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Thermoplastic vulcanizate (TPV) hose development for fluid transfer systems of next generation vehicles

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ABSTRACT

Electrification, weight reduction, sustainability, and carbon emissions reduction goals have gained significant importance in the automotive sector over the past decade. In the context of fluid transfer systems, thermoplastic vulcanizate (TPV) hoses offer various advantages compared to rubber hoses. TPV hoses contribute to weight reduction, being approximately 40% lighter, and exhibit sustainable characteristics due to their reprocessable nature. Moreover, they result in lower carbon emissions throughout the production and recycling cycles. Cost-wise, TPV hoses are advantageous, with improvements ranging from 40% to 55% compared to rubber hoses, making them suitable for the development and production of new automotive components. This research investigates the utilization of TPV, a member of the high-performance materials and technologies category, with a particular emphasis on its application in the automotive sector, specifically in the development and manufacturing of TPV hoses. The enhancement of polymer composites and manufacturing methods will contribute to the establishment of suitable techniques for mass production and to enhance the mechanical, thermal, and chemical stability of TPV hoses. Additionally, this study aims to target the production of reinforced automotive cooling hoses made from TPV as a competitive and sustainable alternative for next-generation vehicles. An assessment of the impact of TPV hoses on vehicles and sustainability strategies will be conducted, comparing them to EPDM hoses.

I. INTRODUCTION

Continuous improvement and development efforts in the automotive sector worldwide are rapidly ongoing, driven by the growing interest in electric vehicles and the adoption of zero-emission policies as global trends. However, there are certain barriers hindering the widespread adoption of electric vehicles, such as short range and battery life, as well as high battery costs. To address the range issue, there has been an increased interest in using lighter materials, including low-density alternatives like thermoplastics. This involves reducing the vehicle's weight, enhancing performance, increasing range, and expanding the interior cabin space. When examining cooling lines in automotive fluid systems, approximately 50-60% of the lines used in this application are rubber hoses, 10-20% are metal pipes, and 20-30% consist of plastic parts and pipes [1]. This is due to the impact of motor-induced vibrations on vehicles with internal combustion engines and the necessity of using rubber materials due to high temperatures with fluid flows. Stringent emission requirements since the 2000s have directed manufacturers towards reducing engine sizes and vehicle weights. In this process, thermoplastic materials have, in some cases, started to be used in conjunction with rubber hoses due to their lighter weight. Since the introduction of next-generation vehicles in 2015, it has been observed that cooling systems no longer reach temperatures above 90°C, and electric motors do not generate vibrations [2]. The difference in operating temperatures between an electric vehicle and a conventional vehicle is shown in Figure 1. This environment has

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made the use of thermoplastic and thermoplastic elastomer materials more appealing. Cooling systems must operate within specific temperature ranges and keep the temperature difference in the system as low as possible. The lower operating temperatures in electric vehicles provide more opportunities for innovative engineering materials like thermoplastics. The use of recyclable materials in line with the eco-friendly policies of electric vehicles contributes significantly to green production. These vehicles have positive effects on the environment throughout the manufacturing, usage, and recycling stages. Issues caused by rubber hoses can be addressed by using alternative materials such as thermoplastic hoses [3].

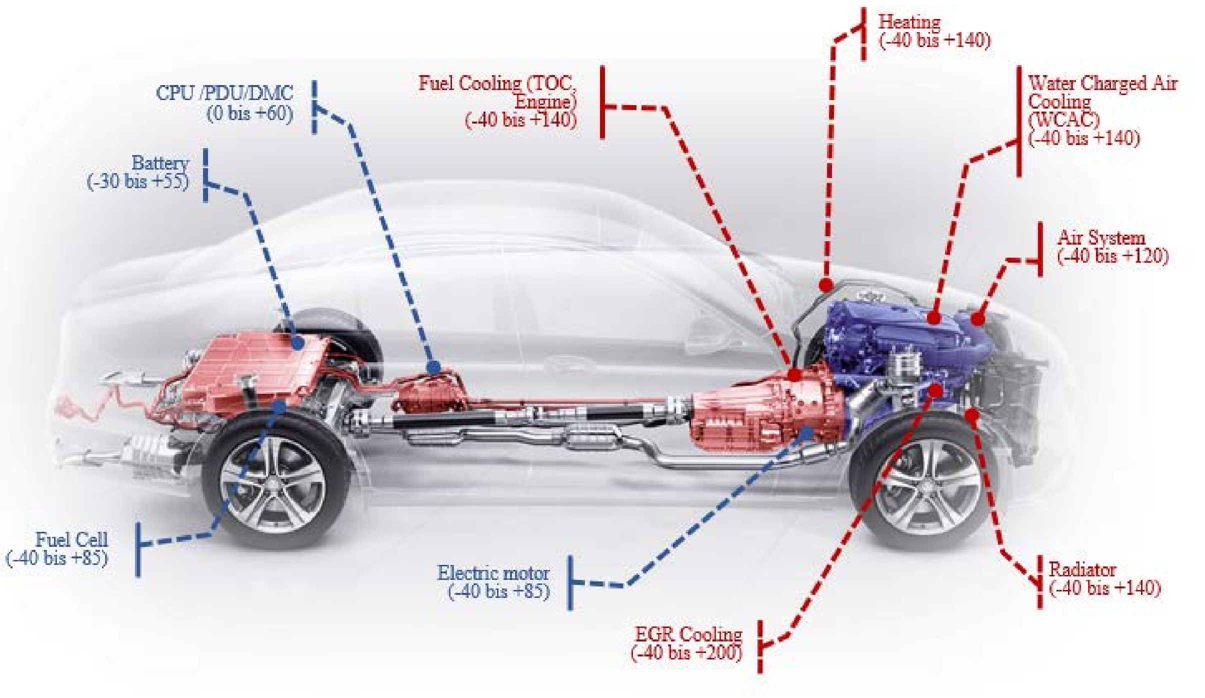


Figure 1. The difference in operating temperatures between an electric vehicle and a conventional vehicle

Thermoplastic vulcanizates (TPV) are dynamically vulcanized blends primarily composed of cured EPDM (ethylene propylene diene monomer) rubber particles embedded within a polypropylene (PP) matrix. TPV and EPDM are two critical elastomer materials commonly used in modern industrial applications. TPV is formed because of the combination of thermoplastic polyolefins and a rubber mixture, which combines processability, impact resistance, and chemical resistance with the advantages of thermoplastic materials [4]. On the other hand, EPDM is derived from the ethylene propylene diene monomer polymer and exhibits high durability against water, oxygen, and chemical substances [5]. The processability of TPV provides flexibility in design, particularly for complex geometries, while the durability and chemical resistance of EPDM highlight its ability to deliver reliable performance under challenging conditions. TPVs are created through the dynamic vulcanization of non-interacting rubber and thermoplastic elastomer. During this production stage, the rubber mixture is melt-blended with the thermoplastic raw material, leading to cross-linking. As a result, cross-linked rubber particles dispersed in the thermoplastic matrix can be observed [6]. Consequently, TPV materials derive their flexibility from rubber and reprocessability from thermoplastics.

Rubber hose and thermoplastic hose production involve different process lines and operating conditions [7]. The process steps diagram provided in Figure 2 illustrates that after feeding the raw materials into the extrusion lines, the vulcanization process is carried out for rubber hoses in the shaping process, while for TPV hoses, a thermoforming (heat shaping) process is employed.

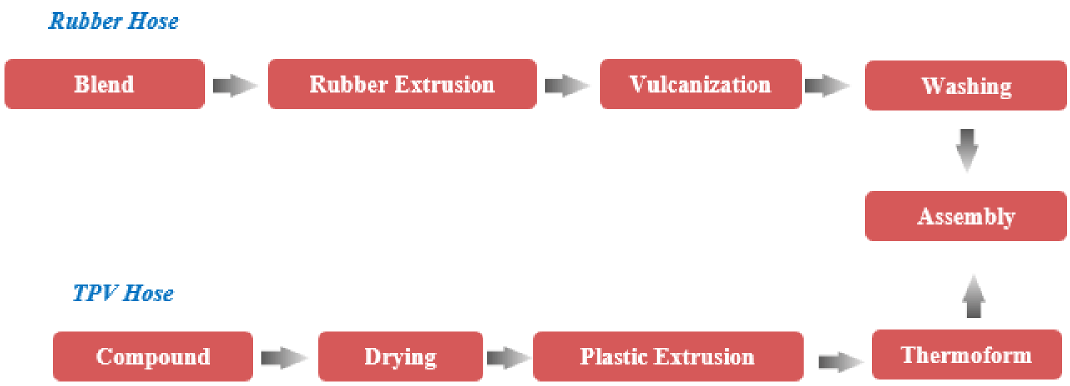


Figure 2. Rubber hose and TPV hose production process steps

The aim of this study is to develop a hose for the cooling systems of next-generation vehicles that is lighter, more competitively priced, and environmentally friendly, while maintaining the same performance as rubber hoses. To achieve this goal, the components constituting the hose need to be as lightweight as possible, with reduced material usage, low process costs, and a low carbon footprint. Within the scope of this study, four different types of hoses were identified based on reinforcement, size, shape, tolerance, process, and hose specifications, and development work has been conducted.

II. EXPERIMENTAL METHOD / TEORETICAL METHOD

2.1 Materials

Thermoplastic elastomers are raw materials defined in the ASTM D1566 standard as "rubber-like materials that, unlike vulcanized traditional rubber materials, can be processed and recycled like thermoplastic materials". In accordance with this material definition, a hose production plan has been designed using TPV raw materials obtained from two different suppliers that comply with this description (A and B). For the reinforcement process, 1100 dtex aramid and polyester yarns have been utilized.

2.2 Method

2.2.1. Extrusion and Thermoform Process

Before the extrusion process, the raw material undergoes a drying process to minimize its moisture content. The material is heated and dried within a casing covered with a motor and heater. By turning the screw inside, the thermoplastic granules are melted under temperature and pressure. The molten thermoplastic is then shaped using a suitable mold design and manufacturing process to achieve the desired diameter and wall thickness along the length of the mold.

Following the extrusion process, the flat hoses produced are cut to the desired length for shaping. Considering the physical behavior of TPV raw materials (stretch ratio), molds for the thermoforming process were designed and manufactured in both 2D and 3D forms. The thermoforming process involves placing an extruded pipe or hose into a mold, and with the application of suitable process conditions, the mold shapes the material. This process is commonly used for shaping plastics, thermoplastics, and composite materials. For thermoforming, the hoses exiting the extrusion process undergo molding according to predetermined parameters. The product, after undergoing the shaping process, is removed from the mold without being exposed to deformation by immersing it in a water pool for shock cooling. After a specified waiting period, the product is taken out of the mold.

2.3 Characterization

2.3.1 FT-IR analysis

FT-IR (Fourier Transform Infrared Spectroscopy) analysis is a powerful technique used to examine the molecular components and chemical bonds of a material. The FT-IR spectra of polymers can be recognized by the characteristic absorption peaks of specific chemical groups. The FT-IR spectra of PP (polypropylene) and EPDM (ethylene propylene diene rubber) polymers will contain distinctive peaks corresponding to their unique properties. The polymers were analyzed with a NICOLET–iS50 Fourier-transform infrared (FT-IR) spectrometer to determine the structural properties and peaks.

2.3.2. Performance Test

Cooling hoses in fluid transfer systems need to be evaluated through tests specified in OEM (Original Equipment Manufacturer) specifications to determine their performance. Considering the critical role these hoses play in the system; it is crucial to assess their performance in line with the tests outlined in OEM specifications. Cooling hoses facilitate the safe and efficient transfer of fluids from one system to another. These hoses may be subjected to high pressures and temperatures, necessitating high-performance and durability characteristics.

2.3.2.1. Burst test

The burst test is a testing method used to determine the maximum endurance capacity and assess the safe operating limits of cooling hoses. This test is conducted to understand how the hose behaves under specific conditions of pressure. The results of the burst test aid in evaluating the appropriateness of the hose's design and manufacturing, playing a critical role in ensuring safe operating conditions.

2.3.2.2. Diameter expansion test

The diameter expansion test is a process that measures how the inner diameter of a hose changes under a specific pressure. The diameter expansion test can be conducted at different pressure levels and temperatures depending on the environment in which the hoses will be used. This test is of critical importance in assessing the reliability and durability of the hoses.

2.3.2.3. Life cycle test

Life cycle tests are a series of tests used to evaluate the performance characteristics of cooling hoses. These tests measure the durability, flexibility, and leak resistance of the hoses. Life cycle tests are necessary to ensure that hoses can operate safely and effectively in a system.

III. RESULTS AND DISCUSSIONS

3.1 Construction Study of TPV Hoses

As seen in Table 1, four different construction studies have been conducted. These construction studies were processed with raw materials having two different hardness values. The hardness value of Raw Material A is 45 Shore D, while Raw Material B has a hardness value of 75 Shore A.

Table 1. Construction iterations

Reinforcement	Test Norm	Hose Form	Form Tolerance	Hose Inner Diameter
p-Aramid	DIN 73411	2D	± 5	12 mm
Polyester	DIN 73411	3D	± 5	16 mm
p-Aramid	DIN 73411	3D	± 3	16 mm
Polyester	DIN 73411	2D	± 3	12 mm

In the reinforcement process during the extrusion, the type of yarn should be selected based on working conditions, and it affects the product's performance. The characteristics of aramid and polyester yarns are provided in Table 2. While polyester has good tensile strength, it has lower tensile strength compared to para-aramid yarns. Aramid is not lighter than polyester, and its density is slightly higher. Aramid is resistant to high temperatures and is non-flammable [8].

Table 2. The characteristics of polyester and para-aramid yarn types

Characteristic	Hose	p-Aramid	Polyester
Strength (cN/dtex)	Burst pressure (bar)	21	7.5
Elongation at break (%)	Diameter expansion (%)	3.5	18
Max. operating temperature (℃)	Operating temperature (℃)	200	150
Thermal elongation (%)	Dimensional stability under temperature	0.2	2

The thermoforming process conditions for the EPDM hose are conducted in an unpressurized environment. The vulcanization process for the EPDM hose takes place in an autoclave at 170 ℃, 8 bars, and for 13 minutes. In contrast, the TPV hose undergoes a heat treatment process in an oven at 160 ℃, for 30 minutes. Prior to the heat treatment process, a lubricant is used during the molding of the EPDM hose, while there is no need for any chemicals during the molding of the TPV hose.

The Thermoforming Process Parameters for TPV Hoses:

- Mold temperature: In the production of TPV hoses, the mold temperature is typically between 100°C and 120 °C. The mold temperature facilitates the adhesion of the hose to the mold and eases the shaping process.
- The thermoforming process temperature: In the production of TPV hoses, the material temperature is typically between 150 °C and 220 °C. The material temperature affects the flexibility and shaping capability of the material.
- Thermoforming time: The production speed can be adjusted depending on the requirements of the application, thereby affecting the cycle time.
- Cooling water temperature: The cooling water temperature should be between 20 °C and 30 °C.
- Cooling time: The cooling time varies depending on the thickness of the hose material and the cooling rate. Too short a cooling time may result in insufficient cooling of the hose material and the formation

of internal stresses. On the other hand, excessively long cooling time may lead to the hardening and brittleness of the hose material.

During the thermoforming process, working temperature and duration are crucial parameters [9]. Generally, the working temperature during the thermoforming process is set to be approximately 20 °C below the material's melting temperature.

3.2 FT-IR Results

Characteristic bands for the polymer phases of two different TPV materials consist of a thermoplastic polymer matrix (PP) and a rubber phase (EPDM) were identified via FT-IR analysis. In the polypropylene phase, bands in the range of 2800-3000 cm^{-1} for C-H bonds and ~1720 cm^{-1} for C=O bonds have been observed. In the EPDM phase, bands in the range of 2800-3000 cm^{-1} for C-H bonds, ~1375 cm^{-1} for CH_3 deformation, and ~1600 cm^{-1} for C-H bonds have been observed. The peaks detected at 1375, 1418 and 1467 cm^{-1} represent C–C and C=C stretching vibrations of vulcanized EPDM structure. The peak intensity appearing at 1645 cm^{-1} can be ascribed to C=C group of 5-ethylidene-2-norbornene (the third monomer of EPDM). The peaks originated at 535 and 1179 cm^{-1} are associated with S–S and C–S bonds of cross-linked PP/EPDM vulcanizates [10-11]. Although the FT-IR spectrum of raw material B shows some distinct peaks at 3394, 3184, 1734 and 1645 cm^{-1} unlike A, many other peaks overlap with A.

3.3 Performance Test Results

3.3.1 Burst test result

According to the DIN 73411 specification, the test can be conducted in an ambient temperature environment. The specification states that the test conditions should have a pressure increase of 0.5±0.2 bar s^{-1}. The requirements for the test result are provided in Table 3.

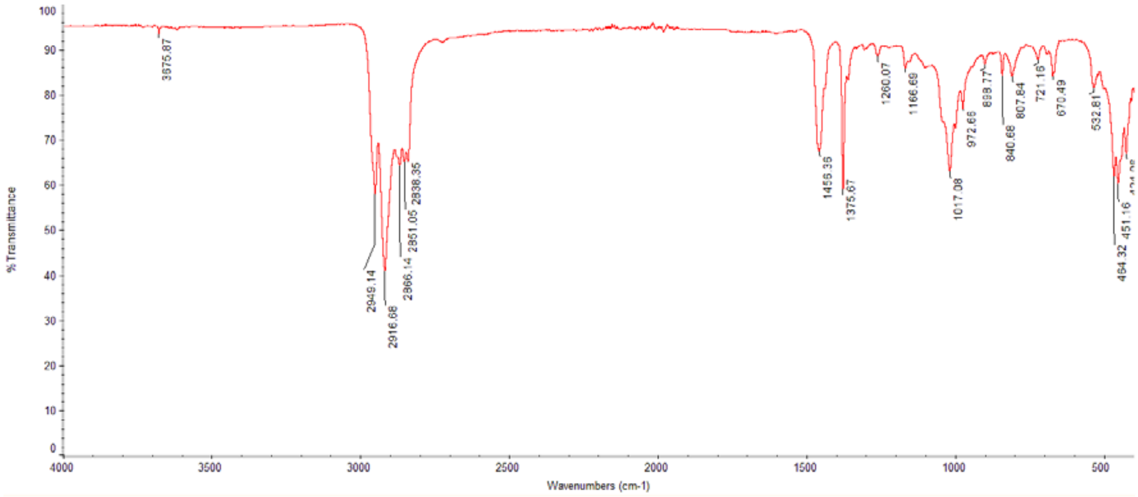
Table 3. The requirements for burst test results according to DIN 73411 specification

Inner Diameter *(mm)*	**Minimum Burst Pressure** *(bar)*
d<20	12
20≤d≤40	10
d≥40	6

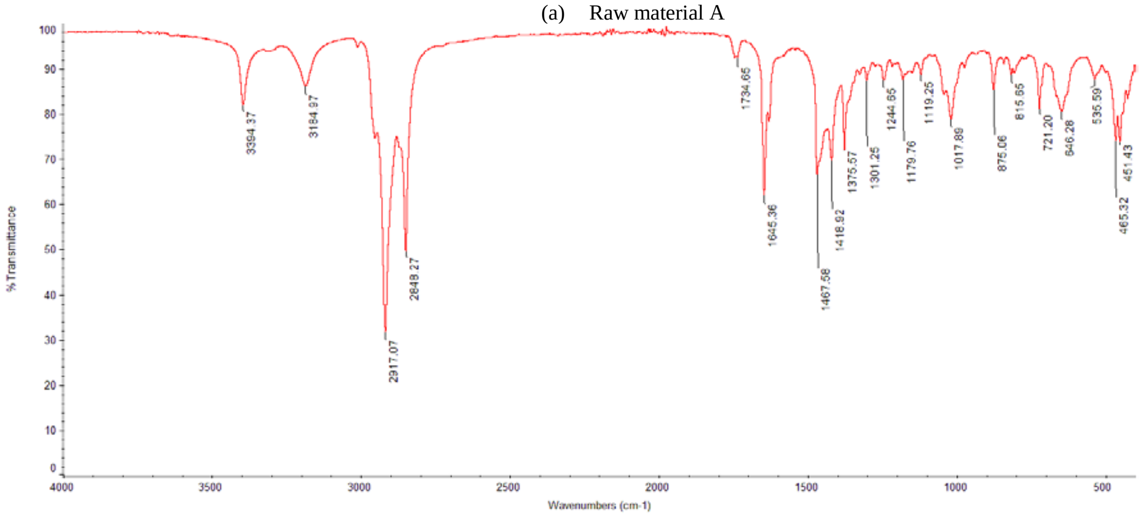
After each construction iteration, samples obtained from each formed reference were subjected to the burst test. As seen in Table 4, all products comply with the requirements of DIN 73411 specification (Table 2).

Table 4. Burst Results of TPV Hoses According to DIN 73411 Specification

Raw Material	**Inner Diameter** *(mm)*	**Reinforcement**	**Hose Form**	**Burst Pressure** *(bar)*
A	12	Polyester	2D	-
B	12	Polyester	2D	23,59
A	12	p-Aramid	2D	>40
B	12	p-Aramid	2D	>26
A	16	Polyester	3D	-
B	16	Polyester	3D	24,88
A	16	p-Aramid	3D	>40
B	16	p-Aramid	3D	29,9



(a) Raw material A



(b) Raw material B

Figure 3. FT-IR results of raw materials a) A and b) B

3.3.2 Diameter expansion test result

The diameter expansion test is conducted by applying 3 bars of pressure to the hose within a 1-minute period. The outer diameter of the hose is measured before applying pressure, and then the outer diameter is measured again after being subjected to 3 bars of pressure to calculate the percentage of diameter expansion. According to DIN 73411 specification, this calculation should not exceed 12%. The test results for the products are provided in Table 5. All references have passed the diameter expansion test.

Table 5. Diameter expansion results of TPV hoses according to DIN 73411 specification

Raw Material	Inner Diameter *(mm)*	Reinforcement	Hose Form	Diameter Expansion *(%)*
A	12	Polyester	2D	3,8
B	12	Polyester	2D	-
A	12	p-Aramid	2D	1,8
B	12	p-Aramid	2D	3,6
A	16	Polyester	3D	-
B	16	Polyester	3D	4,3
A	16	p-Aramid	3D	1,7
B	16	p-Aramid	3D	3,9

3.3.3 Life cycle test result

According to the DIN 73411 specification, it is observed that tests can be conducted under two different conditions: long-term and short-term. To initiate this testing process, the first step is to prepare the test samples.

- Straight hose pieces, at least 200 mm long,
- Elbows or moulded parts with at least 200 mm clear length between pipe unions,
- Test specimens for dynamic long-term as shown in Fig. 3.

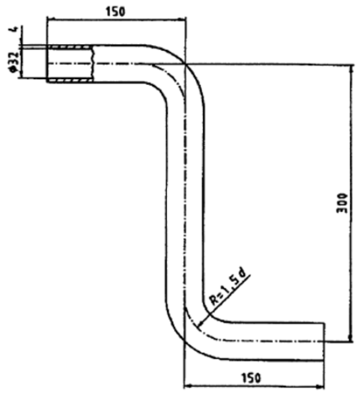
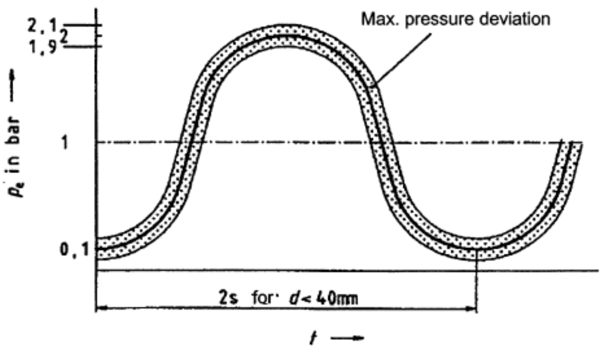


Figure 4. Test specimens for long-term dynamic test

Expectations from the test results are as follows:

- For the long-term test, if the sample shows no leakage, no cracks, and withstands a pressure of 6 bars, the test will be considered passed.
- For the short-term test, if no leakage or cracks are observed in the sample, the test will be considered passed.



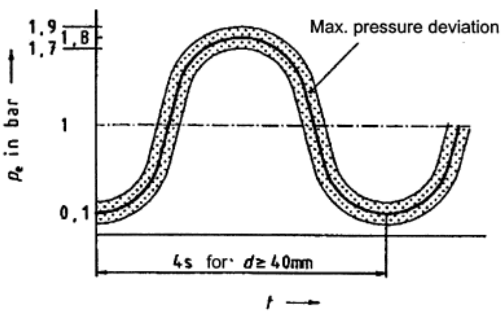


Figure 5. Cycle for short-term test

No leakage or deformation was observed in the developed products when both tests were applied.

3.4 Benchmark Research

In the conducted benchmark studies, it has been observed that TPV hoses are used by leading electric vehicle manufacturers in the industry, as well as in some vehicles with internal combustion engines. Through benchmarking and literature research, it was found that Cooper Standard and Contitech, leading companies in TPV hose production, achieved a 40% weight reduction for Cooper Standard and a 25% weight reduction for Contitech compared to EPDM hoses. In the TPV hose developed by İbraş Kauçuk, a weight reduction ratio of 46% has been achieved. Cooper Standard developed a product with a hardness of 90 Shore A. İbraş worked with 2 different grades of raw materials, completing product development studies with hardness values of 45 Shore D and 75 Shore A. It is stated that Contitech achieved a 50% increased pressure resistance. When comparing burst test results of TPV hoses developed within İbraş against EPDM hoses, it is observed that they provide similar performance.

When examining the relevant patents related to TPV hoses, it has been observed that there are very few patents and studies in this field. The newly studied and developed construction is expected to provide solutions to many problems in the automotive sector, especially in the electric vehicle sector. Additionally, it is expected to demonstrate environmentally friendly performance in compliance with green production policies. US 2005/0170117 A1 patent highlights the economic manufacturing compared to previous hose productions, being more flexible, lighter, recyclable, and having more consistent physical properties. The issues addressed in the patent are experienced in the development of TPV hoses. TPV hoses have been found to have lower unit cost than EPDM and more effective assembly performance. In patent EP3666516A1, the shaping of a dimensionally balanced molded hose is discussed, emphasizing the technical advantage of transforming the previously plastic deformable fluid line into a fixed shape necessary for assembly in a vehicle. It specifically mentions the convertibility of the hose into a dimensionally balanced molded hose, especially through heat shaping. This emphasizes the impact of the thermoforming process on TPV hoses. The result of the thermoforming process has effectively influenced the dimensional aspects of TPV hoses. The observation of the differences in the process through two different mold experiments has proven to be useful.

IV. CONCLUSIONS

In this study involved the production of hoses with different constructions using TPV raw materials obtained from two different suppliers. For the reinforcement process, 1100 dtex para-aramid and polyester threads were utilized. The advantages of TPV hoses in electric vehicles vary. The manufacturability of these hoses allows for the easy creation of complex designs, while their low weight enhances energy efficiency. They exhibit high chemical resistance, and their flexibility combined with impact resistance is noteworthy. These hoses can maintain flexibility even at low temperatures, have a long lifespan, and offer recycling advantages. The low cost of TPV hoses is another factor supporting their preference in fluid transfer systems for electric vehicles. In conclusion, TPV hoses in electric vehicles are not only more advantageous but also more efficient in terms of performance compared to EPDM hoses.

This study observed that TPV hoses have easier process processes compared to EPDM. The process results in lower energy consumption, and production cycles are shorter. Among the compared EPDM hoses and TPV hoses, the density of EPDM rubber is 1.33 g/cm3 and the A and B raw materials of TPVs, which vary depending on their materials, have values of 0.95 - 1.25 g/cm3. Since TPV hoses can be produced with lower wall thickness compared to EPDM, it has been observed that they are quite effective in weight reduction studies. TPV hoses are approximately 45-50% lighter than EPDM hoses. The production cost of TPV hoses is 15-20% lower. From a cost perspective, TPV hoses, which are advantageous, have improved by 40-55% compared to rubber hoses, making them suitable for developing and manufacturing new parts in the automotive sector.

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REFERENCES

1. Alanazi F (2023) Electric Vehicles:Benefits, Challenges, and Potential Solutions for Widespread Adaptation. Appl Sci 13(10):6016. https://doi.org/10.3390/app13106016
2. Xue J, Han Y, Jiao J, Wang L, Shen W (2021) Electric vehicle industry sustainable development with a stakeholder engagement system. Technol Forecast Soc Change 173:121086. https://doi.org/10.1016/j.techfore.2021.121086
3. Dan D, Zhao Y, Wei M, Wang X (2023) Review of Thermal Management Technology for Electric Vehicles. Energies 16(12):4693. https://doi.org/10.3390/en16124693
4. Datta S (2024) Polyolefin-based thermoplastic vulcanizates and thermoplastic elastomers: fundamental chemistry problems. In: Singha NK, Jana SC (eds) Advances in Thermoplastic Elastomers, Elsevier, pp 151-175. https://doi.org/10.1016/B978-0-323-91758-2.00011-8
5. Greene JP (2021) Elastomers and Rubbers. In: Greene JP (ed) Automotive Plastics and Composites, William Andrew Publishing, pp 127-147. https://doi.org/10.1016/B978-0-12-818008-2.00016-7
6. Ning N, Li S, Wu H, Tian H, Yao P, HU G-H, Tian M, Zhang L (2018) Preparation, microstructure, and microstructure-properties relationship of thermoplastic vulcanizates (TPVs): A review. Prog Polym Sci 79:61-97. https://doi.org/10.1016/j.progpolymsci.2017.11.003
7. Reghunadhan A, Akhina H, Ajitha AR, Chandran N, Nair ST, Maria HJ, Thomas S (2024) Thermoplastic elastomers (TPEs) from rubber-plastic blends. In: Singha NK, Jana SC (eds) Advances in Thermoplastic Elastomers, Elsevier, pp 291-314. https://doi.org/10.1016/B978-0-323-91758-2.00008-8
8. Deopura BL, Padaki NV (2015) Synthetic Textile Fibres: Polyamide, Polyester and Aramid Fibres. In: Sinclair R (ed) Textiles and Fashion, Woodhead Publishing, pp 97-114. https://doi.org/10.1016/B978-1-84569-931-4.00005-2
9. Klein P (2022) Fundamentals of plastics thermoforming. Springer Nature, Berlin.
10. Sanches NB, Cassu SN, Dutra R de CL (2015) TG/FT-IR characterization of additives typically employed in EPDM formulations. Polímeros 25(3):247–255. https://doi.org/10.1590/0104-1428.1819
11. Borazan AA (2017) Preparation and characterization of ethylene propylene diene monomer (EPDM) rubber mixture for a heat resistant conveyor belt cover. Anadolu Univ J Sci Technol A Appl Sci Eng 18(2):507–520. https://doi.org/10.18038/aubtda.296523