Effect of palm oil biodiesel blends (B10 and B20) on physical and mechanical properties of nitrile rubber elastomer

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ABSTRACT

Alternative fuels, such as biodiesel, play an important role in protecting the global environment. Biodiesel obtained from palm oil holds promising applications for compression ignition or diesel engines. However, one major concern associated with the adoption of biodiesel is the degradation and material incompatibility between biodiesel and the existing fuel system. Changes in fuel composition with the introduction of biodiesel often create many problems in which the elastomer is normally used as the fuel hose material in a diesel engine fuel system. This study investigated the effect of palm oil biodiesel blends (B10 and B20) on the nitrile rubber elastomer's physical and mechanical properties, such as mass and volume change, hardness, and tensile strength. Biodiesel blends were found to affect the mechanical properties of the elastomer, causing the fuel hose to swell. After an immersion of the elastomers in the biodiesel blends at room temperature for five weeks, biodiesel properties, such as density and viscosity, were also examined. The density and viscosity were found to increase in the blends with increasing biodiesel content. The result of the study shows that the density and kinematic viscosity increased with the percentage of biodiesel blends. The elastomer increased mass change by 58.1%, the volume change by 58%, the tensile strength by 53.5% and the hardness by 52% with increasing biodiesel blends.

1. Introduction

Conventional energy sources, such as coal, petroleum gas, and non-renewable fuel, are becoming depleted; but the dependence on these types of energy is always increasing [1]. For these reasons, the world is searching for an alternative fuel to reduce the reliance on diminishing energy sources. One of the promising alternative fuels is biodiesel [2]. Biodiesel can be produced from animal fat or vegetable oil [3]. To make biodiesel a practical alternative fuel source, several aspects must be considered [4].

Biodiesel is produced with alcohol (usually ethanol or methanol) and a catalyst (typically potassium hydroxide or sodium hydroxide) [5]. This procedure isolates the glycerin from the oil or fat. The next element,

biodiesel, is thinner than the first oil or fat and therefore works better on a diesel engine [6]. The term "biodiesel" refers to 100% fine fuel, assigned as B100, which meets the D6751 standard of the American Society for Testing and Materials (ASTM) [7]. The expression "biodiesel mix" alludes to a mixture of fine biodiesel with diesel, commonly referred to by the letter B, followed by a number [8]. This number refers to the volumetric ratio of biodiesel. Biodiesel can be used in standard diesel engines at any rate - from B1, or, in other words, biodiesel mixed with 99% diesel, to pure biodiesel, known as B100 [9].

Biodiesel provides technical advantages compared to regular diesel. Biodiesel has the ability to improve the cetane number (CN), lubricity, and reduce emissions. The CN is one of the main properties of biodiesel, which represent the ignition characteristics and quality. High CN has a

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short ignition delay that provides better engine operation (easy to cold start, less smoke during starting, less emission, less carbon deposits, and increased fuel efficiency) [10]. Improved CN of biodiesel has been attributed to the presence of saturated molecules and longer fatty acid carbon chains [11].

Regarding lubricity, the degree of unsaturation, oxygenated moieties, and long-chain molecules could effectively improve the lubricity of biodiesel [12]. It reduces the wear of metal-to-metal contact that can enhance the engine life. Biodiesel emissions are considered relatively cleaner compared to those of regular diesel fuel. Because of its oxygen content, soot and carbon monoxide can be reduced. However, nitrogen oxide (NO_x) emissions are reported to be higher in using biodiesel [13].

However, biodiesel has some disadvantages, such as high viscosity, poor oxidation stability, higher corrosiveness, and a short storage period [14–16]. High viscosity may cause deposits on the piston rings. Poor oxidation stability leads to severe operational issues, particularly clogging in the fuel filter, sludging in the crankcase, deposits in the combustion chamber, and sticking moving parts [17]. Moreover, biodiesel also causes earlier failure of fuel system components, such as hose rupture, seal damage and line leakage [18]. Microbial contamination and oxidized products (aldehydes, ketone, insoluble gums, short-chain fatty acids) have been identified as aggravator to accelerate the degradation of fuel system materials [19]. These occur severely when biodiesel is stored for a long time [18].

In the application of fuel systems, biodiesel comes into contact with several materials, including hoses, seals, and gaskets. Material compatibility in biodiesel is different from regular diesel [20,21]. Material compatibility in regular diesel has been well-established. Based on previous experience in the automotive industry, the materials in fuel supply systems were compatible with regular diesel [22]. However, finding alternative fuels, such as biodiesel, generates further insights into the impact on the materials used by manufacturers. Compatibility has an important role in the reliability of system.

In the automotive industry applications, materials that come into contact with fuel can be categorized into ferrous alloys, non-ferrous alloys and elastomers [20]. The degradation of material due to biodiesel has been extensively investigated. Wear, chemical corrosion, electrochemical attack, and material degradation affect materials in biodiesel applications. Numerous studies have investigated that material degradation is a crucial issue related to material incompatibility in biodiesel, particularly elastomer material [23,24]. Among these material categories, elastomers undergo degradation to a greater degree in biodiesel. In addition, common elastomers, like neoprene/chloroprene, natural rubber, and nitrile rubber, were not suitable for application in biodiesel. However, other studies mentioned that elastomers were fully compatible with B20 [20]. The different result may be affected by different type of elastomer, source of biodiesel and experimental conditions.

An elastomer is a polymer with versatile properties. It is a polymer that twists under pressure and returns to its unique shape when the pressure is ejected. There are many types of elastomers, most of which are rubbers. Elastomers are formless polymers with significant segmental movement. Elastomers have been widely applied in automotive components. Various studies have discussed the interactions between automotive component materials and biodiesels [25]. Some examinations have shown that when biodiesel is used as a fuel in diesel engines, the infusion framework endures a few problems, for example, swelling in the elastomeric seals in infusion conveyance, which may cause fuel spillage. The swelling results showed an incongruence between the elastomer and the fuel, causing a significant loss of elastomeric properties and a loss of fixing capacity. Therefore, it is important to investigate to what extent biodiesel influences the swelling of elastomeric seals. Moreover, there is a lack of knowledge on the compatibility of fuel system elastomers with biodiesel blends (B10 and B20), particularly palm biodiesel. This study aims to identify the properties of B20 biodiesel and compare it with B10 and perform an elastomer effect test (physical and mechanical) on critical parts exposed to biodiesel B20 versus B10 with various time of immersion (up to 5 weeks).

2. Literature review

2.1. Biodiesel production

Several sources are used to produce biodiesel, such as soybean [26], sunflower [27,28], palm oil [29], canola [30], cottonseed [31], jatropha [32], and rapeseed [33]. Palm oil has a slightly better benefit than other vegetable oils and is likely to be the feedstock for biodiesel production in several countries, such as Malaysia and Indonesia [34]. Unlike soy and rapeseed, palm oil is a persistent crop. Persistent crop with continuous production means endless and sustainable oil production despite some seasonal peaks and cycles. Palm plantation has the highest oil production per hectare. Palm oil has the highest income per hectare, making it the best source of biodiesel production.

Vegetable oils produce biodiesel. Triglycerides are the fundamental ingredients for vegetable oil. Triglycerides are glycerol esters with long-chain fatty acids, often called fatty acids. Biodiesel is described as mono-alkyl esters of renewable feedstock long-chain fatty acids such as vegetable oil or animal fats for compression ignition engines. When used as fuel, this term is given to esters.

Recently, because of its physical and chemical similarity, biodiesel has been classified as a great alternative to diesel oil [35,36]. It is precisely possible to use it in compression ignition engines with no engine change. Biodiesel is made from animal fats, vegetable oils, and residual fats. Its benefits cannot be overemphasized: it is renewable, non-toxic, does not contain sulfur, biodegradable, and is a better lubricant. Its use generates various social benefits: new jobs, rural revitalization, and global warming reduction.

Biodiesel is a renewable fuel from fatty acid methyl esters (FAME) derived from transesterification from food processing of vegetables, animal fat, and methanol oil. Biodiesel has various benefits and is known as a "green fuel". Compared to regular diesel, biodiesel is relatively safe, non-toxic, and biodegradable. It is oxygenated, sulfur-free, and aromatic and is a cleaner combustion fuel with reduced SOx, CO, unburned hydrocarbons, and particulate matter emissions [37]. Biodiesel has its drawbacks, however, mainly because of the increased density and viscosity [38]. The application of alcohol additives, such as methanol ethanol and can increase the density, and viscosity can be simply reduced [39].

Transesterification or alcoholysis is the hydrolysis-like displacement of alcohol from an ester, and instead of using water, they use alcohol. The reaction is one of the shifting reactions and results from the fuse of the reactants, as shown in the equation below:

$$\text{Oil or Fat} + \text{Methanol} \quad \text{Methyl Esters} + \text{Glycerol} \tag{1}$$
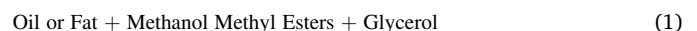
The fatty acids triglycerides are fatty acid esters, and transesterification is a chemical division of heavy molecules that leads to simpler esters. Triglycerides react with alcohol (methyl, ethyl, or other) for a certain duration in the presence of a catalyst at a measured temperature. The finishing products are alkyl esters and glyceride. The main product is the alkyl esters, whose favorable characteristics are used as fuel in compression ignition or diesel engines; glycerin is a byproduct. The chemical equation would accordingly change with higher alcohols.

Various studies have shown that methanol transesterification is more practical than ethanol transesterification. Because of its low cost and physical and chemical benefits, methanol is preferable [8]. Another benefit of using methanol is glycerin separation, which can be received by simple decantation. Currently, most biodiesel is made with homogeneous base catalytic products, such as sodium hydroxide (NaOH) and potassium hydroxide (KOH). These catalysts are often used for several reasons. The catalytic process can catalyze the low reaction temperature, the atmospheric pressure, and the long conversion periods that can

be reduced.

Etim et al. [40] developed a bio-catalyst using biogenic waste materials, such as banana peels and waste chicken egg shells. This catalyst was used in the transesterification of linseed–marula bi-oil methyl ester as a potential factor in an effective and sustainable feedstock for biodiesel production.

Several specifications, including reaction temperature, pressure, reaction time, agitation rate, type of alcohol used and molar alcohol-to-oil ratio, type and the catalyst used concentration and concentration of humidity, and FFA in feed oil, have been recorded to depend on the transesterification process. The optimum values for maximum conversion depend mainly on the physical and chemical properties of the feedstock oil. The main source of biodiesel is homogeneous base catalysts, such as NaOH and KOH. These catalysts are common for several reasons in the industry:

- Capable of catalyzing low reaction and atmospheric pressure reactions.
- High conversion can be achieved in a short period can be achieved.
- Widespread and cost-effective.

Selemani and Kombe [41] investigated a heterogeneous base-catalyzed glycerolysis process to lower the FFA and meet requirements. Alkali-catalyzed transesterification, the most common commercial biodiesel synthesis method, uses moderate temperatures and pressures to obtain a higher than 98% conversion yield. Unfortunately, the technology's effectiveness is limited by the high FFA percentage of oil feedstock.

2.2. Biodiesel properties

The features of several biodiesel fatty esters determine the total fuel characteristics of the biodiesel fuel. Instead, the structural characteristics of the fatty acid and alcohol components of the fatty acids are used to determine the properties of the different biodiesel fatty esters.

The density of a substance, or more precisely its volumetric mass density, is its mass per unit volume. To model combustion processes and other applications, biodiesel density data is required as an operation of temperature. The density of a methyl ester depends on the molecular weight, free fatty acid content, temperature, and water content.

Because palm oil is popular as fuel [42–44], it is necessary to correct the measured density and specific gravity data. Measured results and projections have recently been published on biodiesel properties, but measurements and predictions have rarely or perhaps never been carried out of palm oil biodiesel density.

The experimental density value was modeled at various pressures and temperatures using the modified Tammann-Tait equation, an empirical model widely used to correlate density at high pressure. The parameters of the modified Tammann-Tait equation, the isobaric thermal expansion, isothermal compressibility, internal pressure, and the difference between constant and continuous volume pressure of the specific heating capacity were determined.

The biodiesel viscosity by factor two is greater than diesel, and the thickness increases as the biodiesel level increases. Next, the viscosity is influenced by temperature, and many problems because of the high viscosity are most detectable under low surrounding temperatures and cold engine starting conditions [45]. Kinematic viscosity increases as the biodiesel level increases. This is because biodiesel is viscous more than diesel. The greater viscosity of biodiesel is because it has a higher subatomic weight than diesel.

Its viscosity is one of the main concerns about biodiesel. This diesel viscosity ranges from 2.5 to 3.2 cSt at 40 °C, while the soya oil biodiesel viscosity ranges from 4.2 to 4.6 cSt. The diesel viscosity must be high enough to supply the engine components with sufficient lubrication but low enough at operating temperature. The fuel filter and injection system can be connected to the engine with high viscosity. Vegetable oil

comprises long hydrocarbon lipid chains that reduce the viscosity of the lipids into smaller molecules. This is achieved by the transformative transesterification of vegetable oil and animal fats into alkyl esters to reduce their viscosity. However, the viscosity of biodiesel remains higher than diesel and because the fuel filters are flowing slowly, the engine may not be able to use fuel at low temperatures.

Numerous studies discussed the biodiesel properties such as density and viscosity. Regarding operational and durability, biodiesel has long-term problems due to being more viscous than regular diesel. Gulum and Bilgin [46] measured and predicted the density and viscosity of various diesel-vegetable oil blends. In the other studies, they proposed two-dimensional surface models for predicting the density of biodiesel-diesel-alcohol ternary blends, which have been used in existing compression ignition or diesel engines to improve performance and decrease emissions [47].

Hoang [48] proposed an approach to determine the ratio of biodiesel based on experimental data and empirical equations. The choice of suitable ratio mixing depends on the requirements related to kinematic viscosity. He developed a model for predicting the viscosity and density of biodiesel–regular diesel blends based on various biodiesel types such as jatropha, coconut oil, and waste oil.

Bilgin and Gulum [49] investigated the individual effects of essential transesterification reaction variables on density and viscosity of produced hazelnut oil methyl ester, and determined reaction variables proving the minimum viscosity.

2.3. Elastomer in biodiesel application

An elastomer is a polymer with an ability of "elasticity", usually with a low modulus and high capacity stress compared to other materials. This term is often used interchangeably with the term rubber. The elastomer is an amorphous polymer that exists in the glass above its transition temperature, enabling significant movement in segments so that it can also be highly permeable. Therefore, at ambient temperatures, rubbers are relatively soft and deformable. Their primary application is for sealing, adhesives, and flexible molded components. Elastomers may be thermosets or thermoplastics, known as thermoplastic elastomers or TPEs (the type of cross-links requiring vulcanization). TPEs have two main advantages compared to conventional (vulcanized) thermoset elastomers.

In a significantly shorter cycle time than common rubber compression and/or transfer molding, TPEs are molded or extruded on standard plastic processing equipment. They are produced by copolymerizing two or more monomers using block or graft polymerization techniques. One monomer is a hard or crystalline polymer segment, which is a thermally stable component, while the other is a soft or amorphous part that contributes to the elastomeric or rubber characteristics. The proportion of monomers and the duration of soft and hard segments can be varied to manage physical and chemical properties. Long-chain molecules with different hard and soft sections or alternative structures create blocking techniques. Graft polymerization methods include the connection of a polymer chain to another. The properties of each phase can be generalized, as shown in Table 1.

Various studies discussed elastomer compatibility in biodiesel applications by investigating the degradation effect after a certain

Table 1
Plastic properties.

Hard phase	Soft phase
Continuous use temperature	Lower service-temperature limits
Tensile strength	Hardness
Tear strength	Chemical and fluid resistance
Flexibility	Adhesion to ink adhesives and over molding substrates

immersion time. Several elastomers, such as nitrile rubber (NBR), natural rubber, fluoroelastomer (FKM), butadiene rubber-poly vinyl chloride (NBR/PVC), polychloroprene, hydrogenated nitrile rubber (HNBR), fluoro-viton, neoprene, fluorocarbon, ethylene propylene diene monomer or EPDM, and silicone, have been observed and reported by many researchers. A number of variables were investigated, such as the type of biodiesel, the percentage of biodiesel blends, temperature condition, immersion duration, oxidized, and percentage of acrylonitrile in NBR. Most studies mentioned that higher amount of biodiesel blends changed elastomer properties. The explanation of experiments was quite complicated. Biodiesel and regular diesel have different effects on elastomers due to different chemical structures.

Moreover, the oxidation of biodiesel affects its characteristics. It is susceptible to oxidation under exposure to air when it is stored and the existence of unsaturated fatty acids. Being oxidized, it produces hydroperoxides at the unsaturated points of the fatty acids and these hydroperoxides later decompose to ketones, aldehydes, and shorter-chain carboxylic acids. Esters, as biodiesel's main constituents, can also be easily hydrolyzed in the presence of water to form carboxylic acids [50]. Several different mechanical and physical changes, such as volume, mass, elongation, tensile strength, and hardness, may be involved. Table 2 summarizes the significant findings of the elastomer in biodiesel.

3. Methodology

3.1. General process

The general methodology for determining the elastomer effect test for physical and mechanical components exposed to biodiesel from B20 and B10 is explained in the following section. At the beginning of this research, several methods were used before the elastomer test using the appropriate ASTM standard. The general research flow is shown in the flowchart. This section briefly explains the study's total flow in the flowchart, as shown in Fig. 1. Based on the flowchart, at the beginning of the research, all biodiesel information was collected, especially for B20 and B10, to better understand how this experiment was carried out. The properties of biodiesel can vary depending on the mixture, which can cause the fuel hose, which is mainly elastomer, to change its properties. All this information was collected from articles, journals, and other research material for further examination.

Biodiesel preparation was divided into two, B10 and B20. B10 comprises 10% palm methyl ester and 90% regular diesel fuel. The B20 blend comprises 20% palm methyl ester and 80% regular diesel fuel. This preparation of biodiesel stock, whether buying from the nearest petrol station or blending the biodiesel itself, to obtain the desired blends. After that, the flowchart stated how to find the properties of biodiesel. The properties included in this experiment are the viscosity and density of the biodiesel.

Next, the elastomer specimen was prepared using a diesel car fuel hose. These specimens were cut and shaped according to the ASTM standard to follow the procedure. When all the specimen was completely produced, the experiments were began on the mass and change of volume test. Then, follow up with the hardness and tensile tests to find physical and mechanical defects in the elastomer specimens. After the entire test was completed, analyze all the information from the test, whether in data or graphs, to get the result. Write a discussion on the result of all the experiments that were conducted.

3.2. Experimental works

In this study, biodiesel and diesel engine fuel hoses were the main raw material used to measure the effect of an elastomer on biodiesel. Two types of biodiesels use B20 and B10. A 10% palm methyl ester, a 90% regular diesel furnace. The B20 blend consists of 20% palm methyl ester and 80% regular diesel fuel.

This study used the diesel engine fuel hose as an elastomer specimen.

The nitrile rubber (NBR) fuel hose was used in this experiment. The specification of NBR fuel hoses is shown in Table 3. It must be an elastomer material and recognize the ASTM standard for elastomer and elastic modulus. All experiments follow this standard to obtain the expected result from the previous researcher. This standard covers the shape and dimension of the specimen and the procedure to get the best result.

3.2.1. Biodiesel preparation and test

The physical properties of B10 and B20 biodiesel were investigated to find the percentage of the mixtures, density, and kinematic viscosity. Biodiesel must first be analyzed to confirm that the biodiesel blends used are correct. The percentage of biodiesel in a particular blend can be measured by a biodiesel analyzer. This test is crucial to avoid any mistakes when performing the test because if the biodiesel blend used is wrong, it affects the final value of the experiment. The biodiesel analyzer is given in Table 4. It can measure the concentration rate when putting biodiesel fuel on top of the analyzer from 0% to 100%. The result can be trusted, as the analyzer is compatible with the ASTM D 7371 and EN 14078 standards.

The ASTM Standard D1298 was applied to measure the density of biodiesel for both B10 and B20 biodiesel blends. Measurements were carried out at 15 °C using the Baume Hydrometer density meter, as shown in Table 5. Biodiesel for both blends was chilled and the evaluation was carried out with the hydrometer when its temperatures reached 15 °C and the hydrometer value was calculated when immersed in biodiesel fuel. For each sample, measurements were performed three times, and the average value was documented.

The test method of ASTM Standard D445 has been used. The kinematic viscosity at 40 °C was constant by accumulating the constant tube and recording the time taken for a known volume of the liquid stream under gravity through the calibrated glass viscosity capillary tube. The viscosity baths were used for the viscosity measurements using the viscometer with its specification given in Table 6 to evaluate the viscosity of biodiesel for B10 and B20. In this test, the time taken for biodiesel fuel to travel from point A to point B was recorded. As in the density measurement, the viscosity measurement were repeated three times per sample to find the average value. For the evaluation of the kinematic viscosity rates, which is v_1 and v_2, the equation below can be used from the recorded time taken t_1 and t_2 to find the average viscosity value.

$$v_{1,2} = C \times t_{1,2}$$

where:

$v_{1,2}$ = kinematic viscosity value for v_1 and v_2, respectively, mm^2/s
C = calibration constant of viscosity, mm^2/s and C = 0.014112 for 0.46 mm viscosity tube at 40 °C
$t_{1,2}$ = measured flow times for t_1 and t_2, respectively, s

3.2.2. Elastomer preparation and test

For mass and volume tests, the test was carried out with 10 test coupons of 25 by 50 by 2.0 ± 0.1 mm from an NBR fuel tube, as defined by ASTM D471. For the hardness test, according to ASTM D2240, square-dimensional elastomer specimens (20 mm × 20 mm) and the C-shaped die dumbbell are used for the tensile test ASTM D412. For all specimens with different biodiesel blends, one jar per coupon was used for immersion testing. Each of the samples was statically immersed in B10 biodiesel blends in an individual container that contained 3 test samples for 5 weeks, which is for one blend of B10, while B20 biodiesel has the same amount of elastomer samples and the same period of immersion. This soak analysis was conducted in the laboratory to control room temperature. Each container was labeled with the week and the concentration of biodiesel blends to allow one to draw each week samples from each biodiesel blend for further analysis.

Table 2
Significant findings of elastomer in biodiesel from other studies.

Type of Elastomer	Type of Biodiesel	Percentage of Biodiesel	Significant Findings	Author(s)
- NBR - Polychloroprene - Fluoro-viton	Palm	0, 10, 100%	Nitrile rubber (NBR): - Degradation ↑ (for B10, B100) - Mass ↑ (for B10, B100) - Volume ↑ (for B10, B100) - Tensile strength ↓ (for B10, B100) - Elongation ↓ (for B10, B100) - Hardness ↓ (for B10, B100) Polychloroprene - Degradation ↑ (for B10, B100) - Mass ↑ (for B10, B100) - Volume ↑ (for B10, B100) - Tensile strength ↓ (for B10, B100) - Elongation ↓ (for B10, B100) - Hardness ↓ (for B10, B100) Fluoro-viton - Good resistance - Mass constant - Volume constant - Tensile strength constant - Elongation constant - Hardness constant	Haseeb et al. [51]
- NBR - Fluorocarbon - Neoprene - Ethylene propylene diene monomer or EPDM - Silicone	Soybean	0, 50, 100%	- Formic acid caused higher swelling in NBR, fluorocarbon, neoprene, and silicone than acetaldehyde. - EPDM: Volume ↓ (for B50, B100 and addition formic acid)	Kass et al. [23]
NBR	Jatropha curcas	0, 5, 10, 20, 50, 100%	Degradation ↑ (for higher percentage of biodiesel)	Hu et al. [52]
NBR	Palm	100%	- Degradation ↑ (for higher immersion duration) - Mass ↑ - Volume ↑	Haseeb et al. [53]
- Fluoroelastomer (FKM) - NBR	Soybean	20%	Degradation ↑ (for oxidized as compared to not-oxidized biodiesel). FKM - Volume ↑ - Hardness ↓ - Tensile strength ↓ NBR - Volume ↑ - Hardness ↓ - Tensile strength ↓	Terry et al. [54]
- NBR - Hydrogenated NBR (HNBR) - Butadiene rubber-poly vinyl chloride (NBR/PVC) - FKM	Palm	10%	Varying degradation for different elastomers. NBR - Volume constant - Hardness ↑ - Tensile strength ↓ HNBR - Volume ↑ - Hardness ↓ - Tensile strength ↑ NBR/PVC - Volume ↓ - Hardness ↑ - Tensile strength ↓ FKM - Volume ↑ - Hardness ↓ - Tensile strength ↓	Trakarnpruk et al. [55]
NBR with varying % of acrylonitrile	Coconut	100%	- Degradation ↓ (for higher % of acrylonitrile) - Hardness ↓ - Tensile strength ↓	Linhares et al. [56]
- Natural rubber (NR) - Polychloroprene	Cottonseed	0, 20, 40, 100%	Decrease in the mechanical properties (hardness, tensile modulus and tensile strength) becomes more significant for higher % biodiesel	Kittur et al. [57]
NBR with varying % of acrylonitrile	Soybean	100%	Higher acrylonitrile content increases nitrile rubber samples' resistance to biodiesel. Mass ↑ Hardness ↓ Tensile strength ↓	Linhares et al. [58]
NBR	Palm	100%	- Volume ↑ - Hardness ↓ - Tensile strength ↓	Chandran et al. [59]
- NBR - FKM	Palm, Soybean	0, 5, 20, 100%	NBR - Mass ↑	Alves et al. [60]

Table 2 (*continued*)

Type of Elastomer	Type of Biodiesel	Percentage of Biodiesel	Significant Findings	Author(s)
			- Hardness ↓	
			- Tensile strength ↓	
			FKM	
			- Mass ↑	
			- Hardness ↓	
			- Tensile strength ↓	
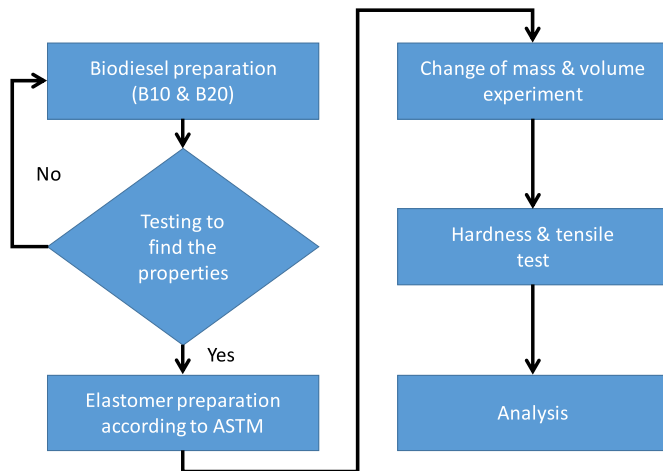
Fig. 1. Flowchart for this study.

Table 3
Specification of NBR.

Parameter	Description
Material	Nitrile Rubber (NBR)
Outer diameter (mm)	16.0
Internal diameter (mm)	10.0
Working pressure (bar/psi)	10/150
Coil length (mm)	100
Weight (kg/mt)	0.17
Volume (m^3)	0.040

Table 4
Specification of biodiesel analyzer.

Parameter	Description
Analytical wavelength/wave Number	5.7 μm, 1745 cm^{-1}
Power requirements	18 V DC, 3.3 amps, internal battery pack
Power supply	Universal AC/DC provided
Weight	5.8 l b. (2.6 kg) with battery −7.0 lbs (3.2 kg)
Dimensions	(17 cm) × 7.8" (19.8 cm) × 5.2" (13.2 cm)
Suggested operating range	5 °C–40 °C
Measurement range	0–100% biodiesel in diesel
Analysis time	Less than 30 s
Instrument repeatability	0–30% ± 0.2%, 20–100% ± 1% of biodiesel (FAME) concentration
Communication port	USB, RS 232

For each week, from week 1 to week 5. Two specimens were drawn from the container, cleaned with filter paper, and quickly dipped into the acetone solution to remove biodiesel on the surface of the sample specimen according to ASTM D471. The rate mass of change was determined by weighing the sample in Analytical Balance Laboratory before and after immersion in the preferred biodiesel. This percentage change in mass was calculated using the following formula:

Table 5
Specification of the hydrometer.

Parameter	Description
Manufacture number	JC-9313
Overall length (mm)	200
Temperature (°C)	15
Minimum scale value	1/1 wt Baume degree
Type	Salt Baume
AS ONE part number	6-9648-01
Scale range	0–30

Table 6
Specification of the kinematic viscosity machine.

Parameter	Description
Scope of mechanical method	0.2 to 300 000 mm^2/s
Voltage	AC220V ± 10%,50 Hz
Temperature control	20 °C–100 °C
Temperature precision	±0.1 °C (±0.01 °C)
Yield intensity	1800 W

$$\%mass\ change = \frac{m_2 - m_1}{m_1} \times 100\%$$

The change in hardness of the specimens was carried out using a shore D before and after immersion in the two biodiesel blends by measuring their hardness according to ASTM D2240. The durometer specifications, as shown in Table 7, are 0.5 HD and 0 to 100 HD accuracy. Durometer hardness was used to determine the respective hardness of soft substances, usually plastic or rubber. The test measures, under the stated situation of force and time, the penetration of a specified indent or material. After the cleaning process of the samples to remove excess biodiesel on the surface of the elastomer, the specimen was put on a hard, flat surface for the first time. Then, the device's indenter was pushed into the specimen to make sure that it was parallel to the surface. In a second, the hardness was obtained from a strong link to the specimen.

With the Universal Test Equipment Model of extended length, tensile strength testing of duplicate test dumbbell dies C shape (Fig. 2). Using AutoCAD software to draw the shape and print as a reference, the elastomer was cut using that reference as a guideline to get the exact dimension, just like in the ASTM. After the soaking experiment for B10 and B20 biodiesel blends, samples were carried out for unsoaked samples. The tests were carried out to evaluate the degree of change in the mechanical properties of the material disclosed in particular biodiesel blends. Using ASTM D412 as a reference, the Instron 5585 Universal Tensile Machine (UTM) is used by clamping the specimens. The UTM stretches the specimens until they break into two parts and the tensile

Table 7
The specification of the hardness durometer.

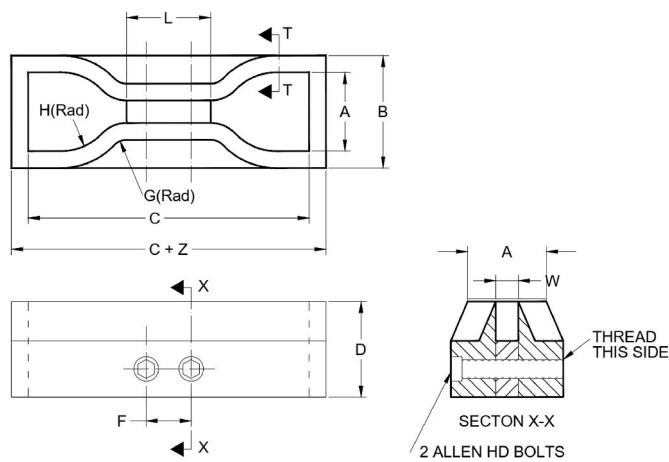| Parameter	Value
Scale value	0–100°
Pressure stroke	0–2.5 mm
Pressure end pressure (Type D)	0.55N–8.06 N

Fig. 2. The dimension of dumbbell shape dies C.

stress and expansion value of the elastomer in the software are recorded. Fig. 3 shows the specimens for several testing.

4. Results and discussion

4.1. Biodiesel

After the blending process, it is not clear whether the blend is completely blended as we want. Therefore, this test assists in determining the percentage of biodiesel. Table 8 shows the result B10 from the analyzer. It can be seen from Table 8 that the blend for B10 is correct and that the property of this blend is ready to be tested. The blend that has been tested is stated to be B10. From test 1, the measurement range is 10.3% which exceeds 10%. While in test 2, the value percentage shown by the analyzer is 10.2% and for test 3, the measurement range is 9.8%. Three tests are performed to calculate the average value. In the end, the value of this blend from this analyzer is 10.1%, which is close enough to 10% of the B10.

Table 8
Result B10 and B20 biodiesel analyzer.

Test	Measurement range (%)	Error (%)
Biodiesel 10% (B10)		
1	10.3	3.0
2	10.2	2.0
3	9.8	2.0
Biodiesel 20% (B20)		
1	19.98	0.10
2	20.05	0.25
3	19.96	0.20

The result shows that the blend for B20 is correct and that the property of this blend is ready to be tested. It states that the blend that has been tested is B20. The measurement range from test 1 is 19.98%, which is less than 20%. While in test 2, the percentage value shown by the analyzer is 20.05% and the measuring range for test 3 is 19.95%. To calculate the average value, three tests are performed. Finally, the value of this blend from this analyzer is 19.99%, which is close enough to 20% of the B20. Errors were calculated by comparing to the exact number of percentage. It shows that good agreement with small discrepancies with the maximum error by 3% in B10.

4.1.1. Density

Table 9 shows preliminary density results for different blends of palm oil biodiesel. All experiments were carried out using B10 and B20. It was found that the density also increases as the percentage of the mixture increases. B10 obtains 0.860 g/cm^3 for this experiment, while 0.863 g/cm^3 for B20 biodiesel. It is clearly shown that the fuel mixture increases the fuel density by increasing the biodiesel content. However, this

Table 9
Density of biodiesel blends.

Biodiesel blend	Density value
B10	0.860 g/ml
B20	0.863 g/ml

Fig. 3. (a) The specimen for mass and volume test, tensile and hardness test; (b) Ready for soaking test; (c) Specimens for tensile test.

results are in the range of standard value.

4.1.2. Viscosity

Table 10 shows the value of the B10 biodiesel blend test. The tests were run 3 times to calculate the time taken for the biodiesel to approach point B from point A.

Table 11 shows the value of the test of the B20 biodiesel blends. The tests were run 3 times to calculate the time taken for the biodiesel to approach point B from point A.

B20 is thicker than B10 from the information and graph. B10 has an average viscosity of 3.71 mm, while B20 biodiesel has an average viscosity of 3.93 mm^2/s. As shown in Table 12, the viscosity range for biodiesel should be an interval of 1.9 mm^2/s and 6.0 mm^2/s. The B10 and B20 Biodiesel incentive has shown that it is within that range. The link between kinematic viscosity and biodiesel level in the sample shows that kinematic viscosity increases as biodiesel levels increase in biodiesel. This results in higher biodiesel blends, leading to higher viscosity than lower biodiesel blends.

4.2. Elastomer

4.2.1. % of mass change

Fig. 4 shows the result of immersion analysis on the percentage mass change of the elastomer samples for the B10 and B20 biodiesel blends for 5 weeks. The B20 samples gradually increase from week 1 to week 5. While elastomer samples that were immersed in B10 biodiesel blends had a lower percentage of mass change than B20 because the mass of change increases as the biodiesel content increases. All elastomers of the sample showed significant weight changes in contact with biodiesel fuel B10 and B20 due to swelling, which increased fluid absorption. The increase in mass change due to the ester interaction present in biodiesel with the elastomer through the dipole-dipole interaction causes swelling, which results in the percentage of mass change in the B20 blends being greater than B10.

For comparison between these two biodiesel blends, the percentage of mass in the biodiesel blends B10 for the elastomer samples is higher than for the samples immersed in the biodiesel blend B20. Due to the lower viscosity value of B10, this result shows the absorption of B20 biodiesel by elastomers by more than B10. In B10, biodiesel is more absorbed into the elastomer than B10, as B20 is more viscous than B10. This issue causes the elastomer to be swelling, and if it becomes worse, its potency affects the fuel delivery system.

Referring to the previous discussion in the literature review, the experiments agreed with several researches by Haseeb et al. [51,53] for a similar type of elastomer and biodiesel. NBR degrade in biodiesel through complicated reactions because it has polar and non-polar elements which shows the complexity of mixture [61]. NBR is categorized as a complex family of unsaturated copolymers of acrylonitrile and butadiene. The increased mass of NBR can be attributed to the absorption solvent. The impact of different percentages of biodiesel bears different characteristics based on their dissolution characteristics and molecular polarity [51].

4.2.2. of volume change

In Fig. 5, the percentage volume shows the same behavior as in the mass test. The B20 elastomer sample increases significantly for 5 weeks. The volume change for the elastomers in the B20 blends was high compared to the B10 blends. Commonly, due to immersion in elastomer

Table 10
Time taken for B10.

B10	Time taken for biodiesel to approach point B from point A (s)
Test 1	258
Test 2	259
Test 3	271

Table 11
Time taken for B20.

B20	Time taken for biodiesel to approach point B from point A (s)
Test 1	278
Test 2	275
Test 3	282

Table 12
Average viscosity at 40 °C (mm^2/s) for B10 and B20 biodiesel blends.

Biodiesel Blend/Test	1	2	3	Average	Standard Deviation	Standard Error
B10	3.6409	3.6550	3.8243	3.7067	0.1020	0.0589
B20	3.9231	3.8808	3.9796	3.9278	0.0496	0.0286

specimens, fuel retention takes place, biodiesel has superb solvent properties, and biodiesel can disperse elastomers. It is a solvent that can affect an elastomer in an exact state. Elastomers are balanced in biodiesel and cause samples to swell or change the volume. When biodiesel blends also increase, the percentage volume of the sample changes. The increase in volume or swelling appeared to be beyond that of extraction as the increase in liquid concentration increased.

With a similar type of elastomer and biodiesel, this experiment also had good agreement with research by Haseeb et al. [51]. However, this work had a small discrepancy with Trakarnpruk et al. [55]. Their experiment showed no significant change in volume for NBR elastomer. The difference in the results can be assigned to the different parameters of experiment, such as temperature and time of immersion. They used 100 °C and 1008 h of immersion condition; meanwhile, this study used room temperature and 840 h of immersion condition.

4.2.3. Hardness

Table 13 shows the value of the hardness of the unsoaked elastomer specimen. Each of the immersion specimens undergoes a five-time test run at a different spot on the surface of the specimens and the average of the value was recorded at the end of the test. All the values of the hardness test are in the HD unit. Table 14 and Table 15 show the value of the hardness test using elastomer samples immersed in different blends of biodiesel (B10 and B20) for 5 weeks.

Fig. 6 shows that, upon immersion in the two different biodiesel blends, all samples showed an increase in hardness. The hardness of the B10 biodiesel samples is higher compared to the B20 biodiesel samples for a five-week soak period. Both the hardness values for B10 and B20 gradually increase after being immersed for five weeks. From the figure, the hardness of the elastomer increases as the soaking time increases.

The results of the hardness changes for the elastomers are shown in Table 16. For the NBR elastomer specimens, the hardness in conditions B10 and B20 decreases in value compared to the hardness of the original elastomer specimen due to the biodiesel blend reaction. Upon exposure of the elastomer to B10 and B20, these crosslinking agents and/or filler seem to act and thereby worsen the physical and mechanical properties [53]. The results showed that after immersion in B10 for 5 weeks, the specimen lost a 31.8% hardness compared to its as received condition. However, the loss of hardness in B20 was 28.7% for the same period of immersion time. Trakarnpurk et al. [55] reported that after the disclosure of the NBR elastomer to B10 at 100 °C for 6 weeks, the hardness was found to increase by 5%. This dissimilarity may illustrate the different test temperatures, where in this test run at room temperature, which is 23 °C, while the research test temperature is 100 °C.

Nevertheless, the hardness of the test of the sample for B20 is greater than that of B10. This may indicate a greater fading after immersion in biodiesel for the elastomer. The higher the hardness of the samples, the higher the cross-linked. These hardness results were consistent with other results in terms of mass and volume changes for elastomers. Higher mass gains mean higher volumes, which ultimately lead to a
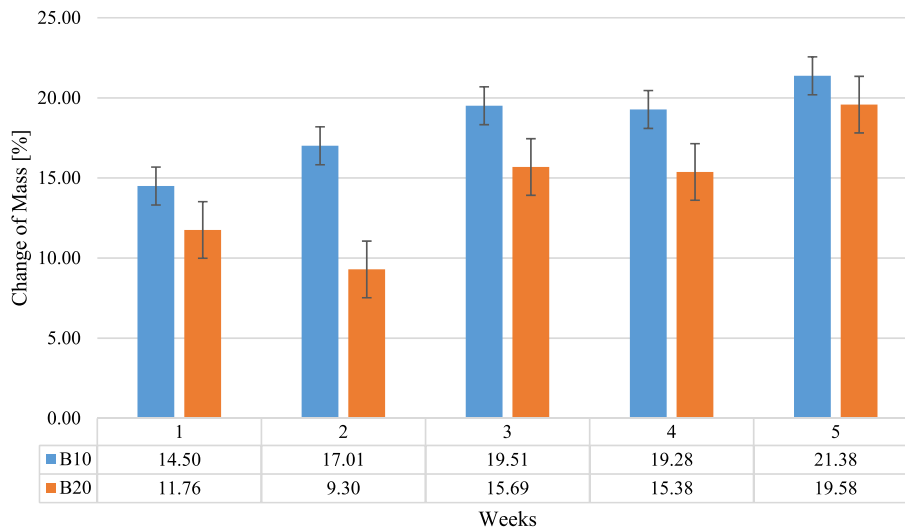
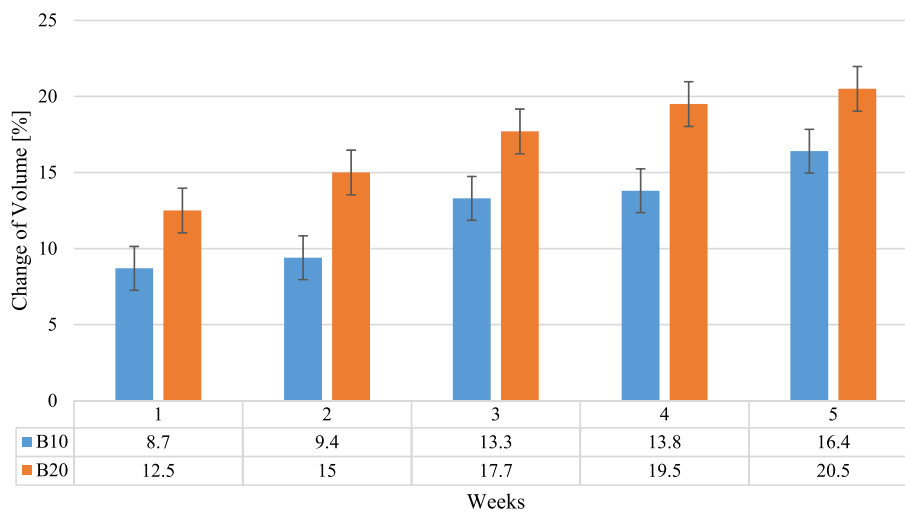Fig. 4. Percentage of mass change for biodiesel blends B10 and B20.

	1	2	3	4	5
B10	14.50	17.01	19.51	19.28	21.38
B20	11.76	9.30	15.69	15.38	19.58

Fig. 5. Percentage volume change for B10 and B20 biodiesel blends.

	1	2	3	4	5
B10	8.7	9.4	13.3	13.8	16.4
B20	12.5	15	17.7	19.5	20.5

Table 13
Unsoaked specimen in hardness test.

Test/ duration	1	2	3	Average	Standard Deviation	Standard Error
Unsoaked	38.0	34.0	36.5	36.2	2.02	1.17

higher hardness decline as the elastomer is reduced by the cross-link.

4.2.4. Tensile strength

In the tensile test, both elastomer samples for B10 and B20 biodiesel blends undergo tensile stress and tensile stress. The results were recorded and analyzed when the samples were pulled and split into two parts,

as shown in Fig. 7.

Fig. 7 shows the difference in tensile strength for different samples of elastomers that were immersed for 5 weeks in B10 biodiesel blends. The specimen on week 2 has the highest value of tensile stress 2.6 MPa, while the minimum tensile stress is 1.9 MPa and about 2.24 mm/mm tensile strain for specimen week 4. The extensions for week 1 and week 3 share the same tensile strain, about 2.85 mm/mm. Thus, the longer the immersion/soaking time, the decrease in the elastomer's expansion. Tensile stress is also reduced when immersion time increases. Fig. 7 also shows that the week 2 specimen has the highest tensile stress which is 2.54 MPa while week 4 has the lowest tensile stress value compared to other specimens for B10 blends at 2.09 MPa.

Slippage of the specimen occurs during the time of tensile testing,

Table 14
B10 blends hardness test.

Specimen/Weeks	1	2	3	4	5	Average	Standard Deviation	Standard Error
1	21.5	20.0	21.0	20.0	22.0	20.9	0.89	0.40
2	21.5	21.0	20.0	20.5	21.0	20.8	0.57	0.25
3	21.5	23.0	21.0	24.0	23.0	22.5	1.22	0.55
4	21.0	22.5	23.0	23.5	23.0	22.6	0.96	0.43
5	25.0	25.0	23.0	25.5	25.0	24.7	0.97	0.44

Table 15

B20 blends hardness test.

Specimen/Weeks	1	2	3	4	5	Average	Standard Deviation	Standard Error
1	23.0	23.5	23.5	23.0	23.0	23.2	0.27	0.12
2	22.0	24.0	22.0	23.5	24.5	23.2	1.15	0.51
3	25.0	23.5	23.0	25.0	23.5	24.0	0.94	0.42
4	24.0	23.0	24.0	25.5	25.5	24.4	1.08	0.48
5	23.5	28.0	26.0	25.5	26.0	25.8	1.60	0.72
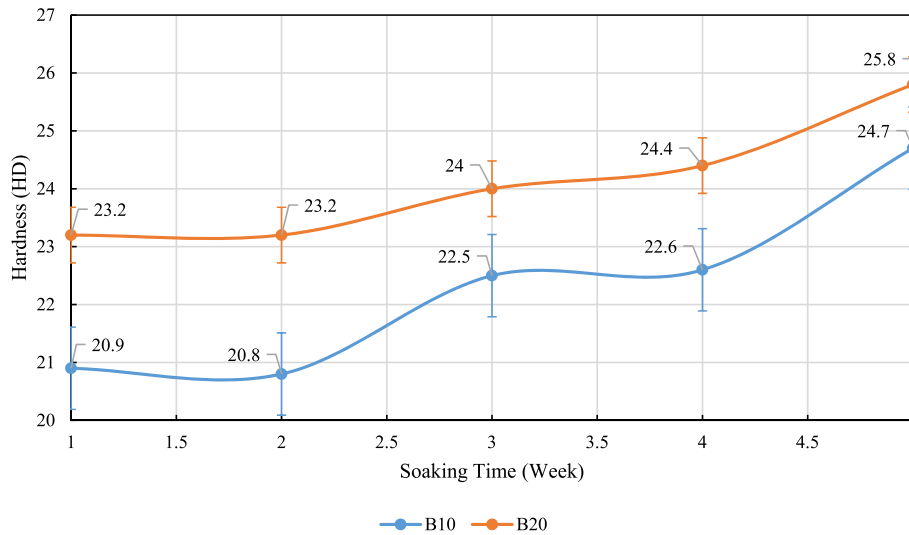
Fig. 6. The comparison of hardness test elastomer specimen.

Table 16

Hardness losses for 5 weeks.

Test blends	B10	B20
Before immersion (HD)	36.2	36.2
After immersion (HD)	24.7	25.8
Losses (%)	31.8	28.7

which makes the extension of elastomer for week 5 higher than the specimen in week 4. The test specimen might slip off the universal tensile machine (UTM) clamp due to the biodiesel. This is because biodiesel has a slippery characteristic, which might be why this problem occurs. To avoid this mistake, the elastomer specimens must be thoroughly rinsed so that no biodiesel remains on the specimens that could disturb the result.

Fig. 8 shows the difference in tensile strength for immersion of different elastomers for 5 weeks in B20 biodiesel blends. The sample received in week 1 shows 3.6 MPa tensile strength and 3.7 mm/mm
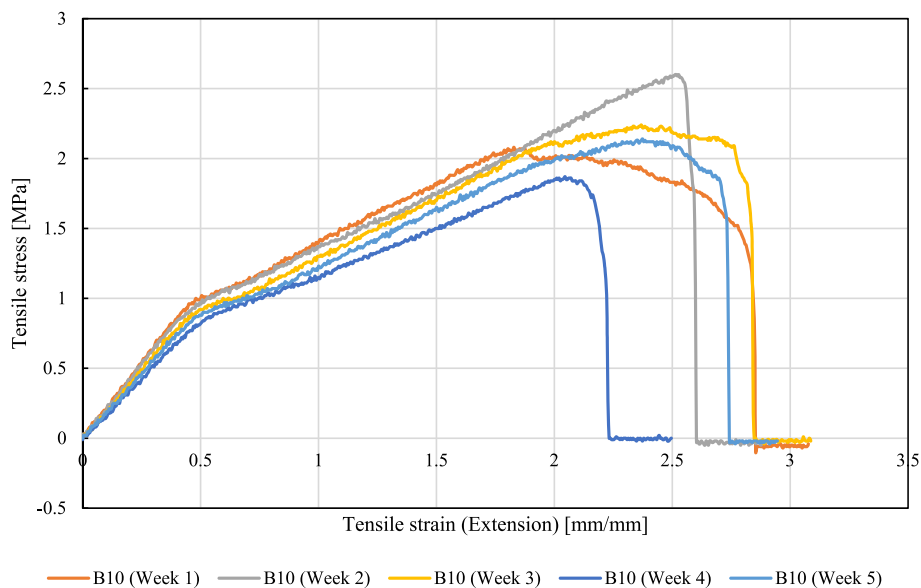

Fig. 7. Tensile stress of B10 biodiesel blends.

tensile strain. The lowest tensile stress and tensile strain compared to other specimens is the sample from week 5 with 1.57 MPa and 2.09 mm/mm. Separately, week 1 has the highest tensile strain with 3.68 mm/mm, and the tensile stress is 3.63 MPa. Due to the direction of the elastomer, while clamped to the machine, and not vertical results, the sample of week 3 is decreased in tensile strain and stress compared to week 4. When the specimen is not clamped vertically, it affects the tensile test because the acting force on the elastomer results in a double force, which is vertical and horizontal. To avoid this issue, happen again. The specimens must be clamped vertically and correctly to confirm that there is no problem or error during the analysis.

There are some flaws in both tests during the tensile test, as the results are not truly correct. This can be caused by a failure to clamp the specimen. This failure occurs when the specimen is not clamped vertically and the elastomer specimen acting in two forces was explained. The theoretical result is not factual because of this flaw. The tensile stress of the original specimen is much higher than the tensile stress of both biodiesel mixtures. Biodiesel is known to be hygroscopic [62]. Therefore, this nature may lead to the introduction of water into the polymer matrix. This dispersal of water in the polymer matrix affects and deteriorates the mechanical properties of the elastomer.

Fig. 9 presents the relationship between ultimate tensile stress versus immersion or soak weeks for the blends of biodiesel B10 and B20. As noted in the figure above, the change in value in ultimate tensile stress for the B20 elastomer sample decreased with increasing weeks but increased in week 4 with 164.73 N before decreasing in week 5 with 116.07 N. Under the same test conditions for the B10 elastomer samples, the ultimate tensile stress increased for two weeks from 144.27 N to 180.45 N and then decreased before increasing again at week 5. This also means that when the soak time increases, the lower the ultimate tensile strength. For the B10 blends, week 1 and week 5 seem to be an error due to the orientation of the specimen while the specimens are clamped vertically to the machine. Thus, the result does not move according to the movement of the graph. In B20 blends, the specimen for week 4 is greater than that for week 3 due to failure when clamping the specimen. All elastomer specimens must be clamped correctly according to the UTM manual guide, which is strictly vertical clamping to avoid any problems during the test.

From the graph, in comparison of the maximum load that was applied to both of the sample mixes. The maximum tensile stress in samples from B20 biodiesel blends is slightly higher than in samples soaked in B10 biodiesel blends. The larger contraction in the tensile

strength indicates the greater loss of cross-links between the polymer cells during immersion, while the elastomer is in the specimen state. The relatively small decreases in tensile strength could lead to a small dissolution of the fuel curing and cross-linking agents, while the mechanical features are getting worse. Thus, the mechanical properties and different behavior of the tensile test are the same as that of the hardness test.

All in all, four mechanical and physical parameters were investigated. Table 17 shows the comparison of present work to the other researches. Mostly, the result of elastomer experiment in biodiesel shows similar tendency and has potential degradation, particularly tensile strength. Higher concentration of biodiesel generates higher elastomer degradation with different magnitude. However, all references were conducted in different experiment conditions which can affect the different results in detail.

5. Conclusions

Biodiesel, as an alternative fuel, has composition and chemical characteristics that are different from regular diesel. Therefore, it is expected that biodiesel interacts with materials in a different way. In addition, biodiesel compositions from different feedstocks have which complicate the phenomena. Different composition and characteristic of biodiesel would give different effect to elastomer. The elastomer experiments have been conducted to investigate the consequences of B10 and B20 biodiesel blends (palm) on the physical and mechanical properties of the elastomer. Then, the results have compared to other studies. The following conclusions can be deduced from the results obtained from the characterization of the palm oil-based biodiesel blend and its effect on the degradation of the NBR fuel hose system.

- The density and kinematic viscosity increased with the percentage of biodiesel blends. The mass change increased by 58.1%, the volume change increased by 58%, the tensile strength increased by 53.5%, and the hardness increased by 52% with increasing biodiesel blends.
- The study of the preliminary and factorial composition results of the impact of biodiesel on the elastomer resistance showed that the concentration of biodiesel damaged the properties of the elastomer, leading to swelling.
- The diffusion of biodiesel with increasing concentrations led to a reduction in mechanical elastomer properties. This would explain
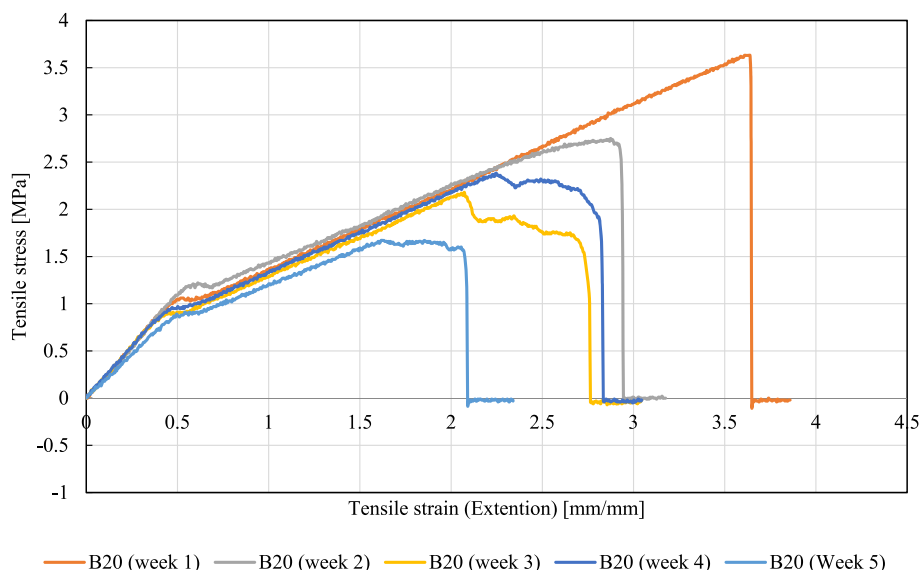

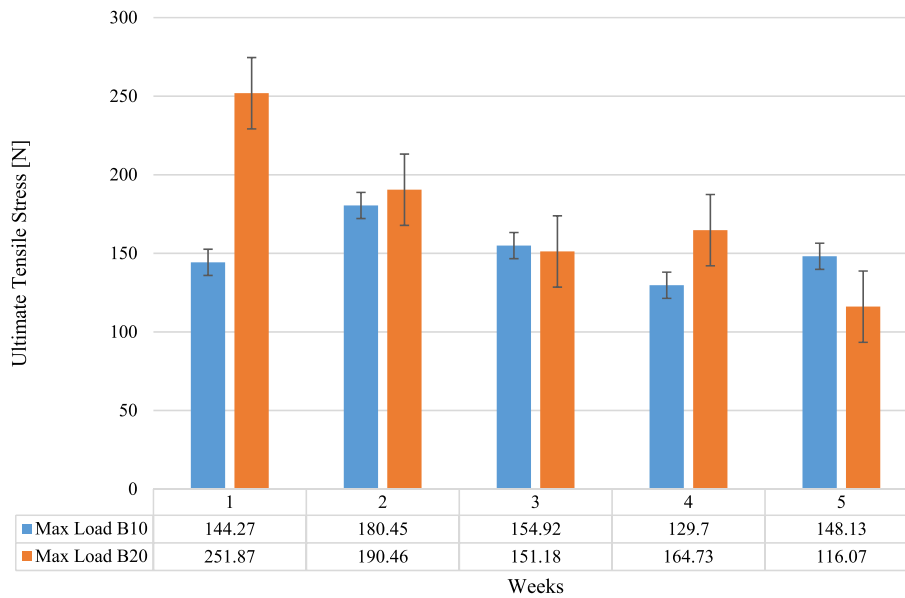**Fig. 8.** Tensile stress of B20 biodiesel blends.

Fig. 9. Maximum tensile stress for biodiesel blends B10 and B20.

Table 17
Comparison investigation of NBR elastomer in palm biodiesel.

Percentage of Biodiesel	Mass	Volume	Hardness	Tensile Strength	Author(s)
10, 20%	Increase	Increase	Increase	Decrease	Present work
10, 100%	Increase	Increase	Decrease	Decrease	Haseeb et al. [51]
100%	Increase	Increase	Decrease	Decrease	Haseeb et al. [53]
10%	Decrease	Constant	Increase	Decrease	Trakarnpruk et al. [55]
100%	–	Increase	Decrease	Decrease	Chandran et al. [59]
0, 5, 20, 100%	Increase	–	Decrease	Decrease	Alves et al. [60]

the hardening of the fuel hose and the sudden development of a fuel delivery system that introduced the fracture mark.

- It may be advised to use B10 blends or even reduce contact with NBR-based materials, but a material change is imperative in the event of higher blend levels.

Other materials with improved fuel hose properties, such as Viton and Teflon, should be considered for future research to obtain better results. In addition, the soaking period must also be extended to test the material's critical problem when in contact with various biodiesel blends. Precautionary steps must be carefully practiced during the test, as the result of the fault may alter the entire analysis and the outcomes may not be legitimate.

Credit author Statement

Ibham Veza: Formal Analysis, Methodology, Writing - Reviewing & Editing, Validation. **Zulkarnain Zainuddin:** Resources, Writing – original draft. Project Administration. **Noreffendy Tamaldin:** Supervision, Funding acquisition. **Muhammad Idris:** Methodology, Visualisation, Resources, Writing - Original Draft, Conceptualization, **Irianto:** Funding Acquisition, Writing - Reviewing & Editing. **I. M. Rizwanul Fattah:** Validation, Writing - Reviewing & Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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