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Characterization of High-Pressure Fuel Hose with Braided Reinforcement

Mustafa Ertekin[1] 0000-0002-5492-7982
Gözde Ertekin [1] 0000-0003-2150-9255
Gökçe Bakiler[2] 0000-0002-0422-5050
İrem Seçkin İşcan[2] 0000-0002-3960-2506
Seçkin Erden[3] 0000-0002-8560-3585

[1] Ege University, Faculty of Engineering, Department of Textile Engineering, 35100, Bornova, İzmir, Türkiye
[2] Erenli Kauçuk ve Plastik Sanayi, 35170, Kemalpaşa, İzmir, Türkiye
[3] Ege University, Faculty of Engineering, Department of Mechanical Engineering, 35100, Bornova, İzmir, Türkiye

Corresponding Author: Gözde Ertekin, gozde.damci@ege.edu.tr

ABSTRACT

This study aims to investigate the effect of material type and braiding angle on the performance characteristics of the reinforced multi-layered hose, to manufacture a high-pressure fuel hose. For this purpose, NBR (Acrylo-Nitrile Butadiene rubber)/CPE (chlorinated polyethylene) fuel hose was manufactured using a single-screw extruder and for the production of the reinforcement layer, braiding technology was used. With an attempt to discuss the effect of braiding angle on the performance characteristics of the reinforced multi-layered hose, the take-up speed of the radial braiding machine was altered. E-glass, aramid, carbon, polyester, and basalt yarns were used for the production of the braided layer. Then CPE (chlorinated polyethylene) rubber was extruded for the cover application. Performance properties of the fuel hose such as hardness, ply adhesion, vacuum collapse bursting pressure, and diametric expansion were measured and evaluated according to the requirements of the related standards. The results revealed that, with increased braiding take-up speed, ply adhesion, vacuum collapse, and diametric expansion properties of hoses increase, while hardness, permanent deformation, and bursting pressure of hoses decrease. It has been determined that NBR/Basalt/CPE fuel hose produced in 4m/min braiding take-up speed provided optimum functional and adhesion properties, because of its hardness, permanent deformation, bursting, and vacuum test values at 25°C are within the limit. Additionally, the results were verified by running finite element analysis (FEA) using the ANSYS simulation program.

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KEYWORDS

High pressure, rubber composites with technical textile reinforcement, high-performance yarns, braiding, fuel hose.

1. INTRODUCTION

Hoses are manufactured using a range of materials and configurations depending on their function. There are several types of hoses such as air intake, radiator, fuel-oil, vacuum, breather, power steering, and brake hoses. They can be used in a wide range of application areas like automotive, construction equipment, railways, defense, farm track equipment, etc. These hoses can be produced using a single material, or multi-layered structure and reinforcement layers can also be used to increase durability, resistance against coolant, fuel oil, chemicals, high pressure, vacuum, etc. Formed hoses that are normally with reinforcement are mandrel built. First, the tube is extruded with a specific ID, and then the reinforcement (braiding or knitting) is applied to it followed by crosshead extrusion for cover applications with specific wall thickness [1]. There are several studies carried out on the deformation analysis and fatigue damage of the braided composite hoses used in automotive industry [2-17]. This study differs from the previous researches by using braiding technique with technical yarns during the production of the fuel hoses.

In the automotive industry, the transportation of fuel and air

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are critical factors for the operation. Fuel hoses are designed for the transportation of fuel oils in engines and fluids in hydraulic systems. Hoses made from rubber have been the primary means of carrying fuel or air although metal tubes have also been used in some instances. A fuel line hose consists of an inner tube, a textile reinforcement, and an outer layer. An inner tube has to be resistant to variable fluids and heat acc. to the user requirements. These rubber types would be NBR (acrylonitrile butadiene rubber), ECO (epichlorohydrin rubber), ACM (acrylic rubber), or FKM (fluorocarbon rubber). A textile reinforcement is used to increase the functionality of the hose. Moreover, an outer layer should be resistant to ozone gas, fuel, and heat again acc. to the user requirements. These rubber types would be CPE (chlorinated polyethylene rubber), CR (chloroprene rubber), ECO (epichlorohydrin rubber), ACM (acrylic rubber), or FKM (fluorocarbon rubber) (Fig.1). The recent trend has been led to develop multilayer hoses using hybrid materials with special functionalities and specific requirements [1, 18].

Nitrile rubber is used in oil and fuel seals and hoses in the automotive industry due to its high abrasion resistance and chemical resistance. This polymer has good oil and fuel resistance and heat resistance, but it has low permeability, poor electrical isolation, weak stretching feature, and ozone resistance Nitrile is a Butadiene-Acrylo Nitrile (ACN) polymer. ACN ratio varies between 18-50% in nitrile rubber mixes. Nitrile rubber has a polar structure thanks to the acrylonitrile monomer in it and thus has high fuel and oil resistance features [19].

The CPE (Chlorinated Polyethylene) polymer is classified according to the Cl content. These ratios are between 25% and 42%. It has good thermal stability, oil resistance, ozone, and water resistance, and also its resistance to burning is good. It can be used in the cable industry and in the production of all kinds of extrusion and molded parts where resistance to air, oil, and chemicals is required [19].

There are several methods such as braiding, spiraling, helical wrapping, knitting, and circular weaving for the manufacture of hoses [21]. Braiding, which is also used in this study, is defined as a textile process of intertwining at least three parallel strands (or yarns) of fiber to manufacture narrow fabrics like cords and ropes with non-orthogonal fibre orientation or to cover (overbraid) some profile [22-24]. The braiding technique is mainly used for the production of smaller bore hoses, up to around 50 mm internal diameter, particularly for medium to high-pressure applications, such as automotive brake hoses [21].

Fuel hoses provide the fuel in vehicles to reach the engine from the tank. Fuel systems can vary from several interconnected circuits, depending on the operating pressures, functions, and engine capacity of these circuits. Fuel hoses used in fuel systems are designed according to high operating pressure, temperature, and chemicals to be exposed (Fig. 2).

Figure 1. Layer configuration of a fuel hose [20]

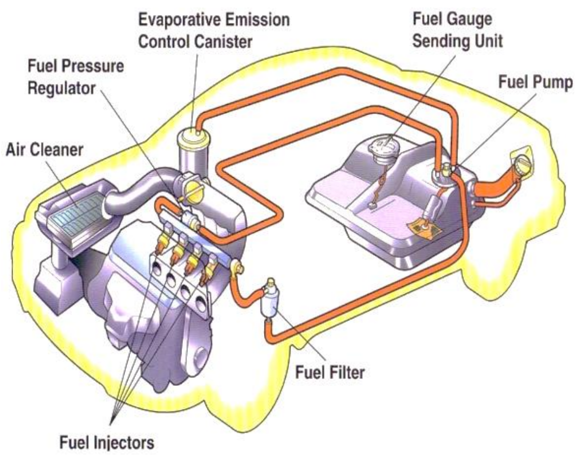


Figure 2. Example of fuel system [25]

Especially in recent years, the significant decrease in petroleum reserves and the economic concerns have accelerated the alternative fuel production activities of fuel oil producers. While the search for alternative fuel use in the sector continues rapidly, the use of existing fuel (diesel, gasoline) resources in an efficient manner and with the least harm to the environment has come to the fore and the issue has now become supported by laws. Under the main heading that the automobile engine works with less fuel, with more efficiency, and with less damage to the environment, fuel permeability has been brought to the agenda for all products used in fuel systems and studies have been initiated in this regard. Achieving the permeability limit in fuel hoses can be possible with the improvement studies to be carried out on the following matter [26]:

- Using high-performance elastomers,
- To produce two-component rubber hoses,
- Using different materials together with rubber,
- Improving the chemical properties of the hose,
- To install a material with low permeability between the two layers.

Two-component hose production is a preferred method because it means to implement new technology, the result to be achieved serves the targeted purpose with all parameters and it allows competing globally. Because markets now demand products that are cheaper, lighter, more robust, and more aesthetically appealing [26]. Additionally, commercial fuel hoses used in industry are manufactured by using two-component hose production method by combining the rubber hoses with circular knitting technique, which has disadvantages such as needle breakages and consequently productivity and labour loses.

This study aims to investigate the effect of material type and braiding angle on the performance characteristics of the reinforced multi-layered hose, to manufacture high-pressure fuel hoses. For this purpose, NBR (Acrylo-Nitrile Butadiene rubber)/CPE (chlorinated polyethylene) fuel hose was manufactured and for the production of the reinforcement layer, braiding technology was used. With an attempt to discuss the effect of braiding angle on the performance characteristics of the reinforced multi-layered hose, the take-up speed of the radial braiding machine was altered. E-glass, aramid, carbon, and basalt yarns were used for the production of biaxial braided fabrics. Then CPE (chlorinated polyethylene) rubber was again used for the cover application. Some performance properties of the fuel hose such as hardness, ply adhesion, vacuum collapse bursting pressure and diametric expansion were measured and evaluated according to the requirements of the related standards.

2. MATERIAL – METHOD

2.1. Material

This paper investigates the performance properties of a NBR (Acrylo-Nitrile Butadiene rubber)/CPE (chlorinated polyethylene) fuel hose reinforced with braided structures. For this purpose, NBR and CPE were used as inner and outer layers of the fuel hoses, respectively. Additionally, E-glass, aramid, carbon, and basalt yarns were used as textile reinforcement in the multi-layered fuel hose.

NBR rubber mixture was used in the inner layer of the hose construction with its high fuel resistance feature. The recipe consists of NBR polymer, filler, plasticizer, additional chemicals, and curing agents. In rubber mixture recipes, the amount of ingredients is given proportional to 100 parts of rubber (PHR; “Part per Hundred Rubber”) by weight in the recipe. Total weight is related to banbury mixer volume. In this study, NBR polymer containing a 33 % ACN ratio. A peroxide vulcanization system was used as a vulcanization system to strengthen the adhesion of the NBR rubber mixture with the second layer rubber mixture and to improve the physicomechanical properties. The recipe of NBR rubber mixture following the MS263-20 International Automotive material test standard was used in the study.

The CPE rubber mixture was coated on the braided layer and formed the outer layer of the hose. The recipe consists of NBR polymer, filler, plasticizer, additional chemicals, and curing agents. In the recipe, CPE polymer containing above 33% Cl value, which is the optimal % Cl value of CPE rubber to increase oil and fuel resistance. A peroxide curing system was used as a curing system. The recipe of CPE rubber mixture following the MS263-20 International Automotive material test standard was used in the study.

The specifications of the yarns used as textile reinforcement are listed in Table 1.

Table 1. The specifications of the yarns [27]

Type of yarn	Yarn count (tex)	Number of filaments	Tensile strength (GPa)	Elongation (%)
Carbon	-	3K	230-600	1.5-2
Basalt	132	-	93-110	3.1-6
E-glass	300	-	72.5-75.5	4.7
Para-aramid	110	-	71-140	2.8-3.6
Polyester HT	167	-	1.1	14.5

2.2. Production of NBR and CPE rubber mixtures of the fuel hoses

The raw materials specified in the NBR and CPE rubber mixture recipes were weighed in an automatic formulation-weighing machine. Rubber mixture production's first step has been done with the help of intermesh rotor type Banbury, which has a capacity of 50 lt (Fig. 3a). Rotor cycle, pressure and temperature values, time, and cooling water system temperature can set on the system of banbury. In this study, different set parameters were used for the production of NBR and CPE rubber mixtures. Production parameters of the mixtures are listed in Table 2.

The second step of rubber mixture production was done with open mill mixing (Fig. 3b). Mixtures were transferred separately to the open mill to get the final shape. In open mill thickness and width of can set. The final shape values of NBR and CPE values were 10 mm of thickness, 80 mm of width.

The cooling step was done with the help of a batch-off system as a final step of rubber mixture production (Fig. 3c). According to the open mill, mixtures were transferred separately to the batch-off system to cool down the mixture. Mixtures were passed inside of the cooling pool and left to cool.

2.3. Production of the inner layer of the fuel hoses

The inner layer of the fuel hose was produced by using NBR rubber mixture in a single-screw extruder (Fig. 4a). The setting parameters of the extruder according to the type of NBR rubber mixture are given in Table 3.

Table 2. Production parameters of the NBR and CPE mixtures

Type of mixture	Process no	Definition of process	Time(s)/ Temperature (°C)	Rotor cycle (rpm)	Pressure (bar)
NBR rubber mixture Banbury	1	NBR rubber mixing	5s	49	50
	2	Adding filler+plasticizer+chemicals+curing agents	65°C	49	50
CPE rubber mixture Banbury	1	CPE rubber mixing	30s	49	50
	2	Adding filler+plasticizer+chemicals+curing agents	75°C	49	50

*Cooling water temperature: 30 °C

(a) (b) (c)

Figure 3. (a) Intermesh banbury with the capacity of 50 lt, **(b)** Open mill, **(c)** Batch-off system

(a) (b)

Figure 4. (a) Rubicon extruder, (b) T head extruder

Table 3. The setting parameters of extruders used in the production of inner and outer layers of hoses

Parameter	Rubicon single-screw extruder	T head extruder
Head temperature (°C)	75	75
1st area temperature (°C)	70	70
2nd area temperature (°C)	65	65
Feed temperature (°C)	60	60
Screw cycle (rpm)	8	9
Pulling speed (m/min)	7	8
Vacuum pressure (mmHg)	650	670
Head pressure (bar)	130	135
Cooling water temperature (°C)	23-24	23-24
Dimensional stability of the product (%)	2	2

2.4. Production of the braided hoses

After the production of the inner tube of the hoses, five different yarns, whose specifications were listed in Table 1, were used for the production of 2D biaxial braided reinforced hoses. The braiding process was performed on a radial braiding machine built up in laboratory with 48 carriers (Fig. 5) in three different take-up speeds (4, 6, and 8 m/min) which resulted in different braid angles (65°, 55°, 45°, respectively) and braid cover factors. A low carrier speed with a higher take-up speed results in loose braided structures with low braiding angles, which have a low cover factor [28]. Fig.6 shows the obtained braiding angle values at three different hose take-up speeds.

2.5 Production of the outer layer of the fuel hoses

To increase the adhesion between the textile reinforcement and the cover layer, a special solution mixture that is a combination of NBR rubber and solvent is applied to the reinforcement (Fig 7a). Then, CPE rubber was used for covering the braided hose. The covering process was performed on a T head extruder (Fig. 4b). The setting parameters of the extruder according to the type of CPE rubber are given in Table 3.

2.6. Vulcanization process

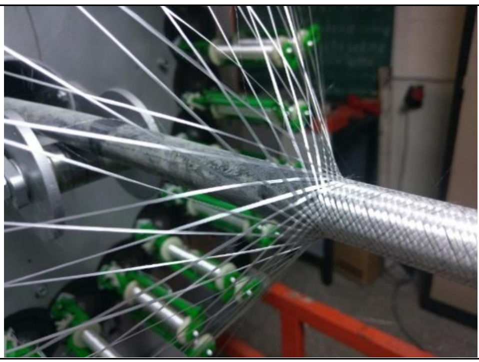
The final product of the extrusion process is NBR/braided fabric/CPE construction hose. As the hoses are raw, the shape of the hoses can be changeable. To keep the constant shape of the hoses, a vulcanization process was carried out (Fig.7b). The hoses were placed in autoclaves and cured at 9 bar pressure for 15 minutes.

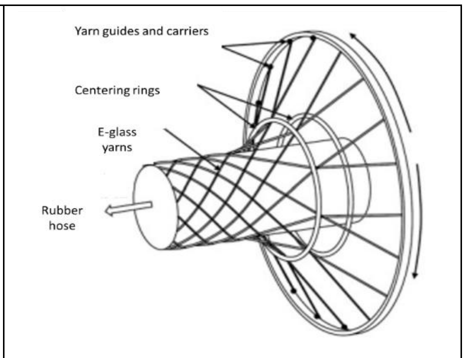
2.7. Testing Methods

To determine the performance characteristics of the hoses, quality tests were performed according to their main usage where high pressure is required.

2.7.1. Hardness measurement from the hose

The hardness values of the braided hoses were measured by shoremeter (DIN 53505).





(a) (b)

Figure 5. (a) Braiding process, (b) Schematic view of the radial braiding machine

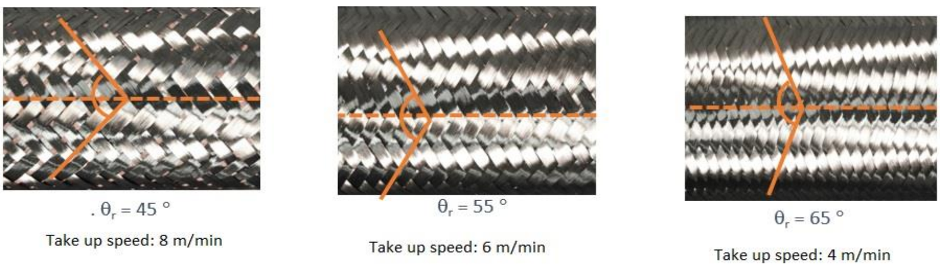


Figure 6. Braiding angle values depending on the take-up speeds

(a)

(b)

Figure 7. (a) Solution applying process, **(b)** Vulcanisation process

2.7.2. Ply adhesion test

Zwick universal testing equipment was used for the measurement of ply adhesion of the hoses. The test was carried out according to DIN 53530 to find adhesion force (N/mm) between the inner and outer layers. According to the standard samples should be at least 150 mm long, 200 mm wide and the test speed 100 mm/min respectively.

2.7.3. Permanent deformation test

Permanent deformation test was applied to determine how much the hoses undergo deformation under certain heat and load. The test has been carried out according to PV 3307 test standard. Suitable apparatus was used for the test with four samples. Test temperature and duration shall be 160°C and 22 hours with 50% compression. All thickness of samples were measured before the test (h_0), under 50% compression (h_1), and after (h_2) the test to determine the change of the thickness. Permanent deformation percentage calculated according to Equation (1).

$$PD\ \% = \frac{h_0 - h_2}{h_0 - h_1} * 100 \quad (1)$$

2.7.4. Burst test

Burst test was conducted at both room temperature and 110°C, according to standard TL 52624. One end of the hose was assembled to the bursting test machine and the other end was plugged with a fitting. Fluid that consists of 50/50 % volume destilled water and volume cooling liquid, was pumped inside the hose at a rate of 20 bar/sec. The pressure, where the hose bursted, was detected. At 100°C test, fluid inside the test machine was heated up and fed inside the hose.

2.7.5. Vacuum test

A vacuum test according to standard MS200-43 is applied to measure the vacuum strength of the hoses. One end of the hose was connected to the vacuum machine, the other end was closed with a gauge. The width of the hose is measured with a caliper from the middle of the hose. The manometer connected to the vacuum device was operated until it shows the desired vacuum value. After waiting for the specified time at the desired vacuum value, the width is measured from the middle part. The percentage change between the initial and final width values gives the slump value. In this study, the test was applied by keeping it in a 100 mmHg vacuum for 15 seconds.

2.7.6. Diametric expansion test

Diameter expansion test was conducted at both room temperature and 110°C in accordance with DIN 73411. In order to investigate the expansion behavior of the hose with hot fluid that is a mixture of water and coolant liquid, the degree of 110 C was selected.The test was applied to measure the swelling percentage of the hoses under 3 bar pressure. The width of the hose was measured with a caliper at the middle region. After the hose was connected to the device, the pressure was fixed at 3 bars and the second width measurement value was taken. The percentage change between the initial and final width value gives the swelling value.

Limit values were taken from the requirements of a high-pressure fuel hose. Tests, where do not mention any limits, can help evaluation of all limited results. All test limits are given in Table 4.

2.7.7. Finite Element Analysis

The studied fuel hose constructions were modeled as three dimensional (3D) and analyzed as static structural by using the finite element (FE) software ANSYS. The model consisted of the inner NBR layer which was braided over by textile reinforcements, and finally the outer CPE layer. The mechanical properties of the materials used in the FE model are given in Table 5. Element types used in meshing of the geometric model, which were given in Table 6, were chosen as program controlled. Loading conditions were defined as fixed supports at both ends of the hose and a linear pressure ramp of 0.8 MPa to be achieved in 1 s of inflation period.

Table 4. The requirements of a high-pressure fuel hose

Test	Unit	Limit values	
		Minimum	Maximum
Hardness measurement from hose	Shore A	65	75
Ply adhesion	N/mm	2	-
Permenant deformation	%	-	65
Diametric expansion at 25°C	%	-	-
Burst test at 25°C	bar	70	-
Diametric expansion with coolant at 110°C	%	-	-
Burst test with coolant at 110°C	bar	-	-
Vacuum	bar	-	15

Table 5. Mechanical properties of the materials used in the FE model [27, 29, 30]

Material	Young's modulus (GPa)	Poison's ratio (-)	Shear modulus (GPa)	Tensile strength (MPa)	Elongation (%)
NBR (Inner layer)	3.4	0.49	-	12.4	1.4
CPE (Outer layer)	4.1	0.49	-	14.8	3.1
Carbon fabric	3.4	0.1	1.55	-	1.4
Basalt fabric	4.1	0.3	1.58	-	3.1
E-glass fabric	3.5	0.2	1.46	-	4.8
Para-aramid fabric	2.9	0.3	1.12	-	3.6
Polyester (HT) fabric	0.8	0.495	0.27	-	15

Table 6. Element types used in the meshes

Geometry	Type of element	Element shape	Element name
Reinforcement	Tetrahedral	TET10	SOLID187
Inner layer	Hexagonal	HEX20	SOLID186
Outer layer	Hexagonal	HEX20	SOLID186
Contact surfaces	Quadrilateral	QUAD8	CONTAC174
Contact surfaces	Quadrilateral	QUAD4	TARGE170
Contact surfaces	Quadrilateral	QUAD8	SURF154

3. RESULTS AND DISCUSSION

According to MS 263-20 Type-A standard, the hardness values of the hoses should be between 65–75 ShoreA (Table 4). Fig. 8 illustrated that hardness values of all types of hoses are within the limit values. As braiding take-up speed decreases, the hardness values of the hoses increases. This situation can be explained by the tight structure of the braided materials produced with lower braiding take-up speed. The denser structure can lead to an increase in hardness independently from the type of rubber.

The ply adhesion characteristic of the hoses should be higher than 2 N/mm (Table 4). The ply adhesion results revealed that, NBR/carbon/CPE and NBR/polyester/CPE hoses produced with the braiding take-up speed of 8 m/min exhibit acceptable values (Fig. 9). Hoses produced with a braiding take-up speed of 8 m/min provide higher ply adhesion characteristics than those produced with lower braiding take-up speed. This is due to the looser braided construction and lower yarn consumption in the production with the braiding take-up speed of 8 m/min. The more the contact areas between the rubber materials used for the production of the inner and outer layers of the hoses, the higher the ply adhesion characteristic of the structures.

For high-pressure fuel hoses, the permanent deformation value should not exceed 65% (Table 4). As is expected, NBR/braided fabric/CPE hoses with denser knitted structures exhibit higher strength properties. A hybrid composite material with a higher strength value will be more resistant to deformation under pressure in a hot environment. Fig.10 showed that the permanent deformation values increase with higher braiding take-up speed hence lower consumption. A hybrid hose construction in which less fiber is used is expected to give worse permanent set values because of its low strength properties. Also, the permanent deformation values of the NBR/basalt/CPE and NBR/polyester/CPE hoses produced with the braiding take-up speed of 4 m/min are within the acceptable limit. Hoses produced with a braiding take-up speed of 4 m/min have denser character than the others. It is thought that braiding take-up speed and type of material have a synergic effect on permanent deformation parameters since the permanent elongation values of the carbon, e-glass, and aramid braided hoses produced with the braiding take-up speed of 4 m/min are not within the limits.

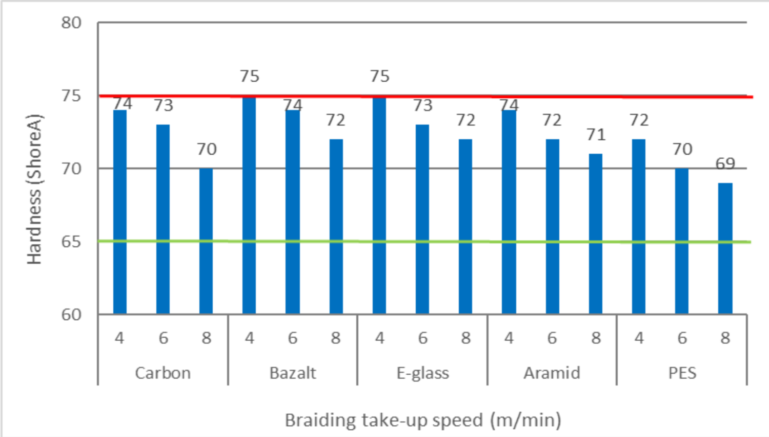


Figure 8. Hardness values of the braided hoses

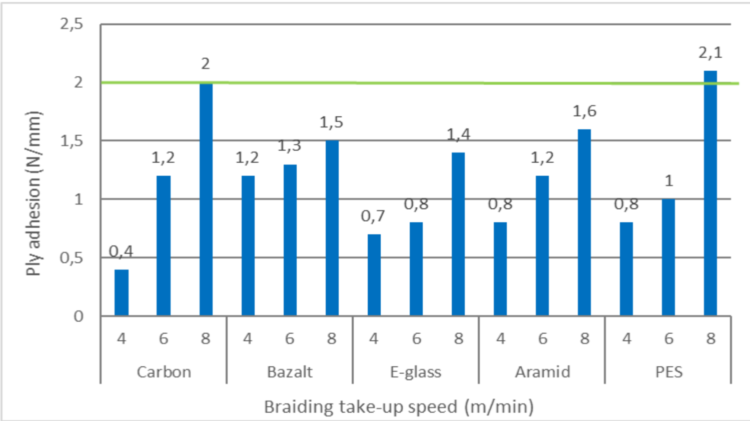


Figure 9. Ply adhesion results of the braided hoses

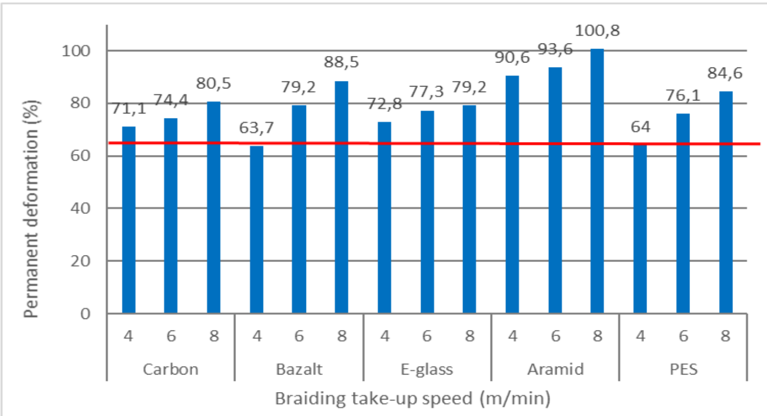


Figure 10. Permanent deformation results of the braided hoses

There is no limit specified for the diametric expansion test at 25 °C in the ASTM D380, MS 263-20 TypeA standard. According to the results, it is observed that the diametric expansion rates of the hoses varied between 0.2 and 3.6 %. For all braided hoses, as the braiding take-up speed increased, diametric expansion rates have been increased, as well. It is thought that the most effective parameter influencing this parameter is the density of the braided structures. The diametric expansion rate of the looser braided structure is higher because the looser structure leads to an increase in the gap between the loops which reduces the cover factor of the fabric. When the effect of material types is examined, it is found that the lowest diametric expansion rates at 25°C were obtained from NBR/carbon/CPE hoses for all braiding take-up speeds. Since these fuel hoses will run in hot circumstances on the engine block, this test was additionally performed at 110 °C, to predict the diametric expansion behavior of the hoses in hot conditions. The diametric expansion rate values at 110 °C exhibited the same inclinations. As the braiding take-up speed increased, the diametric expansion rates have been increased (Fig. 11).

One of the most important criteria for high-pressure fuel hoses is the bursting pressure at 25°C. According to Table 4, the bursting pressure characteristic of the hoses at 25°C should be higher than 70 bar. As seen in Fig. 14, NBR/carbon/CPE and NBR/aramid/CPE hoses produced with the braiding take-up speeds of 4 and 6 m/min have acceptable bursting pressure values. Also, the bursting pressure values of NBR/basalt/CPE and NBR/E-glass/CPE hoses with the braiding take-up speed of 4 m/min are higher than 70 bar. Additionally, for all braiding take-up speeds, the bursting pressure results of the NBR/polyester/CPE hoses are out of the limit values. This may be due to the chemical and physical properties of the polyester yarn. It is a conventional yarn used in the polyester sector where less functionality is required. It can be explained by the low tensile strength of the polyester fiber. Its low tensile strength leads the hose not to resist pressure loaded to the structure. Regardless of the material type, the bursting pressure values of the hoses have been decreased as the braiding take-up speed increased. This situation can also be explained by the loose structure of the braided materials produced with higher braiding take-up speed. A loose structure will cause the hose to deform and burst more easily under high pressure. Rubber hoses expand more in hot conditions resulted in decrease of pressure resistance and large deformation. Since these fuel hoses will run in hot circumstances on the engine block, this test was additionally performed at 110 °C, to predict the bursting pressure of the hoses in hot conditions. The bursting pressure values at 110 °C exhibited the same inclinations. As the braiding take-up speed increased, the bursting pressure values have been decreased (Fig. 12).

The vacuum collapse test values of the fuel hoses should be lower than 15 bar concerning ASTM D380 standard. The results revealed that the vacuum collapse values of all hose types were within the limits (Fig. 13).

The FE model prepared and run in ANSYS software contained 11.515 elements and 27.542 nodes. The solutions took 8 s, required a memory size range of 835-865 MB, and had a result file size range of 16.063-18.125 MB. The total deformation values of the hoses with defined constructions were obtained via FEA by including 5% standard deviation rate (Fig. 14 (a-e) and Table 7).

The results revealed that NBR/basalt/CPE hoses provided the lowest total deformation value. By using finite element analysis, it was predicted that NBR/basalt/CPE constructed hoses can be preferable for high-pressure fuel hoses.

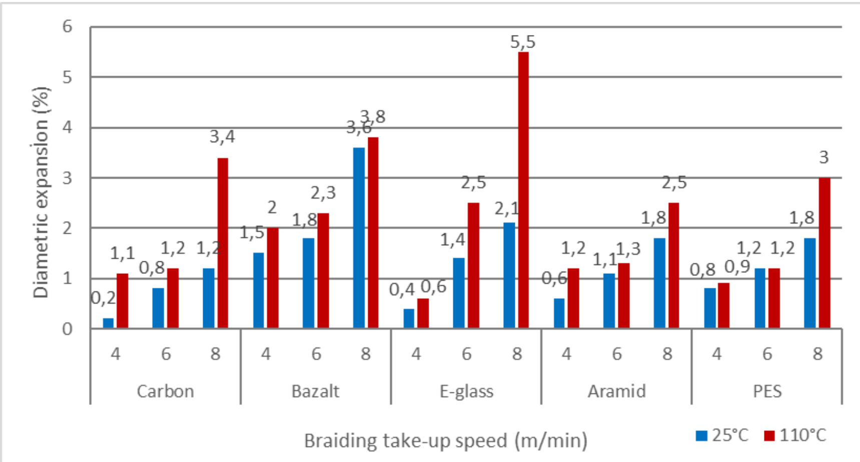


Figure 11. Diametric expansion results at 25 °C and 110 °C of the braided hoses

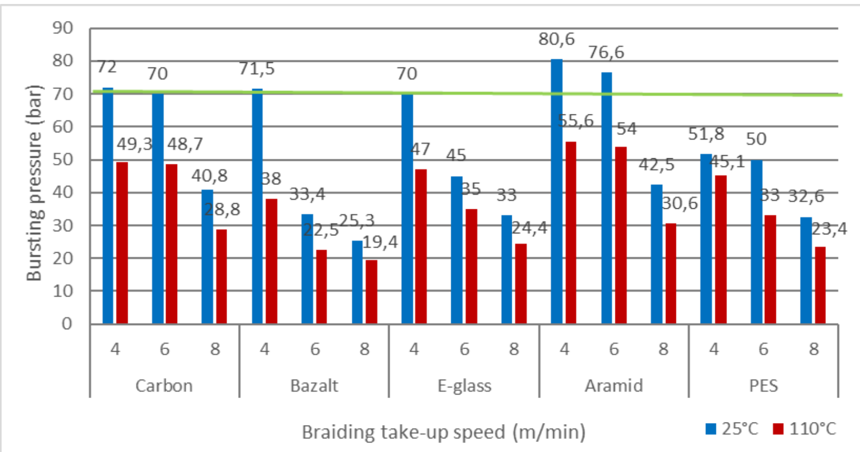


Figure 12. Bursting pressure results at 25 °C and 110 °C of the braided hoses

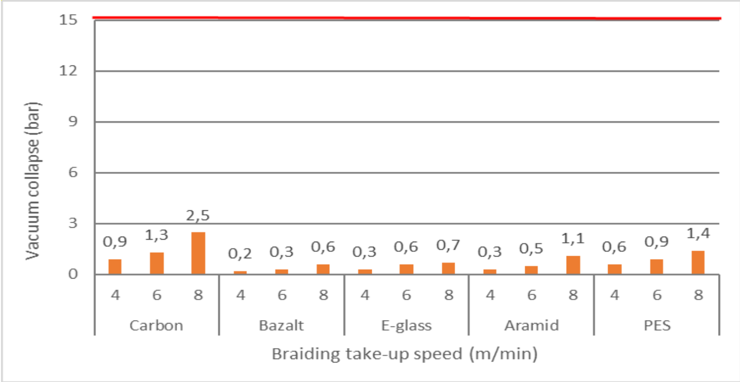


Figure 13. Vacuum collapse test results of the braided hoses

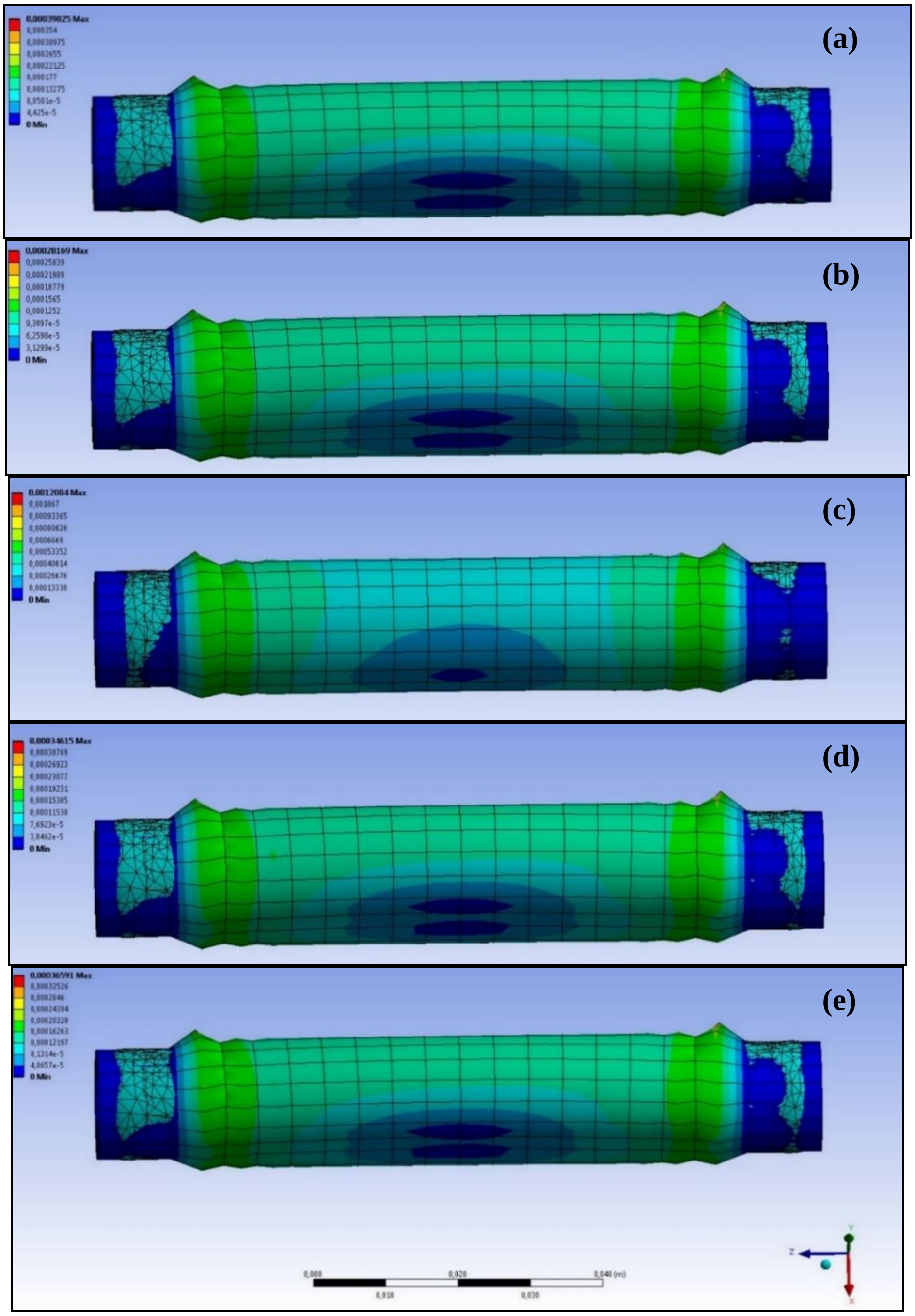


Figure 14. FE results of (a) NBR/Carbon/CPE, (b) NBR/Basalt/CPE, (c) NBR/Polyester/CPE, (d) NBR/Aramid/CPE, (e) NBR/E-glass/CPE hoses

Table 7. Total deformation values of the fuel hoses

Material	Total deformation (mm)
NBR/Carbon/CPE	0.398
NBR/Basalt/CPE	0.282
NBR/Polyester/CPE	1.200
NBR/Aramid/CPE	0.346
NBR/E-glass/CPE	0.366

4. CONCLUSION

This study aims to investigate the effect of material type and braiding angle on the performance characteristics of the reinforced multi-layered hose, to manufacture a high-pressure fuel hose. For this purpose, NBR (Acrylo-Nitrile Butadiene rubber)/CPE (chlorinated polyethylene) fuel hose was manufactured using a single-screw extruder and for the production of the reinforcement layer, braiding technology was used. With an attempt to discuss the effect of braiding angle on the performance characteristics of the reinforced multi-layered hose, the take-up speed of the radial braiding machine was altered. E-glass, aramid, carbon, polyester, and basalt yarns were used for the production of biaxial braided fabrics. Then CPE (chlorinated polyethylene) rubber was extruded for the cover application. Performance properties of the fuel hose such as hardness, ply adhesion, permanent deformation, vacuum collapse, bursting pressure, and diametric expansion were measured and evaluated according to the requirements of the related standards.

The results are summarized below:

- By using finite element analysis, it was predicted that NBR/basalt/CPE constructed hoses can be preferable for high-pressure fuel hoses.
- With increased braiding take-up speed, ply adhesion, vacuum collapse, permanent deformation and diametric expansion properties of hoses increase, while hardness and bursting pressure of hoses decrease.
- As a result of the vacuum test, it was observed that all hose types had a collapse percentage within the limit.
- It has been determined that NBR/Basalt/CPE fuel hose produced at 4 m/min braiding take-up speed provides optimum functional and adhesion properties, except ply adhesion property of basalt hose with 4m/min, because of its hardness, permanent deformation, bursting and vacuum test values at 25°C are within the limit. Additionally, the results were verified with the results of the Ansys simulation program.

In future studies, it is planned to develop an adhesive solution and improve process parameters to enhance the ply adhesion force of the NBR/basalt/CPE hoses whose ply adhesion values were out of the limits.

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