Effect of silicone surfactant and distilled water on the structure, morphology, density, and compressive strength of polyurethane foam with utilization of castor oil

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Abstract. Polyurethane (PU) foam is used almost everywhere—from packaging to insulation and construction—but its production still relies largely on petroleum-based ingredients. In this study, we explored castor oil as a renewable alternative to conventional polyols, aiming to create PU foams that are both sustainable and versatile. We prepared the foams by reacting castor-oil-based polyol with methylene diphenyl diisocyanate (MDI), using different amounts of water as a blowing agent (1%, 10%, and 20% w/w) and silicone surfactant (2%, 10%, and 18% w/w) to help stabilize the foam structure. By adjusting these components, we examined how the formulations affected the foam's appearance, density, and strength. Small changes in water and surfactant content led to three clear foam types: a rigid foam (1% water, 18% surfactant), a semi-rigid foam (10% water, 2% surfactant), and a flexible foam (20% water, 10% surfactant). The rigid foam showed the highest strength and density, while the semi-rigid and flexible versions had progressively softer and lighter structures. Overall, our findings show that castor-oil-based PU foam can be tuned to meet different performance needs simply by adjusting its formulation. This offers a practical and renewable pathway for producing PU foams with properties comparable to those made from petroleum-based materials.

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1 Introduction

Castor oil—derived from the seeds of the castor bean plant—is a versatile material that plays an important role in many aspects of daily life. Its lightweight nature, resistance to water and rust, and excellent heat and electrical insulation make it valuable across a wide range of applications. Because of these advantages, global demand for castor oil continues to rise, with production reaching around 1.7 million tons per year [1]. This increase reflects its broad use, particularly in the manufacture of polyurethane foams (PUFs), which account for roughly 40% of global castor oil consumption.

Beyond serving as a primary raw material, waste castor oil can also be recycled through various processes—including glycolysis, methanolysis, hydrolysis, ammonolysis, and aminolysis—to produce new, high-value products. These environmentally friendly recycling pathways reduce reliance on fossil-based resources and support more sustainable material cycles [2].

One of the most promising uses of castor oil is as a natural replacement for petroleum-derived polyols in polyurethane foam production. Castor oil offers two primary advantages: it is renewable and environmentally friendly. In addition, it can enhance the mechanical performance of the resulting foam [2]. Prior research has shown encouraging results. For instance, Seo et al. (2014) [3] reported that castor-oil-based polyurethane foams exhibit improved compressive strength and wear resistance. Likewise, Singh et al. (2020) [4] found that combining castor oil with petroleum-based polyols can yield foams with superior properties compared to those made solely from conventional polyols. These findings suggest that integrating castor oil into polyurethane production not only reduces dependence on petroleum but also offers environmental and economic benefits.

Additional studies further highlight these advantages. Lee et al. (2021) [5] demonstrated that castor oil can serve as a partial or full replacement for traditional fossil-derived polyols. Their work revealed several key benefits: reduced carbon footprint, improved mechanical properties (such as higher compressive strength and elastic modulus), and enhanced thermal stability. Castor-oil-based foams also tend to have lower density, which is advantageous for lightweight applications, such as in automotive components. Altogether, these findings position castor oil as an appealing and eco-friendly alternative for producing high-performance polyurethane foams.

The formulation of polyurethane also depends on the molar ratio between castor oil and other reactants, such as glycol solutions or MDI, depending on the targeted properties. Previous studies have shown that castor oil can increase compressive strength and stability, while glycol tends to improve elasticity and overall mechanical performance. Ionescu et al. (2016) [6], for example, investigated various molar ratios between castor oil and MDI and identified ratios of 1:1, 1:1.6, and 1:2 as optimal for achieving polyurethane with strong mechanical properties.

Polyurethane is a polymer of urethane functional groups (-NHCOO) discovered by Otto Bayer. This polyurethane can be used as a foam known as polyurethane foam. The foam is one of the engineering foam polymers widely used in industry and has become a commercial product. It is widely used as an insulation material, electrical insulation, sealant, and foam in the automotive industry, etc. [7]. Its production usually uses polyols made from petroleum, which can cause environmental problems, such as the depletion of non-renewable energy sources [7]. Therefore, to reduce environmental problems by reducing environmental waste, one alternative raw material that can be used is castor oil. It contains ricinoleic acid, a monounsaturated fatty acid with a long chain rarely found in other vegetable oils. Ricinoleic acid gives castor oil its viscosity and stability properties. The use of castor oil in polyurethane foam production can increase the tensile strength, compressive strength, and ductility of polyurethane foam, making castor oil suitable for use in polyurethane foam production, since it can also improve the mechanical properties of polyurethane foam as well as reduce the use of chemicals that are harmful to the environment and health [8]. In polyurethane foam production, important raw materials comprise isocyanate (MDI), blowing agent, and surfactant. In general, the blowing agent used is hydrochlorofluorocarbon (HCFC) and chlorofluorocarbon (CFC), but these materials are no longer used because they cause pollution, while a study by Choe et al. (2004) [9] has developed a blowing agent using water, which is more environmentally friendly. The formulation of each material can affect the final result of the foam so in this study, the composition variation of distilled water and silicone surfactant was employed to see their effect on the properties of polyurethane foam produced.

2 Research methods

Polyurethane foam production uses castor oil as a substitute for polyol by reacting it with distilled water, silicone surfactant, and Methylene Diphenyl Diisocyanate (MDI). Distilled water acts as a blowing agent that serves to develop the foam [10], silicone surfactant acts as a surfactant that serves to reduce surface tension and to dissolve distilled water with MDI [11], and MDI acts as an isocyanate, serving as a connecting agent that binds polyol and forms a polymer network structure [10].

In this study, the polyurethane foam is produced using a varied composition of surfactant and distilled water, which is useful to produce the desired properties of polyurethane foam and **ASTM D1622** (density) and **ASTM D1621** (compressive strength), along with equipment models and measurement procedures.Table 1 shows the composition of the materials used in the study.

Table 1. Composition of materials used.

Sample	Polyol MDI	MDI (%)	Surfactant (%)	Distilled Water (%)
1	1 : 01	10	2	1
2	1 : 01	10	10	1
3	1 : 01	10	18	1
4	1 : 01	10	2	10
5	1 : 01	10	10	10
6	1 : 01	10	18	10
7	1 : 01	10	2	20
8	1 : 01	10	10	20
9	1 : 01	10	18	20

3 Results and discussion

3.1 Effect of distilled water composition on the properties of polyurethane foam

In polyurethane foam production, the addition of distilled water is used as a blowing agent or foam formation booster. Blowing agent plays an important role in forming air bubbles in the polyurethane system, which ultimately produces foam with controlled structure and desired physical properties.

To determine the effect of distilled water composition on the polyurethane foam produced, it can be referred to Table 2 mentioned in a study by Seo et al. 2003) [13]. The table provides information on various parameters, such as foam density, compressive strength, and foam type resulted from the distilled water composition variation used.

Table 2 shows the different density values resulted from the use of 1, 10, and 20% distilled water composition and 2, 10, and 18% surfactant composition. According to the prevailing concept in the existing literature, the greater the density value of an object, the more rigid the object tends to be. From the density testing data obtained, it can be concluded that the types of foam formed are rigid, semi-rigid, and flexible, in line with Xie et al.'s (2015) findings [14].

The standard deviation was calculated using Equation 1 to analyze this data.

$$s = \sqrt{(\sum x^2 \text{-} nX^2)/(n\text{-}1)} \qquad (1)$$

Where:
s = Standard deviation
x = Value of one observation
n = Number of observations
X = Arithmetic average of total observation

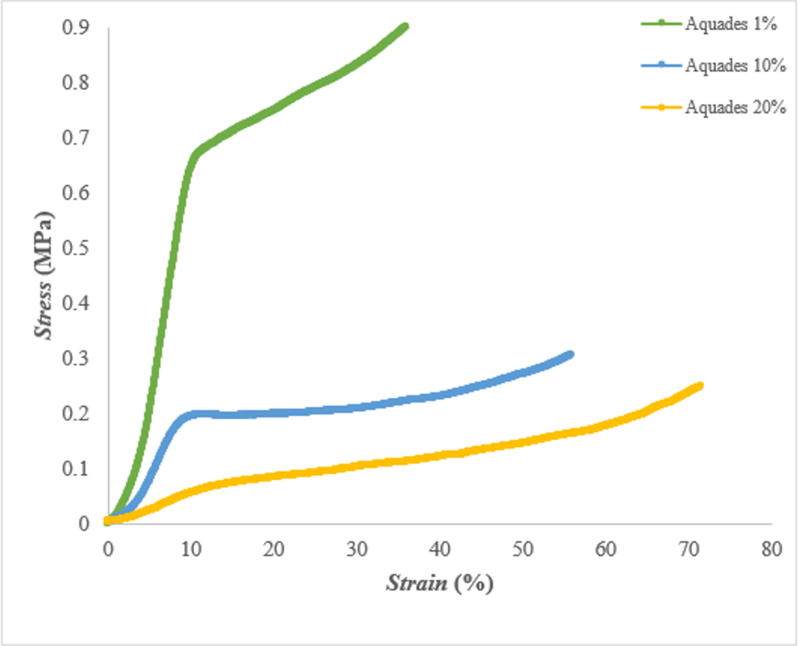
Table 2 presents the calculation results of standard deviation in density testing on polyurethane foam samples at all variations of surfactant and distilled water composition.

Table 2. The properties of polyurethane foam resulted from the use of surfactant and distilled water composition variation.

Surf. (%)	Distill. (%)	Density (gr/cm^3)	*Young's* Modulus (MPa)	Compressive Strength (MPa)	Foam Type
2	1	0.139370	2.6012	0.81	Rigid
10	1	0.116657	1.5391	0.53	Rigid
18	1	0.112617	1.5979	0.59	Rigid
2	10	0.055929	0.5227	0.21	Semi Rigid
10	10	0.060683	0.6451	0.23	Rigid
18	10	0.051448	0.3789	0.16	Semi Rigid
2	20	0.090007	0.3733	0.12	Flexible
10	20	0.053263	0.3295	0.13	Flexible
18	20	0.050458	0.3529	0.16	Flexible

3.1.1 Analysis of compressive strength testing results

In polyurethane foam strength testing, one of the analyses performed is constructing a stress-strain graph for each tested composition. This aims to obtain information about the mechanical response of the foam to the applied load as well as to determine the *Young's* modulus value of each composition. Based on Table 2, a stress-strain graph can be created for 2, 10, and 18% surfactant composition and 1, 10, and 20% distilled water composition. This graph will show the relationship between the stress applied to the polyurethane foam and the strain that occurs in response to the stress. Figure 2 shows the stress-strain graph of each composition. The x-axis represents the strain in percentage (%) units, while the y-axis represents the stress in megapascals (MPa) units. This graph will show how the polyurethane foam responds to the applied stress, whether it is elastic (returns to its original shape after the load is removed) or plastic (undergoes permanent deformation).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Stress (MPa)
Strain (%)
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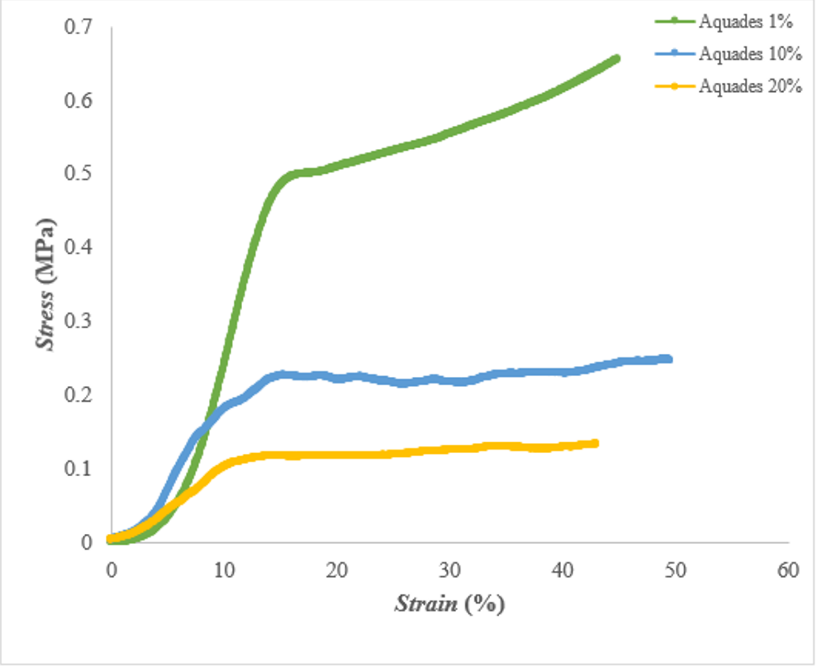
(a)


Aquades 1%
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Aquades 20%
Stress (MPa)
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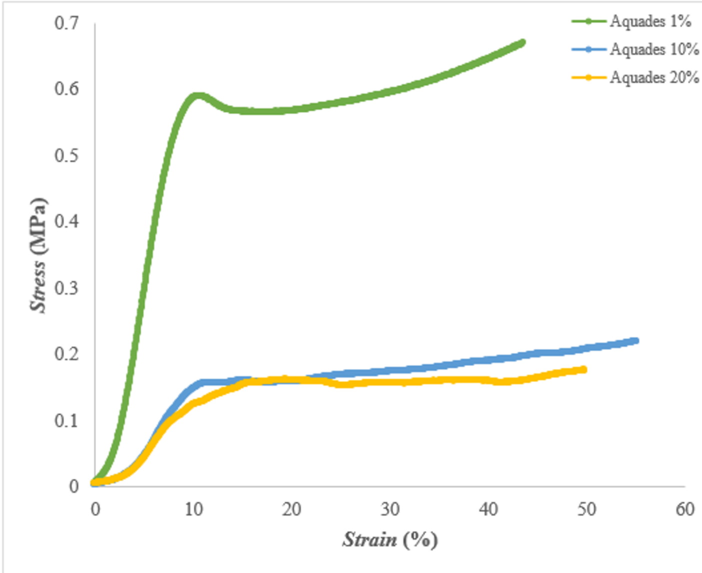


(c)

Fig. 1. Stress-strain graph at 1, 10, and 20% distilled water composition: (a) 2% surfactant composition, (b) 10% surfactant composition, and (c) 18% surfactant composition.

Table 2 shows that 2, 10, and 18% surfactant composition and 1, 10, and 20% distilled water composition produced different compressive strength and *Young's* modulus values. According to the existing literature, the greater the *Young's* modulus value of an object, the stiffer the object will be. Therefore, the compressive strength value of an object also tends to increase as the *Young*'s modulus value increases. Figure 1(a) shows the stress-strain graph and *Young's* modulus value of each sample. *Young's* modulus value is obtained from the slope of the linear regression line on the stress-strain graph. As shown in Table 2, the compressive strength values at 2% surfactant composition and 1, 10, and 20% distilled water composition are 0.81, 0.21, and 0.12 MPa, respectively. The table also shows that the *Young's* modulus values at 2% surfactant composition and 1, 10, and 20% distilled water composition are 2.6012, 0.5227, and 0.3733 MPa, respectively. When the resulting *Young's* modulus and compressive strength values are compared, it can be seen that the data support Seo et al.'s findings (2003) [13].

Figure 1(b) shows the stress-strain graph and *Young's* modulus value of each sample. The *Young's* modulus value is obtained from the slope of the linear regression line on the stress-strain graph. The compressive strength values are shown in Table 2, where the use of 10% surfactant composition and 1, 10, and 20% distilled water composition produced compressive strength values of 0.53, 0.23, and 0.13 MPa, respectively. The table also shows that the *Young's* modulus values at 10% surfactant composition and 1, 10, and 20% distilled water composition are 1.5391, 0.6451, and 0.3295 MPa, respectively. When the resulting *Young's* modulus and compressive strength values are compared, it can be seen that the data align with Seo et al.'s findings (2003) [13].

Figure 1(c) shows the stress-strain graph and *Young's* modulus value of each sample. The *Young's* modulus value is obtained from the slope of linear regression line on the stress-strain graph. Meanwhile, Table 2 shows that the compressive strength values obtained from 18% surfactant composition and 1, 10, and 20% distilled water composition are 0.59, 0.16, and

0.16 MPa, respectively. The table also shows that the *Young's* modulus value at 18% surfactant composition and 1, 10, and 20% distilled water composition are 1.5979, 0.3789, and 0.3529 MPa, respectively. When the resulting *Young's* modulus and compressive strength values are compared, it can be seen that the data are in accordance with Seo et al.'s findings (2003) [13].

The results show a clear trend: polyurethane foams with lower Young's modulus values also exhibit lower compressive strength. In other words, when the foam becomes less stiff, it also becomes weaker under compression. This pattern is closely linked to the amount of distilled water used during the formulation. A higher water content—such as 20%—produces a lower Young's modulus, making the foam more flexible and reducing its compressive strength. These findings indicate that adjusting the distilled water content in the formulation directly influences key mechanical properties, particularly stiffness and strength. In this study, increasing the distilled water composition consistently led to decreases in both Young's modulus and compressive strength of the final foam.

3.1.2 Analysis of density test results

Density testing of the polyurethane foam was carried out to determine the mass and volume of each specimen, following the ASTM D1622 standard for foam density. Measurements were taken using an AS 220.R2 analytical balance, ensuring accurate and precise mass readings.

The role of distilled water in foam production is particularly important when it comes to density. As shown in Table 2, increasing the amount of distilled water results in a noticeable decrease in foam density. This outcome can be explained by the chemical reaction between distilled water and Methylene Diphenyl Diisocyanate (MDI). When these two components react, they generate carbon dioxide (CO_2), which acts as a blowing agent that creates pores within the foam structure.

A higher water content produces more CO_2, which in turn forms a greater number of pores. These pores expand the foam's volume significantly without adding much mass, ultimately lowering the foam's overall density. Therefore, the more distilled water used in the formulation, the lower the density of the resulting polyurethane foam.

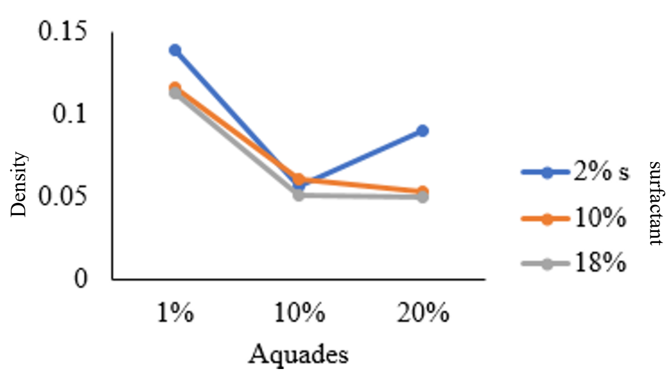


Fig. 2. Effect of the addition of distilled water composition variation on polyurethane foam density.

It can be seen from Figure 2 that the greater the distilled water composition used, the lower the density value of the foam. Foam composed of 1% distilled water and 2% surfactant has a density value of 0.139370 g/cm^3. Foam composed of 10% distilled water and 2% surfactant has a density value of 0.055929 g/cm^3. Foam composed of 20% distilled water and

2% surfactant has a density value of 0.090007 g/cm^3. Foam composed of 1% distilled water and 10% surfactant has a density value of 0.116657 g/cm^3. Foam composed of 10% distilled water and 10% surfactant has a density value of 0.060683 g/cm^3. Foam composed of 20% distilled water and 10% surfactant has a density value of 0.053263 g/cm^3. Foam composed of 1% distilled water and 18% surfactant has a density value of 0.112617 g/cm^3. Foam composed of 10% distilled water and 18% surfactant has a density value of 0.051448 g/cm^3. Foam composed of 20% distilled water and 18% surfactant has a density value of 0.050458 g/cm^3. These findings are less in accordance with those of the existing literature, since the resulting foam exhibits a lower density value at 10% distilled water composition compared to that of 20% distilled water composition. According to the existing literature, the expected result is that the greater the distilled water composition used, the lower the density value obtained [13].

3.2 Effect of silicon surfactant composition on the properties of polyurethane foam

The addition of silicone surfactant in polyurethane foam production has several important functions. One of the main functions of silicone surfactant is as a stabilizer. Surfactants play a key role in producing polyurethane foam with a uniform and stable cell structure. In this system, silicone-based surfactants help prevent the formation of cells that are either too large or too small, resulting in a more consistent and well-defined foam morphology. Beyond stabilizing cell size, surfactants also act as emulsifying agents, allowing components that normally do not mix—such as water and polyurethane precursors—to blend effectively.

This function is possible because surfactants are amphiphilic molecules, containing both hydrophilic (water-attracting) and hydrophobic (water-repelling) segments [12]. The hydrophilic portion interacts with the distilled water used as a blowing agent, while the hydrophobic portion associates with the polyurethane-forming components such as castor oil and MDI. The presence of a surfactant therefore enables these otherwise immiscible components to disperse uniformly, improving overall homogeneity and stability during foam formation.Table 2 presents the data showing how different silicone surfactant compositions influence foam characteristics, including density, compressive strength, and Young's modulus.

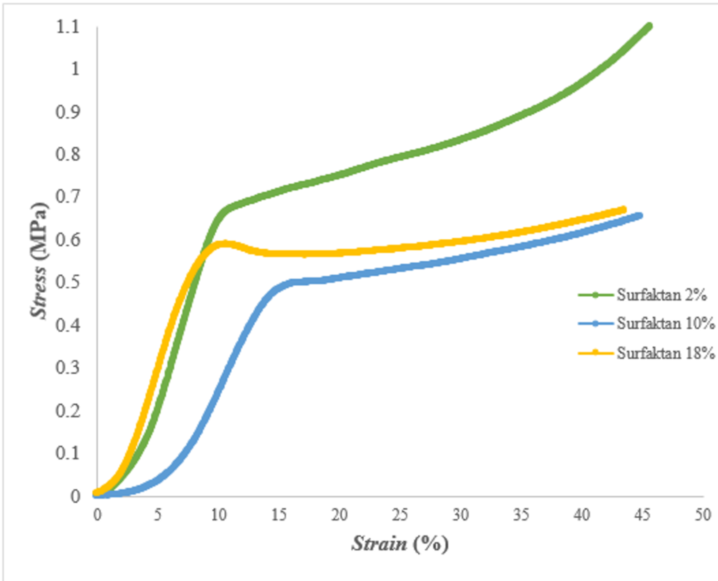
3.2.1 Analysis of compressive strength test results

The compressive strength test was conducted to examine how varying the amount of silicone surfactant affects the mechanical performance of the resulting polyurethane foam. According to Kaur and Kumar (2013) [15], foams produced with a surfactant composition higher than that of the blowing agent generally exhibit greater compressive strength. Conversely, when the surfactant content is lower than the water content, the foam tends to be weaker.

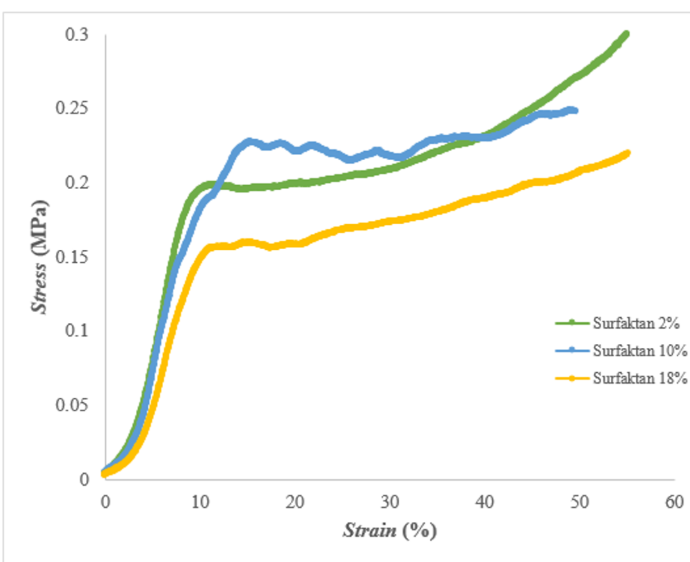
The results in Table 2 show the compressive strength values for polyurethane foams formulated with 2%, 10%, and 18% silicone surfactant, combined with 1%, 10%, and 20% distilled water. These values provide insight into how the balance between surfactant and water affects the foam's structural integrity.

To further illustrate this behavior, the stress–strain curves for each sample are shown in Figure 3. These graphs display how the foam responds to increasing strain and allow the Young's modulus to be calculated from the slope of the linear portion of the curve, representing the elastic region of the material. From these curves, we can clearly observe how different combinations of water and surfactants influence the stiffness and compressive characteristics of the foam.

The *Young's* modulus value can then be used to evaluate the stiffness and mechanical properties of the polyurethane foam formed. In this context, the greater the silicone surfactant composition used, the greater the strength of the polyurethane foam tends to be.



(a)



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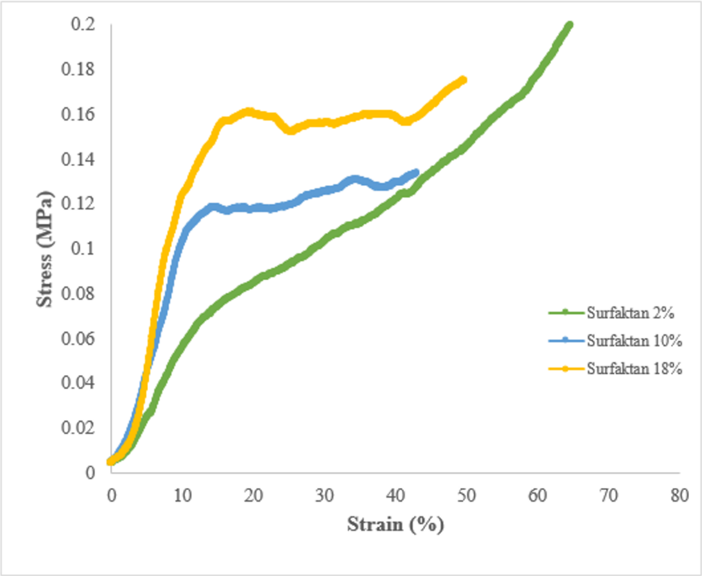

(c)

Fig. 3. Stress-strain graph at 2, 10, and 18% surfactant composition: (a) 2% distilled water composition, (b) 10% distilled water composition, and (c) 20% distilled water composition**.**

Figure 3(a) shows the results of compressive strength testing using 1% distilled water composition and 2, 10, and 18% surfactant composition. The stress-strain graph shows the relationship between the stress and strain of each polyurethane foam sample, as well as the *Young's* modulus value obtained from the graph. As shown by the results in Table 2, the compressive strength values at 2, 10, and 18% surfactant composition are 0.81, 0.53, and 0.59 MPa, respectively. The table also shows that the *Young's* modulus values at 2, 10, and 18% surfactant composition are 2.6012, 1.5391, and 1.5979 MPa, respectively. In this case, there is a discrepancy between the compressive strength value of the foam composed of 2% surfactant and that in the existing literature. Usually, the compressive strength value at a lower surfactant composition should be smaller compared to that of at a higher surfactant composition. This discrepancy may be caused by the inhomogeneous stirring process during foam production, so that during curing, the foam produced exhibits uneven hardness. This can result in a variation in the compressive strength value of the foam. However, for the foams composed of 10 and 18% surfactant, the results support Kaur and Kumar's findings [15].

Figure 3(b) shows the results of compressive strength testing using 10% distilled water composition and 2%, 10%, and 18% surfactant composition. The stress-strain graph shows the relationship between the stress and strain of each polyurethane foam sample, as well as the *Young's* modulus values obtained from the graph. As shown by the results in Table 2, the compressive strength values at 2, 10, and 18% surfactant composition are 0.21, 0.23, and 0.16 MPa, respectively. The table also shows that the *Young's* modulus values at 2, 10, and 18% surfactant composition are 0.5227, 0.6451, and 0.3789 MPa, respectively. In this case, there is a discrepancy between the compressive strength value of the foam composed of 18% surfactant and that in the existing literature. Usually, the compressive strength value at a higher surfactant composition should be greater compared to that of at a lower surfactant composition. This discrepancy may be caused by the inhomogeneous stirring process during foam production so that during curing, the foam produced exhibits uneven hardness.

Figure 3(c) shows the results of compressive strength testing using 20% distilled water composition and 2, 10, and 18% surfactant composition. The stress-strain graph shows the relationship between the stress and strain of each polyurethane foam sample, as well as the *Young's* modulus value obtained from the graph. As shown by the results in Table 2, the compressive strength values at 2, 10, and 18% surfactant composition are 0.12, 0.13, and 0.16 MPa, respectively. The table also shows that the *Young*'s modulus values at 2, 10, and 18% surfactant composition are 0.3733, 0.3295, and 0.3529 MPa, respectively. When the resulting *Young*'s modulus and compressive strength values are compared, the data are in accordance with Kaur and Kumar's findings [15].

The previously described principle states that the smaller the *Young's* modulus value of the foam, the lower the compressive strength value of the foam tends to be. Conversely, when the foam has a higher Young's modulus, its compressive strength also tends to increase. This relationship is closely connected to the mechanical behavior of polyurethane foam. Young's modulus reflects the stiffness or rigidity of a material, while compressive strength indicates how well the material can withstand forces that attempt to deform it.

Foam with a lower Young's modulus is more elastic and more easily deformed, which naturally results in lower compressive strength. On the other hand, foam with a higher Young's modulus is stiffer and less prone to deformation, leading to higher compressive strength values. This trend is consistent with the expected mechanical behavior of polyurethane-based materials.

3.2.2 Analysis of density test results

Surfactants are amphiphilic molecules—containing both hydrophilic (water-attracting) and hydrophobic (water-repelling) segments—which allows them to play multiple roles in polyurethane foam production. In this study, silicone surfactants function primarily as stabilizing agents that help control cell formation and ensure uniform pore structure. Their presence allows components that would not normally mix to be dispersed evenly, contributing to a more consistent foam morphology.

By influencing cell size, distribution, and stability, higher surfactant compositions can promote the formation of larger or more numerous pores. These pores increase the overall volume of the foam without significantly adding mass, ultimately leading to a lower density.

In the context of density, the use of silicone surfactant in polyurethane foam production can result in a foam density reduction effect. This occurs because surfactant, through its hydrophilic and hydrophobic properties, affects the reaction and gas distribution of blowing agents (pore-forming agents) in the foam. The use of larger amounts of silicone surfactant can lead to increased pore formation and better dispersion of the gas blowing agent in the polyurethane foam. This results in an increase in the number and size of pores in the foam structure, resulting in lower foam density.

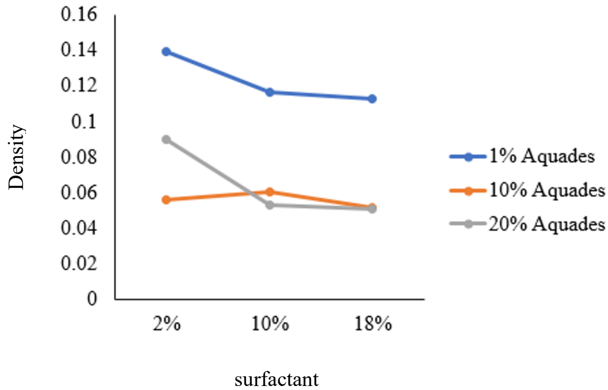

Fig. 4. Effect of the addition of surfactant composition variation on polyurethane foam density.

It can be seen from Figure 4 that the greater the surfactant composition used in polyurethane foam production, the lower the density value of the foam. Foam composed of 2% surfactant and 1% distilled water has a density value of 0.139370 g/cm^3. Foam composed of 10% surfactant and 1% distilled water has a density value of 0.116657 g/cm^3. Foam composed of 18% surfactant and 1% distilled water has a density value of 0.112617 g/cm^3. Foam composed of 2% surfactant and 10% distilled water has a density value of 0.055929 g/cm^3. Foam composed of 10% surfactant and 10% distilled water has a density value of 0.060683 g/cm^3. Foam composed of 18% surfactant and 10% distilled water has a density value of 0.051448 g/cm^3. Foam composed of 2% surfactant and 20% distilled water has a density value of 0.090007 g/cm^3. Foam composed of 10% surfactant and 20% distilled water has a density value of 0.053263 g/cm^3. Foam composed of 18% surfactant and 20% distilled water has a density value of 0.050458 g/cm^3. Silicone surfactant, which is used as an additive in polyurethane foam production, has an important role in influencing the physical properties of the foam, such as density. In addition, surfactant can also mix components that are not mutually soluble in the polyurethane system. In the context of density, the use of silicone surfactant in polyurethane foam compositions results in a foam density reduction effect. The reduction of foam density by silicon surfactant occurs because when the surfactant is added to the polyurethane mixture, the hydrophilic part of the surfactant molecules will interact with the water phase or water-in-air phase in the system. Meanwhile, the hydrophobic part of the surfactant molecules will interact with the polyurethane phase. These interactions help to improve the dispersion of the ingredients in the system and facilitate the formation of more homogeneous and well-distributed pores. The reduction in foam density by silicone surfactant is related to the regulation of pore formation. The greater the surfactant composition used, the more effective the dispersion and pore formation process in the polyurethane foam. As a result, the size and distribution of pores in the foam become more consistent, leading to a decrease in the overall density of the foam.

4 Conclusion

Based on the study that has been carried out, the following conclusions are obtained:

Polyurethane foam production uses castor oil as polyol by reacting it with distilled water, silicone surfactant, and Methylene Diphenyl Diisocyanate (MDI). Distilled water acts as a blowing agent that serves to develop foam, and silicone surfactant acts as a surfactant that serves to reduce surface tension and to dissolve distilled water with MDI so as to produce three types of polyurethane foam: rigid, semi-rigid, and flexible.

The greater the distilled water composition used, the more CO_2 gas is formed. The addition of more CO_2 gas causes the polyurethane foam to expand more. Excessive addition of distilled water can result in a decrease in the mechanical strength of polyurethane foam. Excessive addition of distilled water can reduce the density of polyurethane foam. Thus, increasing the distilled water composition can reduce the strength and density of polyurethane foam.

The 2% surfactant composition and 1, 10, and 20% distilled water composition produced the compressive strength values of 0.81, 0.21, and 0.12 MPa, respectively, with the average density values of 0.139370, 0.055929, and 0.090007 g/cm^3, respectively. The 10% surfactant composition and 1, 10, and 20% distilled water composition produced the compressive strength values of 0.53, 0.23, and 0.13 MPa, respectively, with the average density values of 0.116657, 0.060683, and 0.053263 gr/cm^3, respectively. The 18% surfactant composition and 1, 10, and 20% distilled water composition produced the compressive strength values of 0.59, 0.16, and 0.16 MPa, respectively, with the average density values of 0.112617, 0.051448, and 0.050458 g/cm^3.

The greater the composition of silicone surfactant, the more uniform the pore cell size of polyurethane foam. The close cell structure of polyurethane foam produces smaller and more organized pores. Uniform pore cell size can increase the strength of polyurethane foam. Uniform pore cell size can also reduce the density of polyurethane foam. Thus, increasing the silicone surfactant composition can increase the strength of polyurethane foam and at the same time decrease its density.

The 1% distilled water composition and 2, 10, and 18% surfactant composition produced the compressive strength values of 0.81, 0.53, and 0.59 MPa, respectively, with the average density values of 0.139370, 0.116657, and 0.112617 g/cm^3, respectively. The 10% distilled water composition and 2, 10, and 18% surfactant composition produced the compressive strength values of 0.21, 0.23, and 0.16 MPa, respectively, with the average density values of 0.055929, 0.060683, and 0.051448 g/cm^3, respectively. The 20% distilled water composition and 2, 10, and 18% surfactant composition produced the compressive strength values of 0.12, 0.13, and 0.16 MPa, respectively, with the average density values of 0.090007, 0.053263, and 0.050458 g/cm^3, respectively.

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