global fast fashion industry market is expected to surpass the 250-billion-euro mark by 2028. With a rapid growth of about 3.8% annually, the fast fashion industry has caused consequences in this industry [4-6].

To address the current global textile waste pollution problem, the European Commission proposed in early July 2023 to implement a waste management scheme that would require textile manufacturers in the region to pay a waste management fee [7]. These proposals aim to make manufacturers responsible for covering the costs of managing and treating textile waste. This would incentivize them to reduce waste and implement circularity in textile production.

On the other hand, consumers in Vietnam's key export markets are increasingly concerned about environmental protection. Without a clear transition strategy, textile enterprises risk losing orders to competitors who prioritize sustainable development. [8].

Therefore, the solution of recycling scrap fabric right at the factory could be one of the essential research directions that may contribute a small part to the green transition of the Vietnamese textile and garment industry.

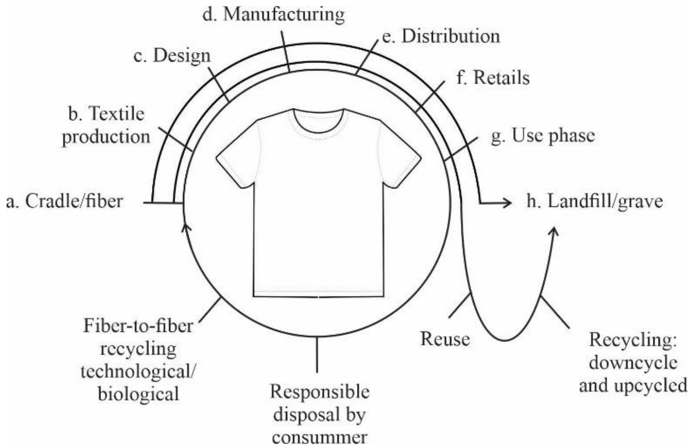

Figure 1. Sustainable elements in apparel manufacture
(Adapted from S. Radhakrishnan (2015) - Fashion industry and sustainability [9])

According to S. Radhakrishnan [9], the life cycle of materials and products in the garment-fashion industry in a sustainable production system or green production is depicted in Figure 1, starting from the source of raw materials (a) through the textile processing process (b) to create sheet materials; with the research and design of sheet fabrics and other types of bonding materials into garments (c), the mass production of these products forms a textile production process chain (d) to distribute products to consumers through retail channels (e, f, g), and finally the products after use are disposed of in landfills (h). Reusing waste from the production process of the garment, fashion and consumer industries to create new products for daily life is very necessary. According to the diagram above, the larger the recycling rate (reuse, upcycle, downcycle), the smaller the amount of waste going to landfills.

With the above idea, this study chose the downcycle option, using a combination of binder materials with fabric and clothing scraps to create a new product line with relatively good tensile and compressive strength, they can be used to replace wood, bricks, plastic, etc. serving in civil life with long-term use but when discharged into the outside environment still does not cause pollution.

2. RESEARCH MODEL AND METHOD

2.1 Fabric composite molding model using vibration method

Rags or old clothes are made from many different types of fibrous materials. According to a report by the Lenzing Group in 2015 [4], they include 62.1% petroleum-based synthetic fibers such as polyester, 25.2% cellulose fibers and protein-based fibers, 6.4% wood-based cellulose fibers, 1.2% wool fibers and 1.5% other natural fibres. Some woven, knitted, and non-woven structures decompose over time, yet they retain mechanical properties like tensile strength and abrasion resistance. Based on these characteristics, to create a solid product with a suitable shape from these scraps, it is necessary to make a mixture with a chemical bond between the binder and the fabric at room temperature. The raw materials mixture self-solidifies into a product and can be used in daily life.

Therefore, one of the main contents of the study is to select the bonding components in the mixture and carry out the mixing, determining the process of forming the final product. To do this, it is necessary to design and manufacture a shaping device or vibration molding tool with a dynamic diagram, as shown in Figure 2.

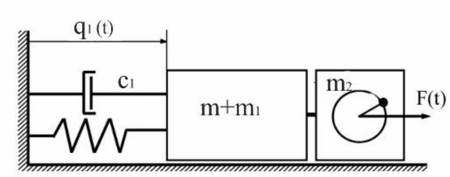

Figure 2. Model of a one-degree-of-freedom vibratory molding tool

where:

$q_1(t)$ is the coordinate of movement of the mold and the vibration motor;

m - mass of molded material;

m_1 - mass of the mold;

m_2 - mass of the vibration motor;

k_1 - spring stiffness between the support and the vibration mold;

c_1 - viscous damping coefficient of the system;

F(t) - vibration force.

Specialized vibration motors are available on the market in many different types, but here we choose a single-phase AC motor with a capacity of 0.25 kW, 220 V. If we call the centrifugal force caused by the 2 eccentric blocks mounted on the motor, they have a value proportional to the square of the rotation speed n and according to the motor's instruction manual when n = 2840 rpm then $F_0 = 0.98$ kN. Therefore, F(t) has the form of a harmonic function in the horizontal direction of the system:

$$F(t) = F_0 \cos\omega t, \quad (1)$$

in which $\omega = \frac{2\pi n}{60} = 297.4 \ rad/s$ - frequency of vibration; t is calculated in seconds.

According to document [10], the vibration motion of the mold is $q_1(t)$ which has the form of a harmonic function with the same frequency as the vibration motor but has an amplitude according to the formula:

$$A_1 = \frac{F_0}{\sqrt{[(k_1 - (m + m_1 + m_2)\omega^2)^2 + c_1^2\omega^2]}}, \quad (2)$$

With the above single-degree-of-freedom vibrating molding tool experimental model, it can be seen that it is easy to manufacture and suitable for initial experiments. Equation (2) allows choosing the stiffness of the spring so that the system oscillates at the resonant frequency or the oscillation amplitude value A_1 is the largest or

$$k_1 = (m + m_1 + m_2)\omega^2, \quad (3)$$

During the molding process, m changes from the mold without material (m = 0) until the mold is filled ($m = m_{max}$), however, the mass of the mold m_1 and the vibration motor m_2 are relatively large compared to the mass m of the molding material. Therefore, the k_1 value will be selected approximately according to formula (3). Specifically, with the motor rotation speed of 2840 rpm and the system design for 3 different molds, the stiffness value k_1 of the spring is selected according to Table 1.

Table 1. The stiffness value k_1 of the spring in the vibratory molding tool is selected according to the mass of the mold

Mold type	Dynamic parameters of vibratory molding tool			
	$(m_1 + m_2)$ [kg]	m_{max} [kg]	min k_1 [N/mm]	max k_1 [N/mm]
Compressed cube	9.35	2.35	827	1035
Hexagonal tiles	11.80	3.10	1044	1318
Pull sample bar	12.50	1.50	1106	1238

The total mass of the mould (m_1) and mass of the vibration motor (m_2) of the compressed cube, hexagonal tiles and pull sample bar are 9.35 kg, 11.8 kg and 12.5 kg, respectively corresponding to the average mass of the mould when filled with a casting mixture (m_{max}) of 2.35 kg, 3.1 kg and 1.5 kg.

The hardness of springs on the market are usually selected within the range of min k1 and max k1 values of Table 1. In this study, we used springs with hardness k = 1100 N/mm, when installed in the vibrating tool, the system operates very effectively, and the vibration process easily removes air bubbles in the casting mixture.

2.2 Fabric composite composition and product properties

In today's competitive market, garment enterprises must meet green production standards alongside economic and social criteria. This study focuses on recycling waste generated during the production process. Scraps fabric from the cutting table need to be processed into reusable products, which are expected to become sustainable materials that are harmless to living organisms and do not require burning or burial. A molding tool is developed to combine the scraps with a binder. The vibration molding process removes all air bubbles from the mixture, creating a tight and uniform bond between the components. Under normal temperature conditions, these components bond through a catalyst or chemical reaction, forming a solid material with either brittle or flexible mechanical properties.

2.2.1. Mixture of scraps and binder poured into mold

To obtain a solid product with flexible mechanical properties, the commonly used binders for scrap are thermosetting synthetic polymer solutions (thermoset molding) such as Epoxy, Urea-formaldehyde, Unsaturated Polyester (UPE), Phenol formaldehyde (PF), Melamine Formaldehyde, etc. In terms of cost and technological capability, UPE was chosen to be used in this study. The binder mixing formula is described in Table 2 below after the testing process:

Table 2. Binder base mixing formula

Chemical type	Mixing mass for 1 kg of substrate [g]
Unsaturated Polyester Resin 8201	800
$CaCO_3$ stone powder	150
TiO_2 powder	45
Methyl Ethyl Ketone Peroxide (MEKPO)	4
Pigment color	1

To obtain a solid product with brittle mechanical properties, the most economical binder with scraps and suitable for the vibration molding technology of the project is cement used in construction.

2.2.2. Shape and size of molds in testing mechanical properties of composite products

To evaluate the usability of fabric composite products after curing, in this study, two types of molds were made for tensile testing (for flexible products – the matrix material is thermosetting plastic) and for compression testing (for brittle products - the matrix material is cement).

For tensile testing, the mold creates sample bars with dimensions of 300 × 70 × 36 mm, which are then machined to the final shape according to Vietnamese standard TCVN 197-2000 [11], resulting in a gauge length of 200 mm and a width of 60 mm, as shown in Figure 3. For compression testing, the mold produces cubic specimens measuring 100 x 100 x 100 mm in accordance with Vietnamese standards TCVN 3118:2022 [12].

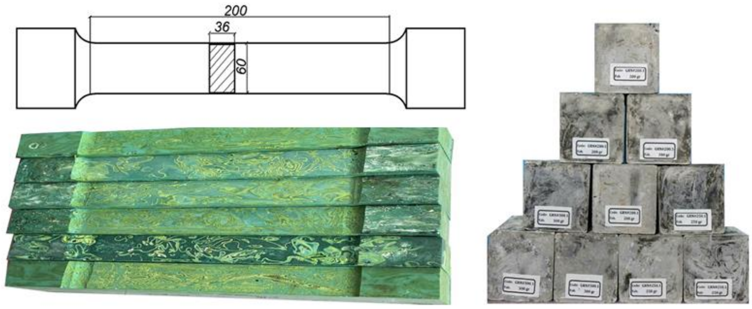

Figure 3. Shape and size of product sample prepared for tensile and compression tests

3. EXPERIMENTAL RESULTS AND DISCUSSION

The objective of the study is to propose a solution to transform all scrap fabric on the cutting table of a ready-made garment enterprise into products that do not harm the environment in the future, but the cost of the above processing is at the lowest possible level. This requires the proportion of scrap fabric components in the fabric composite mixture to be as high as possible. In addition, the mechanical, chemical and physical properties of the molded product can be usefully used in some cases in human life. Therefore, the experimental model is to determine the mechanical properties (tensile strength, compressive strength, specific gravity), and physical properties of each sample, corresponding to the proportion of mixed components and the cost of raw materials for each unit mass of molded products.

3.1. Experimental results

For convenience in the process of experimental molding on the manufacturing tool, for each size of each molding sample, the scrap fabric component in the mixture will be prepared by pre-weighing with a certain mass of 200g, 250g and 300g, so when converted to the scrap/binder ratio in practice, it will be the odd numbers below.

Therefore, for each type of binder base material, the vibratory forming tool will produce structures of the dimensions specified above and with scrap content ratios of 19.2%, 23.8% and 31.6% for tensile test specimens or ratios of 9.3%, 12.5% and 15.7% for compression test specimens. The finished molded products are stored for 30 days before being put into the testing machine. The tensile and compression machine used for testing here is the "Servo Hydraulic Universal Testing Machine - SHT4106". Table 3 shows the results of receiving technical and economic data of the plastic molded product and Table 4 shows the brittle molded product.

Table 3. Properties of plastic molded products (Scrap fabric - Unsaturated polyester solution)

Mixing scheme	Scrap/Binder Ratio	Tensile strength [Mpa]	Specific gravity [g/cm^3]	Price of raw materials used for 1 kg of scrap fabric [VND]
1	19.2%	26.4	1.29	156,000
2	23.8%	18.3	1.23	126,000
3	31.6%	12.6	1.15	95,000

Table 4. Properties of brittle molded products (Scrap fabric - Construction cement)

Mixing scheme	Scrap/Binder Ratio	Compressive Strength [MPa]	Specific gravity [g/cm^3]	Price of raw materials used for 1 kg of scrap fabric [VND]
1	9.3%	8.25	1.77	19,400
2	12.5%	7.10	1.69	14,400
3	15.7%	5.70	1.63	11,500

3.2. Compare economic, technical and application indicators of the product

At compressive strength greater than 5 Mpa or tensile strength greater than 10 Mpa, it is possible to calculate the design of household products used in daily life with certain durability, satisfying the criteria for the problem of processing scrap on the study's fabric cutting table.

The experimental results obtained in Tables 3 and 4 are the technical and economic parameters of the solution to create composite scrap fabric by vibration molding method, allowing the following preliminary comments:

- For plastic materials, within the acceptable mechanical value, the Scrap/Binder ratio increases, the tensile strength decreases and the cost of producing a unit of product decreases.

- For brittle materials, also under the condition of reaching the acceptable mechanical value, the compressive strength as well as the cost of producing a unit of product are inversely proportional to the Scrap/Binder ratio.

- The tensile material of composite scrap fabric from UPE substrate can contain up to 30% of the scraps, but the processing cost for 1 kg of fabric is quite expensive (from 100,000 to 150,000 VND), so it is necessary to design the structure of the final product to have a fairly high use value, such as fine art casting products, decorative items, display materials, etc.

- The compressive material of composite scrap fabric from construction cement can contain 15% of the scraps with a relatively cheap processing (10 times lower than the above solution), however, the product created is relatively rough, suitable for outdoor structures such as paving bricks, ornamental flower pots, anti-erosion structures, foundation materials, etc.

- In this study, the device applying the vibratory molding method is relatively simple, making it accessible for small garment businesses. The research proposes a feasible solution for repurposing scrap fabric into useful materials.

4. CONCLUSIONS

Through research on vibratory molding tools and material testing from scrap fabric, we have developed sustainable production equipment for flexible or brittle recycled materials. This study presents a solution to prevent landfill waste by recycling scrap fabric into practical products instead of burning them or sending them to landfills, paving the way for a greener garment industry. In this study, construction cement or UPE binder was combined with scraps fabric to create materials. However, other binders such as epoxy can also be tested.

Further studies can be conducted to clarify the applicability of these materials in life, including furniture (such as beams and home decorations) and construction (bricks), etc., replacing traditional materials like wood, bricks, and plastics. Additionally, the economic aspects of recycling scrap fabric also need further consideration.

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TÓM TẮT

CHUYỂN ĐỔI XANH: NGHIÊN CỨU TẠO COMPOSITE TỪ VẢI VỤN CỦA NGÀNH MAY CÔNG NGHIỆP THEO NGUYÊN LÝ ĐÚC RUNG

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Chuyển đổi xanh, nhằm mục đích giảm thiểu tác động tiêu cực đến môi trường, hiện đang là xu hướng xã hội. Ngành may mặc và thời trang hiện đang đóng góp 20% vào ô nhiễm toàn cầu. Nghiên cứu này tìm kiếm các giải pháp tái chế chất thải may mặc thành vật liệu hữu ích thay vì đốt hoặc đưa chúng đến bãi chôn lấp. Nghiên cứu đã sử dụng động cơ đúc rung để kết hợp vải vụn với hai chất nền khác nhau (nhựa polyester theo tỷ lệ 19,2%, 23,8% và 31,6% hoặc xi măng xây dựng theo tỷ lệ 9,3%, 12,5% và 15,7%). Với các tỷ lệ này, thí nghiệm đã tạo ra vật liệu rắn có đặc tính dẻo hoặc giòn. Các mẫu vật liệu thu được có hình dạng và kích thước khác nhau đã được thử nghiệm về độ bền kéo và độ bền nén. Kết quả nghiên cứu ghi nhận rằng chi phí thực hiện và thông số kỹ thuật của các vật liệu thu được thay đổi tùy thuộc vào loại và tỷ lệ của chất nền. Đây là bước đầu tiên trong việc tái chế phế liệu dệt may thành vật liệu hữu ích, hỗ trợ các nhà sản xuất hàng may mặc trong việc giảm chất thải chôn lấp. Cần nghiên cứu thêm để làm rõ khả năng ứng dụng của những vật liệu này trong cuộc sống hàng ngày để thay thế các vật liệu truyền thống như gỗ, gạch và nhựa. Ngoài ra, các khía cạnh kinh tế của việc tái chế vải vụn cần được xem xét thêm trong các nghiên cứu tiếp theo.

Từ khóa: Chuyển đổi xanh, phế liệu may mặc, composite vải, đúc rung.