*Science & Technology Development Journal – Engineering and Technology 2024, 6(SI3):11-17*

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**Research article**

# Reuse of human hair waste in the manufacture of composites and assessment of composition effects on mechanical properties

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**ABSTRACT**

Human hair is a common waste material that is found in most parts of the world. Especially, the large amount of human hair accumulation in the waste stream clogs drainage systems causing many environmental problems such as attracting molds and pests, releasing unpleasant odors, slowing drainages, and so on. For waste disposal, human hair can be burned, however, the burning process produces lots of hair dust, foul odors, and toxic gases into the environment affecting human health and life. As one of the solutions to the circular economy, human hair waste has been collected and reused in many fields such as fiber-reinforcing parts in composite materials, adsorbent materials for oil spill cleanup, organic fertilizers for plants, and so on. With focus on producing an efficiency method that offers significant benefits of reusing of waste, the human hair/epoxy composite was fabricated using the hot press technique in this research. Due to the support of the pressing process, the reused human hair waste composition in the composite material was increased compared with the common methods such as hand lay-up and casting techniques. Besides that, the impacts of human hair waste and $CaCO_3$ filler loading on the mechanical properties like tensile strength and flexural strength of the human hair/epoxy composite material were also analyzed for application purposes. As a result, the fabricated composite panel with the ratio of human hair/epoxy at 50/50 added 100 phr of $CaCO_3$ filler introduced the optimal tensile strength, tensile modulus, flexural strength, and flexural modulus at 15.8 MPa, 2.1 GPa, 52.7 MPa, and 7.5 GPa, respectively. The obtained results show the compatibility of the fabricated human hair/epoxy samples compared with the other research which satisfied the requirements for composite applications.

**Key words:** circular economy, composite panel, hair waste

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**History**

- Received: 29-8-2023
- Accepted: 27-12-2023
- Published Online: 31-3-2024

**DOI :**

**https://doi.org/10.32508/stdjet.v6iSI3.1128**



## INTRODUCTION

Nowadays, the environment has been more polluted due to the increasing proportion of domestic and production wastes. Originally, the main source of pollution was caused by untreated wastes which have been produced in municipal, industrial, and agricultural areas. One of the environmental pollutants that can be mentioned is human hair which is found mostly in waste streams. Human hair accumulates and clogs the drainage system due to its slow decomposition [1]. The trapped water causes eutrophication leading to the decay of organic matter which produces odor gases and breeding grounds for pathogens. Currently, burning is the fastest method to decompose human hair waste. However, human hair produces hair dust, foul odors, and toxic gases such as ammonia, carbonyl sulfide, hydrogen sulfide, sulfur dioxide, phenols, nitriles, and so on during the burning process [2]. The other common way of treating hair waste is the burying/landfilling method, even so, dumping hair waste has still caused pollution and health problems. Therefore, the requirement to develop an efficient treatment method for hair waste has been progressively concentrated. As one of the solutions to the circular economy, the reuse of hair waste assists in solving the pollution problem and creating the economy. In some countries, human hair is sold on a large scale for hair wigs to make a fashion statement or hair pads to soak up oil spills [3]. Recently, some experiments on horticultural plants have shown that human hair provides the necessary nutrients for plants because it includes high nitrogen-containing organic substances as well as sulfur, carbon, and so on [4]. However, the manufacturing processes produce hair dust and waste chemicals causing pollution and legal conflicts. Regarding the environment and sustainability, green materials have been focused on through the advancements of bio-materials. Human hair is greatly recognized as an enormous eco-friendly resource in the field of green materials. In this point of view, the human hair indicates high tensile strength at 200 MPa and tensile modulus at 1.74-4.39 GPa which indicates the ability to apply in composite materials [5]. At present, there are a lot of researchers and scientists who have fabricated the composite from epoxy and human hair and

**Cite this article :** Phu P Q, Ngoc N L B, Tham H H, Y T N. **Reuse of human hair waste in the manufacture of composites and assessment of composition effects on mechanical properties**. *Sci. Tech. Dev. J. – Engineering and Technology* 2024; 6(SI3):11-17.

indicated the positive effects such as high tensile and flexural strengths at 15.0 MPa and 25.1 MPa, respectively[6–9]. However, small contents of hair waste (under 25%) have been reused due to the disadvantages of hand lay-up and casting techniques. To build on the efficiency method for recycling more human hair waste, the hot press process was applied in fabricating the hair/epoxy composite in this research.

# MATERIALS AND METHODS

## Materials

Commercial epoxy resin (SM.828, epoxy equivalent weight g/eq (EEW): 184-194) and amine base curing agent (6217C, amine hydrogen equivalent weight g/eq (AHEW): 95) were purchased from Minh Thanh chemical joint stock company, Vietnam. $CaCO_3$ powder (MC-15, purity: > 98.0%, density: 2.7 g/cm$^3$) was bought from Michem Viet Nam joint stock company, Vietnam. Human hair was collected at hair salons in Ho Chi Minh City, Vietnam and then was cut to a length of about 5 mm.

## Procedures

At first, two parts of commercial epoxy and curing agent were mixed with a weight ratio of 7/3. After that, human hair and $CaCO_3$ filler were dispersed into the prepared epoxy resin in the mixing mortar at room temperature for 30 minutes. The compositions of the compounds were prepared with the contents in part per hundred of resin (phr) as represented in Table 1. After the mixing process, the collected mixtures (around 200 g each) were spread into the mold to get a thickness of about 5 mm and then cured at a temperature of 120°C for 30 minutes under a pressure of 50 kgf to form the composite panels. The fabricated samples were stored at room temperature for 72 hours before measuring.

## Methods

The mechanical properties of the fabricated samples were tested using a Testometric M350-10CT machine at the rate of 2.0 mm/min. The samples were prepared with the dimensions 145 x 10 x 5 mm for applying the tensile test following the ASTM D638 standard. For the flexural test, the samples were prepared with the dimensions 80 x 25 x 5 mm and measured using the ASTM D790. Besides that, the morphology of the crack surface of the sample from the tensile test was analyzed by Optika Microscope Italy device equipped with Optikam B0.5 digital camera.

# RESULTS AND DISCUSSION

## Effect of $CaCO_3$ filler content on mechanical properties

In this research, the effects of the filler addition on the mechanical properties of the prepared composite samples were studied. The samples were fabricated with various $CaCO_3$ contents from 0 to 150 phr when the human hair contents were fixed at 100 phr. As can be seen in Figure 1, both tensile and flexural tests indicated a consistent increase in mechanical properties following the increase in the $CaCO_3$ content from 0 phr to 100 phr. It was found that the tensile strength and tensile modulus of the composite respectively increased to 15.8 MPa and 2.1 GPa with the addition of 100 phr $CaCO_3$ filler. Similarly, the addition of 100 phr $CaCO_3$ filler also leads to an increase in the flexural strength and flexural modulus of the 100H-100C sample. Due to the hot press process, the 100H-0C sample indicated the porous formation in the composite structure which affected its mechanical properties. By adding the $CaCO_3$, the porous in the composite can be reduced leading to the improvement of both tensile and flexural results. However, the 100H-150C sample presented a strong reduction of mechanical properties when the $CaCO_3$ filler content reached 150 phr. Especially, the tensile strength, flexural strength, and flexural modulus of the 100H-150C sample indicated the lowest value. Originally, the resin should cover all the filler, however, the 100H-150C sample indicated the overuse of the $CaCO_3$ filler causing poor mechanical properties.

To understand more about the interaction between the composite compositions, the cracked surfaces of the tested samples were observed using the optical microscope device. As can be seen in Figure 2, the 100H-0C samples indicated the remained epoxy resin on the surfaces of the human hairs which indicates that the epoxy resin is strongly adsorbed on human hair surfaces and might be forming the bonding with the amide, amine, and amino acid groups of human hair[10]. The broken epoxy resin stick on the human hair surface might indicate the interaction strength between the matrix with reinforcement is higher than the matrix strength. However, the 100H-150C sample represented the appearance of some smooth hair surfaces which is observed in Figure 2d. This can be explained that the epoxy resin was adsorbed by the $CaCO_3$ filler and there is a lack of resin to cover the human hair due to the increase of the filler contents. Based on this result, the optimal $CaCO_3$ filler content will be 100 phr which represents high mechanical properties.

**Table 1: Composition of the composite sample**

| Sample* | Epoxy (phr) | Curing agent (phr) | Human hair (phr) | $CaCO_3$ (phr) |
|---|---|---|---|---|
| 100H-0C | 70 | 30 | 100 | 0 |
| 100H-50C | 70 | 30 | 100 | 50 |
| 100H-100C | 70 | 30 | 100 | 100 |
| 100H-150C | 70 | 30 | 100 | 150 |
| 50H-100C | 70 | 30 | 50 | 100 |
| 150H-100C | 70 | 30 | 150 | 100 |

* In the table, the samples were named with the number referring to the element composition and the letter H and C referring to human hair and $CaCO_3$ filler, respectively.

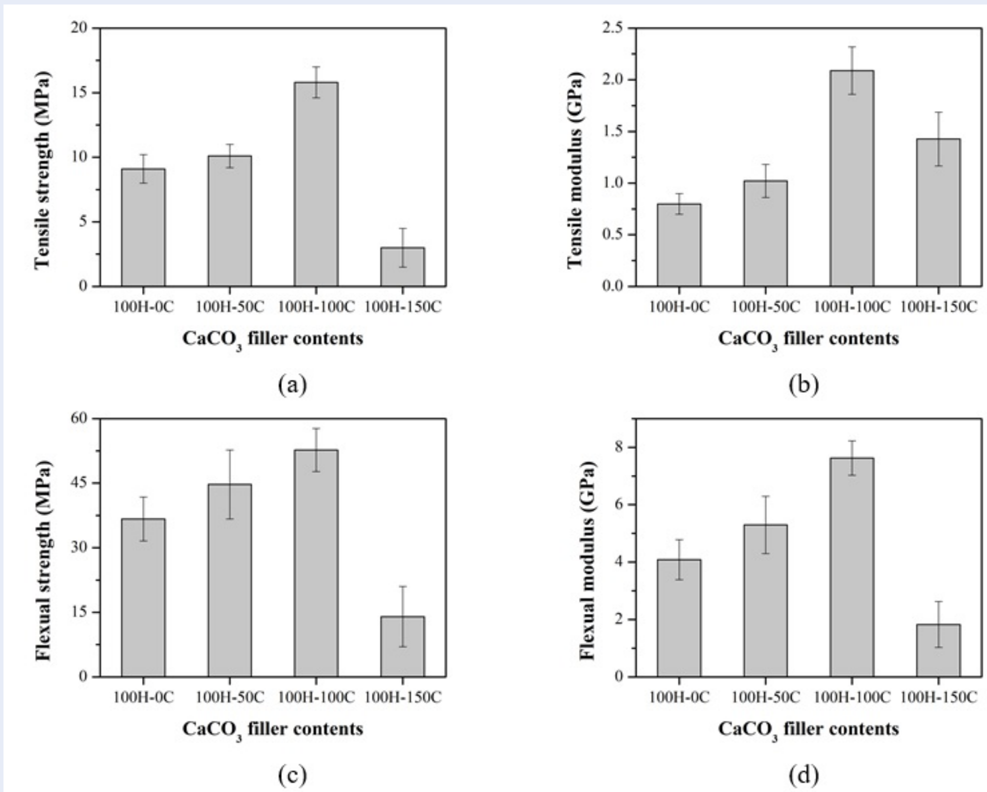


**Figure 1**: Tensile strength (a), tensile modulus (b), flexural strength (c), and flexural modulus (d) of the samples with different $CaCO_3$ filler contents

## Effect of human hair content on mechanical properties

The mechanical properties of the composite are mainly determined by the composition of the human hair, $CaCO_3$ filler, and epoxy resin. In order to determine the influence of human hair on the mechanical properties of the composite products, the human hair content was varied from 50 phr to 150 phr when the $CaCO_3$ content was fixed at 100 phr.

Based on Figure 3, it can be seen that composites with hair contents at 100 phr achieved the highest values in all tensile and flexural tests. The increase of the human hair content from 50 phr to 100 phr indicated the positive effect of the addition of human hair in the composite samples. Human hair takes the role of the reinforcement part in the composite materials leading to the improvement of the mechanical properties. However, the 150H-100C indicates a reduction in mechanical properties. This reduction was

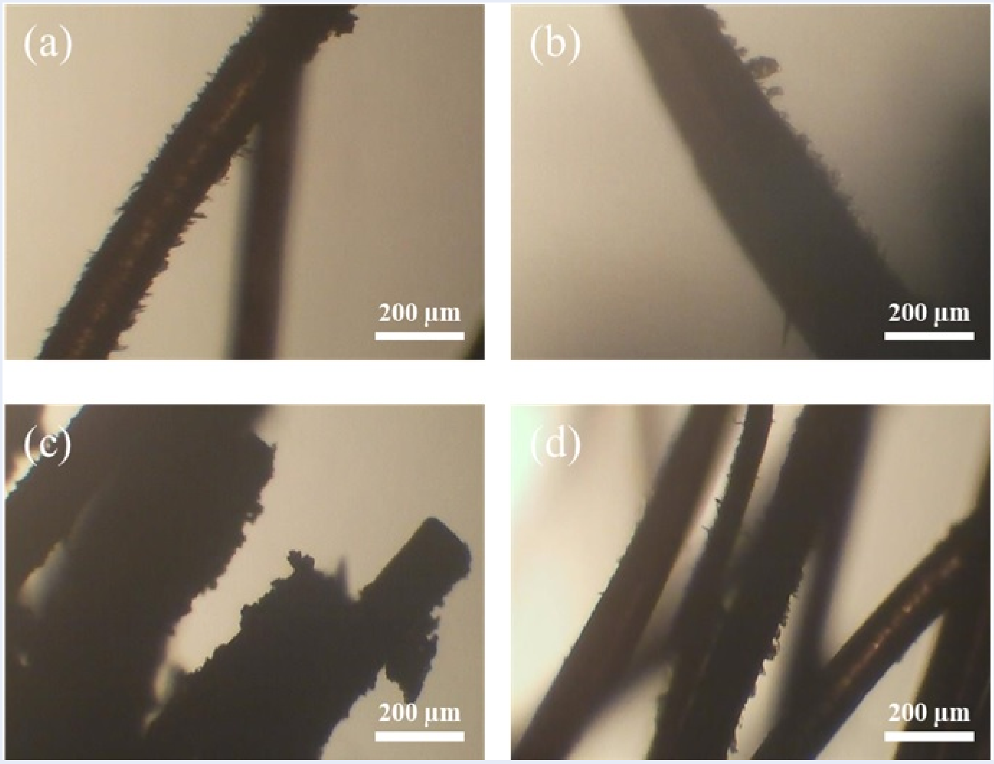


**Figure 2**: Optical microscope images of cracked samples: (a) 100H-0C, (b) 100H-50C, (c) 100H-100C, and (d) 100H-150C

demonstrated by the overuse effects of human hair which represented the insufficient cover of the epoxy resin [11]. From the optical microscope image of the 50H-100C sample shown in Figure 4a, the rough surfaces of the human hairs are present as similar to the 100H-100C sample. Nevertheless, the optical microscope image of the 150H-100C sample in Figure 4b indicates the not good cover of the epoxy resin on the human hair. Furthermore, the mechanical properties of the 100H-100C sample were compared with the other natural fiber/epoxy composite. The collected data are listed in Table 2.

As can be seen in Table 2, the fabricated sample demonstrated compatible mechanical properties with the other natural/epoxy composites. For the hair/epoxy composite, the fabricated sample indicated better tensile and flexural strengths compared with the reference sample which consumed only 20% of wasted hair. In particular, the flexural strength from the prepared sample is double compared with the reference result of the hair/epoxy composite. Furthermore, the tensile modulus of the fabricated hair/epoxy sample is higher than the other reference composite species.

## CONCLUSIONS

Human hair-reinforced epoxy composite has been successfully fabricated in this research. By studying the effects of the filler compositions, the composite reinforced with 100 phr of human hair and 100 phr of $CaCO_3$ indicated high tensile and flexural properties. As a result, the hot press process is illustrated as a suitable technique for reusing an enormous human hair amount in supporting the waste treatment streamline. Furthermore, the fabricated sample demonstrated compatible mechanical properties compared with the other natural fiber/epoxy composite which may be considered as the promised alternative to other natural fibers in the composite materials.

## ACKNOWLEDGMENT

We acknowledge Ho Chi Minh City University of Technology (HCMUT), VNU-HCM for supporting this study.

## CONFLICT OF INTEREST

The authors confirm that there is not any conflict of interest related to the content reported in this paper.

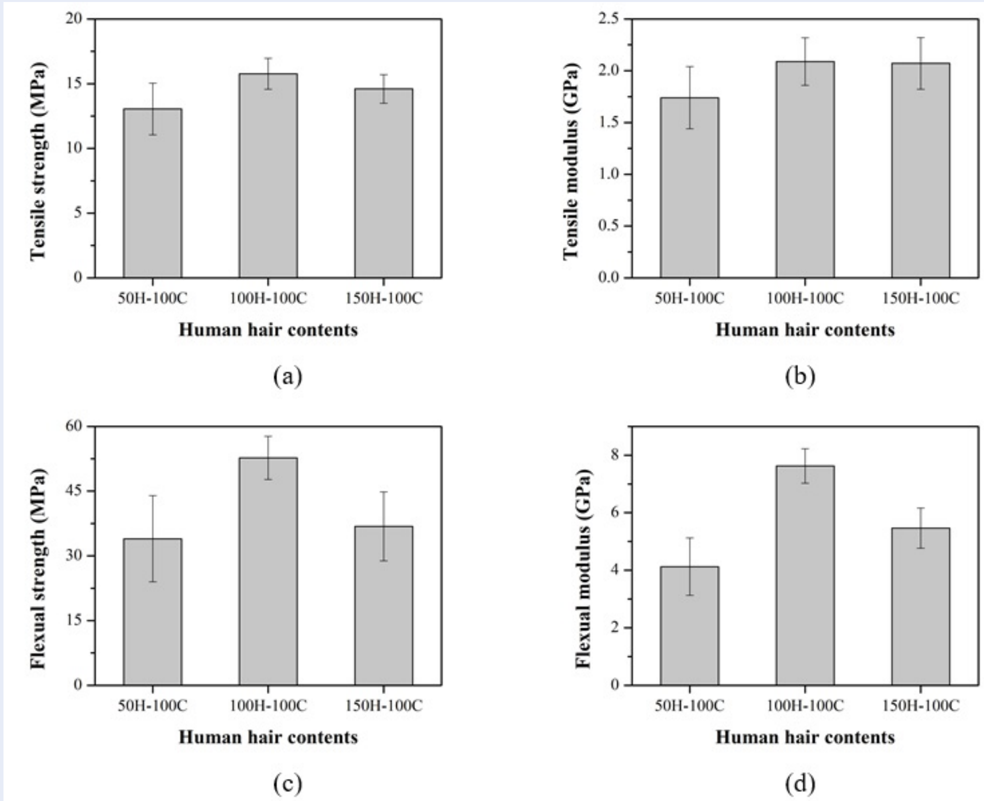


**Figure 3**: Tensile strength (a), tensile modulus (b), flexural strength (c), and flexural modulus (d) of the samples with different human hair contents

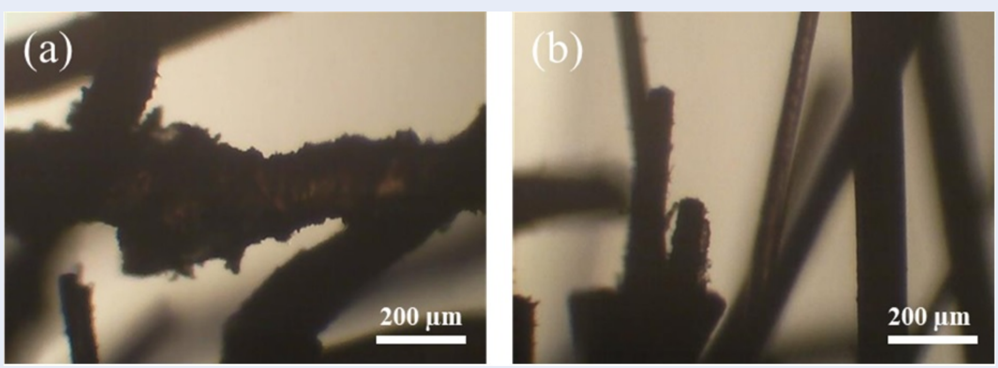


**Figure 4**: Optical microscope images of cracked samples: (a) 50H-100C and (b) 150H-100C

**Table 2: Mechanical properties of various natural/epoxy composite materials**

| Sample | Tensile strength (MPa) | Tensile modulus (GPa) | Flexural strength (MPa) | Flexural modulus (GPa) | Reference |
|---|---|---|---|---|---|
| Hair/epoxy | 15.8 | 2.1 | 52.7 | 7.6 | This work |
| Hair/epoxy | 15.0 | - | 25.1 | - | [9] |
| Jute/epoxy | 16.6 | 0.6 | 57.2 | 8.9 | [12] |
| Flax/epoxy | 35.9 | 1.5 | 61.9 | 1.4 | [13] |
| Sisal/epoxy | 8.4 | 1.0 | 40.5 | 0.4 | [14] |
| Banana/epoxy | 16.1 | 0.6 | 57.3 | 8.9 | [15] |
| Oil palm/epoxy | 29.9 | 1.4 | 51.0 | 3.3 | [16] |

## AUTHORS' CONTRIBUTION

Phan Quoc Phu: planned the research and wrote the manuscript. Nguyen Le Bao Ngoc: fabricated the samples. Huynh Hong Tham: processed the measurement. Tran Nhu Y: analyzed the data.

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*Tạp chí Phát triển Khoa học và Công nghệ – Engineering and Technology 2024, 6(SI3):11-17*

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*Bài nghiên cứu*

# Tái sử dụng tóc người thải trong sản xuất vật liệu composite và đánh giá ảnh hưởng của thành phần đến tính chất cơ học

**Phan Quốc Phú[1,2,*], Nguyễn Lê Bảo Ngọc[1,2], Huỳnh Hồng Thắm[1,2], Trần Như Ý[1,2]**

**TÓM TẮT**

Tóc người là chất thải phổ biến được tìm thấy ở hầu hết các nơi trên thế giới. Đặc biệt, lượng lớn tóc tích tụ trong dòng chất thải làm tắc nghẽn hệ thống thoát nước đang gây ra nhiều vấn đề về môi trường như nuôi dưỡng mầm bệnh, phát sinh mùi hôi, đọng ứ nước bẩn… Đối với việc xử lý chất thải, tóc người có thể được đưa đi đốt, tuy nhiên, quá trình đốt sẽ tạo ra rất nhiều bụi tóc, mùi hôi và khí độc ra môi trường gây ảnh hưởng đến sức khỏe và cuộc sống của con người. Một trong những giải pháp hiện tại trong xu thế kinh tế tuần hoàn là quy trình thu gom và tái sử dụng tóc thải trong các lĩnh vực khác nhau như sợi gia cường trong vật liệu composite, tấm vật liệu hấp phụ dầu tràn, phân bón hữu cơ cho cây trồng... Với mục tiêu nghiên cứu phương pháp hiệu quả nhằm mang lại lợi ích đáng kể cho việc tái sử dụng tóc thải, quy trình ép nóng được áp dụng để chế tạo vật liệu composite từ tóc người và nhựa epoxy trong nghiên cứu này. Nhờ sự hỗ trợ của quá trình ép, hàm lượng tóc người được tái sử dụng trong vật liệu composite đạt cao hơn so với các phương pháp thông thường khác như kỹ thuật lăn tay hay quy trình đổ khuôn. Ngoài ra, ảnh hưởng của hàm lượng tóc thải và bột độn $CaCO_3$ lên tính chất cơ học của tấm vật liệu composite từ tóc người và nhựa epoxy cũng được phân tích cho mục đích ứng dụng. Kết quả cho thấy tấm composite được chế tạo với tỷ lệ tóc người/epoxy ở 50/50 bổ sung thêm 100 phr $CaCO_3$ cho độ bền kéo, mô đun kéo, độ bền uốn và mô đun uốn đạt tối ưu lần lượt ở 15,8 MPa, 2,1GPa, 52,7 MPa và 7,5 GPa. Kết quả nghiên cứu đã cho thấy khả năng ứng dụng của mẫu composite được chế tạo trong thực tế.

**Từ khoá:** tóc phế thải, tấm composite, kinh tế tuần hoàn

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**Lịch sử**

- Ngày nhận: 29-8-2023
- Ngày chấp nhận: 27-12-2023
- Ngày đăng: 31-3-2024

**DOI : https://doi.org/10.32508/stdjet.v6iSI3.1128**



**Trích dẫn bài báo này:** Phú P Q, Ngọc N L B, Thắm H H, Ý T N. **Tái sử dụng tóc người thải trong sản xuất vật liệu composite và đánh giá ảnh hưởng của thành phần đến tính chất cơ học**. *Sci. Tech. Dev. J. - Eng. Tech.* 2024, 6(SI3):11-17.