Research on fabricating non-woven felt based on PA12 for insulation material applications

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Received 18 Aug. 2025; Revised 6 Oct. 2025; Accepted 16 Oct. 2025; Published 18 Nov. 2025.

DOI: https://doi.org/10.54939/1859-1043.j.mst.IMBE.2025.82-87

ABSTRACT

This paper investigates the technological factors influencing the fabrication of non-woven felt based on polyamide 12 (PA12) fibers. The study evaluates the mechanical, physical, chemical, and thermal characteristics of the fabricated material, with particular emphasis on the thermal conductivity of the non-woven fabric for potential application as insulation. Furthermore, various practical applications of PA12-based non-woven felt in diverse fields are presented, including its prospective use in the production and repair of military technical equipment.

Keywords: Polyamide 12 (PA12); Non-woven felt; Insulation material; Thermal conductivity; Mechanical properties.

1. INTRODUCTION

Felt is a type of non-woven fabric produced by compressing and bonding fibers under the combined action of heat, pressure, and moisture. The fibers are compacted until the desired thickness is achieved, forming a sheet-like textile [1, 2].

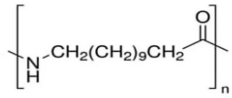
The raw materials used for fabricating non-woven felt may include synthetic fibers, natural fibers (cotton, animal hair, feathers), and adhesives. The production technology is similar to papermaking, where fibers are bonded together through adhesives or mechanical/thermal processes. Felt is widely used in clothing, bedding, upholstery, and other household items. Depending on the intended use, fibers can be arranged either randomly or directionally, reinforced by thermal, mechanical, spunlace, or chemical methods [3].

Figure 1. *Non-woven felt.*

Currently, non-woven felt has found applications in industries such as automotive, construction, design, and insulation. It offers advantages including effective heat retention, durability, water resistance, aesthetic versatility, and recyclability. However, it also presents disadvantages such as susceptibility to moisture absorption and accumulation of dust or microorganisms [6-8].

For insulation purposes, the choice of fiber material is crucial due to exposure to heat and harsh environments. Among synthetic fibers, polyamide 12 (PA12) exhibits superior tensile strength, chemical resistance, low water absorption, and good abrasion resistance, making it an ideal candidate. This work focuses on fabricating non-woven felt based on PA12 fibers and analyzing the effects of technological parameters on the mechanical and thermal properties of the resulting material [5].

Polyamide 12 fibers, or Polyamide 12 (PA12), are a semi-crystalline thermoplastic engineering resin, also known as Nylon 12. It is characterized by high tensile strength and durability, excellent chemical resistance, low water absorption, good abrasion resistance, and impact resistance, making it a widely used material in industries such as automotive, petrochemical, and industrial manufacturing, as well as in flooring and insulation applications. The chemical structure of PA12 is represented as follows [2, 4]:



2. EXPERIMENTAL

2.1. Materials

- Polyamide 12 fibers - Dow Chemical, USA;
- Modified silicone adhesive - China;
- Xylene, PA grade - China;
- Acetone, PA grade - China.

Table 1. *Properties of PA12 fibers.*

Properties	
Glass transition temperature	40 to 50°C
Melting temperature	170 to 180°C
Melting enthalpy	95 J/g
Decomposition temperature	465 to 475°C
Young's modulus	1400 MPa
Coefficient of linear thermal expansion	120 to 140 *10-6/K
Specific heat capacity	1.17 to 1.26 J/(g*K)
Thermal conductivity	0.22 to 0.24 W/(m*K)
Density	1.01 to 1.04 g/cm³

2.2. Methods

The PA12 fibers were first washed with distilled water to remove dust and broken filaments. They were then mixed with modified silicone adhesive and acetone (PA grade, China) at specified ratios and mechanically dispersed at 12,000–20,000 rpm to form uniform fiber mats, similar to handmade papermaking. Multiple layers were stacked to achieve the desired thickness (approximately 2 mm).

The stacked mats were dried and then hot-pressed hot-pressing machine. Pressing was carried out at 140 °C for 15 minutes under a pressure of 5 MPa, ensuring adequate bonding and stability of the non-woven sheets.

Thermal properties were characterized using DSC with a heating rate of 10 °C/min under nitrogen, and TGA 209 F3 (Netzsch, Germany) with a heating rate of 10 °C/min under air.

Mechanical properties, including tensile strength (σ_p), elastic modulus (E_y), total strain, residual strain, and elastic recovery, were evaluated following TCVN 1041-2016 (equivalent to ASTM D638), using an Instron 3367 universal testing machine with a crosshead speed of 5 mm/min. The failure load was recorded directly from the tensile tests.

Thermal conductivity (λ) was measured analyzer according to the transient plane source method (ASTM D276-12).

All measurements were performed on sheet samples with dimensions 2000 × 200 × 2 mm, unless otherwise specified, to ensure reproducibility.

Table 2. *Composition of PA12 non-woven felt samples.*

Sample / Mass	PA12 fibers, g	Modified silicone adhesive, g	Acetone, mL
1	100	0	500
2	100	1	500
3	100	2	500
4	100	3	500
5	100	4	500
6	100	5	500

3. RESULTS AND DISCUSSION

When no adhesive was used, the compressed PA12 fibers showed no bonding between the filaments. Therefore, this study only investigated samples containing adhesive and examined the effect of pressing force on the mechanical, physical, and thermal properties of the non-woven felt.

3.1. Effect of adhesive content on mechanical properties-TCVN 1041-2016

Table 3. *Properties of non-woven felt with varying adhesive content.*

Samples	Tensile strength σ_p, MPa	Elastic modulus E_y, MPa	Total strain,%	Residual strain,%	Elastic recovery,%
1	-	-	-	-	-
2	5,06	11,02	18,0	3,5	60
3	6,08	12,05	19.5	5,0	56
4	7,54	13,56	22,5	6,0	50
5	8,78	15,34	25,8	6,6	44
6	10,52	17,68	28,4	7,0	42

Based on the data presented in table 3, the following conclusions can be drawn: As the adhesive content increases, tensile strength, elastic modulus, total strain, and residual strain all increase. This indicates that higher adhesive content enhances the bonding between PA12 fibers, thereby improving the overall strength of the non-woven felt. However, elasticity decreases with increasing adhesive content, suggesting reduced fiber mobility, decreased porosity, and diminished ability of the felt to recover its original state. For insulation applications, both porosity and elasticity must be sufficient to ensure a low thermal conductivity. Literature review shows that conventional insulation materials typically exhibit elasticity greater than 50%, while the other mechanical properties of the fabricated samples meet the required standards. This observation is consistent with the fact that PA12 fibers possess much higher mechanical properties compared with traditional fibers such as asbestos, fiberglass, and ceramic fibers. Therefore, in subsequent investigations of other technological factors affecting the fabrication process, only Sample No. 3 was selected for further analysis.

3.2. Investigation of the thermo-mechanical properties of non-woven felt

Sample No. 3, after fabrication, had dimensions of 2000 × 200 × 2 mm and was obtained in sheet form, as illustrated in figure 2. The surface of the non-woven felt appeared uniform, with fibers arranged in a random orientation. In addition to adhesive bonding, the fibers exhibited a tendency for self-bonding, indicating that the fabricated material had attained structural stability. Such combined self-bonding and adhesive bonding contributed not only to the material's strength but also to its elasticity and the presence of non-directional pores. SEM images at 500× magnification further confirmed that the PA12-based non-woven felt possessed a porous, spongelike structure in which fibers were interconnected both directly and through modified silicone adhesive, forming a discontinuous material system. The relationship between failure load and strain at different tensile rates, as shown in the figure, provides additional evidence supporting this structural behavior.

Figure 2. *Surface image and SEM micrograph at 500× magnification.*

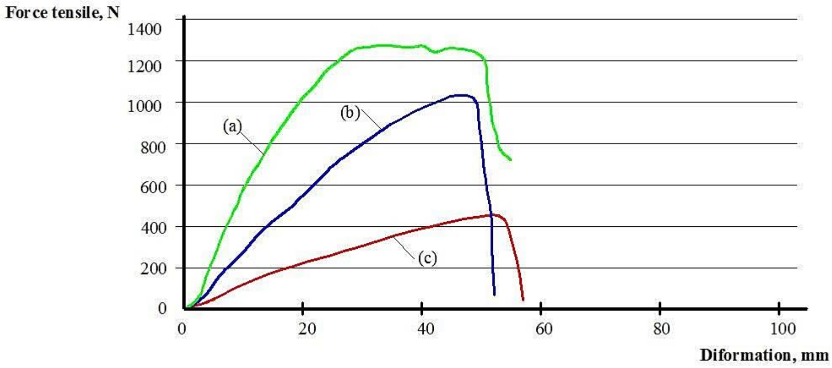


Figure 3. *Dependence of failure load on strain for sample No. 3 at different tensile rates: (a) 5 mm/min, (b) 10 mm/min, (c) 15 mm/min.*

From figure 3, it can be observed that when the material was subjected to tensile loading at different deformation rates, the failure load varied even at the same strain. The failure load decreased as the tensile rate increased. This phenomenon can be explained by the structural characteristics of the material. Similar behavior is also observed in many non-metallic materials; however, the extent of reduction is usually smaller. This difference can be attributed to the fact that many non-metallic materials possess a continuous structure, whereas non-woven felt is inherently a discontinuous material. For insulation applications, such a discontinuous structure is advantageous, as it contributes to a lower thermal conductivity, consistent with the objective of this study.

Figures 4 and 5 present the thermal degradation properties of the material as determined by DSC and TGA analyses.

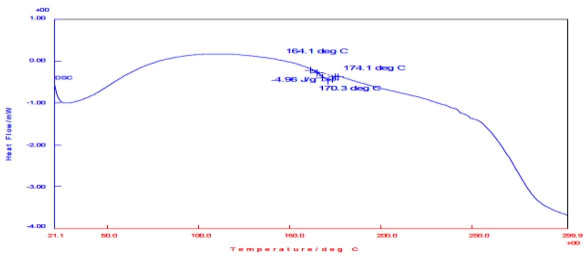


Figure 4. *DSC curve showing the melting point of the non-woven felt.*

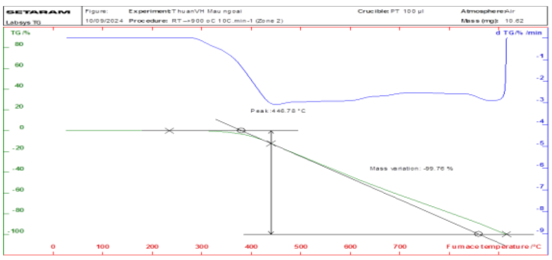


Figure 5. *TGA of the non-woven felt.*

From figure 4, the melting temperature of the non-woven felt was determined to be 170.3 °C, which is consistent with the manufacturer's reported melting point of PA12 (~170 °C). The TGA curve provided similar results. No additional melting transitions were observed below 170 °C, indicating that the adhesive did not affect the thermal behavior at lower temperatures. Likewise, the TGA profile showed no abnormal changes below 200 °C. Based on the melting and decomposition temperatures obtained from DSC and TGA analyses, the PA12-based non-woven felt can be applied as an insulation material at operating temperatures below 150 °C.

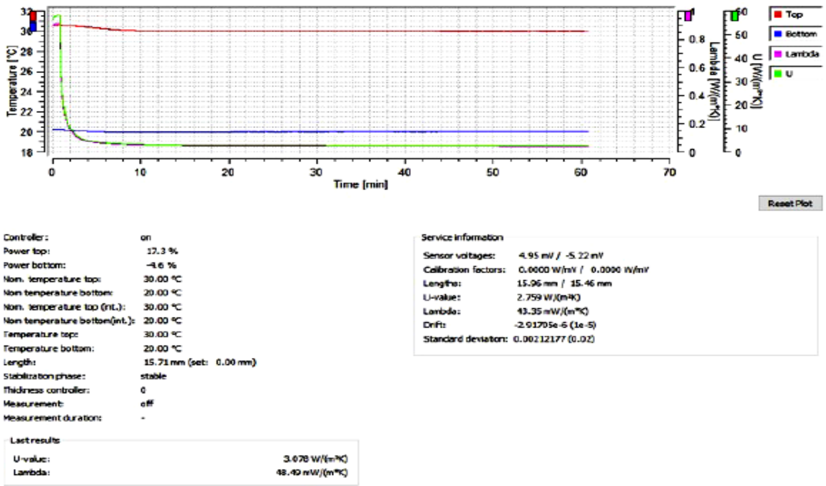


Figure 6. *Thermal conductivity of PA12-based non-woven felt.*

From figure 6, the thermal conductivity of PA12-based non-woven felt was determined to be 0.043 W/m·K. Compared with conventional insulation materials based on ceramic fibers, fiberglass, and asbestos, the PA12 non-woven felt exhibits a lower thermal conductivity. Table 4 presents the thermal conductivity values of several common insulation materials for comparison.

Table 4. *Thermal conductivity of common materials [4].*

Material	Thermal conductivity, W/m.K
Wood	0,13-0,18
PU foam	0,035
PS foam	0,035-0,05
Ceramic fiber	0,07-0,09
Asbestos fiber	0,06-0,09
Air	0,024
Sample No. 3	0,043
Fiberglass	0.04 – 0.05

The fabricated material exhibits low thermal conductivity, making it suitable for use as an insulation material at moderate temperatures. In addition, its durability and structural stability provide significant advantages. These superior properties align with current practical applications, where non-woven felt is increasingly employed in automobiles, high-end interiors, and related fields.

4. CONCLUSIONS

Non-woven felt based on PA12 was successfully fabricated using a wet process with modified silicone adhesive. The mechanical, physical, and thermal properties of the fabricated material were systematically investigated. The results indicate that:

- The material exhibits higher strength compared with conventional insulation materials such as ceramic fibers, fiberglass, and asbestos.
- It has a low thermal conductivity (0.043 W/m·K), making it suitable for insulation applications.
- It demonstrates high stability at temperatures below 150 °C.

Acknowledgements: *This research was funded by the Ministry of National Defense of Vietnam under the project code [2024.85.27]. The authors gratefully acknowledge this financial support.*

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TÓM TẮT

Nghiên cứu chế tạo vải nỉ không dệt trên cơ sở PA12 ứng dụng làm vật liệu bảo ôn

Bài báo đã nghiên cứu các yếu tố ảnh hưởng đến quá trình chế tạo vải không dệt trên cơ sở bông polyamide 12 (PA12). Bài báo cũng đã khảo sát được đặc tính cơ, lý, hóa, nhiệt của vật liệu chế tạo được, đặc biệt là khảo sát hệ số dẫn nhiệt của vải không dệt định hướng sử dụng làm vật liệu bảo ôn. Bài báo cũng đã giới thiệu ứng dụng của vải không dệt trên cơ sở PA 12 ứng dụng trong các lĩnh vực khác nhau và xu hướng ứng dụng trong chế tạo, sửa chữa vũ khí trang bị kỹ thuật quân sự

Từ khóa: Polyamide 12 (PA12); Vải nỉ không dệt; Vật liệu bảo ôn; Hệ số dẫn nhiệt; Tính chất cơ lý.