# The Properties of Nanofiber Membranes Made of Aloe Vera Gel Combined with Polyvinyl Alcohol

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# The Properties of Nanofiber Membranes Made of Aloe Vera Gel Combined with Polyvinyl Alcohol

**Harini Sosiati, Apriyanto, and Abdul Rahim Safarudin**

**Abstract** Aloe Vera gel (AVG), and polyvinyl alcohol (PVA) are compatible materials with the human tissues. The current research studied the characteristic of nanofiber membranes made of AVG (aloe Vera filtrate/AVF) and aloe Vera extract (AVE) combined with PVA with varying AVF concentrations of 10, 20, and 30 wt.%), while AVE concentrations ranged from 0 to 5 wt.%. Changes in surface morphologies and tensile properties of the nanofiber membranes due to AVF and AVE concentrations and the correlation effect between them are the goals of this research. The fiber diameter and tensile strength of AVF/PVA membranes increased with AVF concentration. The AVF/PVA membrane with 30 wt.% AVF showed the highest tensile strength (3.58 MPa) and 233 nm in fiber diameter. The addition of 1% AVE concentration, significantly improved the tensile strength and modulus of AVE/AVF/PVA membrane: i.e., 8.78 MPa and 26.8 MPa, respectively, with a smaller fiber diameter around 124 nm. At AVE concentration higher than 1%, the tensile properties gradually decreased, and fiber diameter increased. As a result, the properties of the AVE/AVF/PVA membranes could be the candidate material for wound dressing due to their comparable properties to that of natural skin.

**Keywords** Aloe vera gel · PVA · Electrospinning, nanofiber membrane · Tensile properties

## 1 Introduction

Aloe Vera (AV) grows naturally in a tropical climate and low rainfall area, mainly in Asia, Africa, Europe, and America [1, 2]. Numerous AV-based industrial products, such as foods and cosmetics, have been well known. AV is also potentially used in medicines due to its significant antioxidant vitamins, which can improve wound healing [2]. Based on various beneficial substances contained in AV, and its properties

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of antibacterial and anti-inflammatory, research and development of the AV-based materials have been extensively carried out.

Studies of AV-based nanofiber membranes have been reported [3–6]. Aghamohamadi et al. [3] have investigated the preparation and various characterizations of AV/polyvinylpyrrolidone (PVP) with different concentration of PVP, and AV acetate/PVP. AV powder and AV *acetate* are present in the crystalline phase. The addition of AV into the PVP increases the fiber diameter of AV/PVP membrane, but the addition of AV *acetate* reveals an adverse effect. However, by enhancing the concentration, both AV and AV acetate increase the fiber diameter of the membranes, and the membrane of AV acetate/PVP 6 wt% has shown the smallest fiber diameter (~95 nm). In this case, the fiber diameter does not linearly affect the tensile properties of the membranes, but the use of AV acetate increased the thermal stability of the membrane.

Studies on the properties of AV extract (AVE)/poly (vinyl) alcohol (PVA) nanofiber membranes have been previously investigated [4–6]. Inserting AVE into the PVA solution reduces the fiber diameter of the AVE/PVA membrane [4, 5] regardless of the molecular weight (Mw) of PVA. The addition of a similar AV concentration into the 10% PVA solution with a different Mw of PVA resulted in a different fiber diameter. The smallest one around 123 nm shown by using the highest Mw (85,000–124,000 g/mol) [4], whereas the use of Mw (22,000 g/mol) [5] and (66,000) [6] resulting in larger fiber diameter. The viscosity of the polymer solution as the spinning solution and other main parameters of the electrospinning process provide an impact on the morphology of membrane (fiber diameter and fiber structure) [5, 6], and also the mechanical properties of the membrane [5].

On the other hand, AV-based electrospun nanofiber membranes have also been investigated and developed for wound dressing and wound healing [7, 8], and tissue engineering [9, 10] applications. The membranes made of AV, chitosan (CS) and polyethylene oxide (PEO) reinforced polycaprolactone (PCL) [7], and AV filled in a mixture of PVA, PVP and polyethylene glycol (PEG) [8] have been investigated for wound dressing and wound healing. The AV/PCL membranes with some different AV concentrations studied for tissue engineering applications [9].

For wound dressing application, the material should be at least high in tensile strength, but not too high in tensile modulus as in the tensile properties of natural skin. Tensile and modulus strengths and elongation at break of the natural skin are ranging between 5–30 MPa, 4.6–20 MPa, and 35–115%, respectively. [7]. The membrane material having the tensile modulus much higher than that of natural skin tends to be easily peeled off from the skin surface. Inversely, the membrane would blend with skin when its tensile modulus is around the natural skin properties. However, a trend indicating that the higher the tensile strength, the higher the tensile modulus is generally shown in the previous results [7, 11].

Therefore, an effort to modify the membrane materials for achieving the tensile properties in the range of natural skin is still a challenge.

In the current research, both AV leaf gel and commercial AV extract (AVE) were used as reinforcing materials for PVA. Fabrication of the nanofiber membranes made of AV leaf gel in terms of AV filtrate (AVF) with PVA and AVE with AVF/PVA

has been carried out to characterization and of the properties of membranes and compare the properties to those of the natural skin. The current discussion focuses on the effect of the AVF and AVE concentrations on the fiber structure and tensile properties of the produced membranes, and their correlation effect.

## 2 Experimental

### 2.1 *Materials and Preparation of the Spinning Solutions*

AV leaf gel, commercial AV extract powder, and PVA Gohsenol (PVOH/PVA, Mw: ~22,000 g/mol) were used as the primary component materials for fabricating the nanofiber membranes. The gel obtained from AV leaf was filtered to be the AV filtrate (AVF). In this case, filtration of the gel was repeated three times to make AVF in good quality. Ten % PVA solution as the matrix prepared by dissolving 10 g PVA powder into 100 g $H_2O$ and was magnetically stirred at 80 ± 2 °C for one hour.

There are two spinning solutions: i.e., AVF/PVA and AVE/AVF/PVA. The first solution of AVF/PVA was prepared by blending AVF in the 10% PVA with varying AVF concentrations of 0, 10, 20, and 30% (w/w). Before preparing the second spinning solution of AVE/AVF/PVA, optimization of the tensile strength of AVF/PVA membranes is carried out. An optimum condition of the spinning solution resulted from the first process was then used as the matrix material reinforced with varying AVE concentrations (1, 3, and 5 wt.%). The spinning solutions of AVF/PVA and AVE/AVF/PVA were prepared similarly. Each of them was mixed by a magnetic stirrer while heated at 80 ± 2 °C for one hour and continued by stirring the solution at room temperature for two hours. The viscosity and electrical conductivity of those spinning solutions were measured.

### 2.2 *Preparation of the Nanofiber Membranes and Characterization*

All the spinning solutions of AVF/PVA and AVE/AVF/PVA were fabricated to be the nanofiber membranes at the optimum conditions: i.e., at applied voltage 15 kV, a fix distance from the needle tip to a collector plate (TCD) 12.5–16 cm, a syringe needle diameter of 8 mm and feed rate 0.5 ml/h. The process parameters were optimized based on the optical micrographs of the thin membranes. The membrane that shows defects-free fibers and straight-oriented fibers are known as reaching optimum parameters. The membranes resulted from the first spinning solutions were designated as Neat PVA, AVF-10/PVA, AVF-20/PVA, and AVF-30/PVA, whereas those from the other spinning solutions were known as AVF-30/PVA, AVE-1/AVF-30/PVA, AVE-3/AVF-30/PVA, and AVE-5/AVF-30/PVA.

The surface morphology of all membrane specimens, including the fiber diameter and fiber structure, were examined by scanning electron microscopy (SEM, Hitachi SU-3500). Fiber diameter in each membrane was measured from at least one hundred points by the ImageJ digital image analysis. The tensile test was conducted on all membrane specimens according to ASTM 882 using an ultimate tensile machine (UTM, Zwick Z0.5 Germany) at a crosshead speed of 10 mm/min and a gauge length of 20 mm. Five pieces of specimens are carried out for each tensile testing.

## 3 Results and Discussion

### *3.1 Morphological Characterization*

SEM images of the nanofiber membranes (Fig. 1) exhibit that each membrane has a different fiber diameter and structure, leading to having a difference in properties. In the electrospinning process the characteristic of produced membranes is mainly affected by the properties of polymer solution as the spinning solution (viscosity which is related to the concentration, electrical conductivity), and processing parameters (applied voltage, TCD, the diameter of the spinneret, flow rate) [12, 13]. In general, increasing the spinning solution viscosity increases the fiber diameter [5, 11].

AV filtrate reinforced PVA membranes demonstrate comparatively small fiber diameter, and straight-oriented fibers in a neat PVA, AVF-10/PVA, AVF-20/PVA membranes, with average fiber diameter increases from 136 to 166 nm (Fig. 1a, b, c). The AVF-30/PVA (Fig. 1d), shows the most substantial fiber diameter (223 nm) among the AVF/PVA membranes, and straight-oriented fibers are not formed. The most significant difference shown in this membrane is strong bonding between the fibers. Their fiber diameters are present in the range from 0 to 300 nm (Fig. 2). Figure 3 shows the average fiber diameter for all membranes, which increases with both AVF and AVE concentrations. Those are generally corresponding to the enhancing viscosity and decreasing the electrical conductivity of the spinning solution. However, viscosity and electrical conductivity in the present study did not change linearly. The trend is the opposite of the general.

On the other hand, introducing a small amount of AVE with a concentration of 1% into the AVF-30/PVA changed the fiber structure and significantly decreased the fiber diameter (Fig. 1e). An increase of AVE concentration to 3 and 5%, however, remarkably improved the fiber diameter and changed the fiber structure. Among all nanofiber membranes, the combination of 30% AVF and 1% AVE in the PVA solution seemed to be the best. The distribution of its fiber diameter in the range from 0 to 100 nm is the highest, indicating that the membrane has the smallest average fiber size (124 nm). In contrast, the AVE-5/AVF-30/PVA membrane has the most sizable fiber size, so the distribution of the fiber size is mostly in the range from 200 to 300 nm and from 300 to 400 nm (Fig. 2).

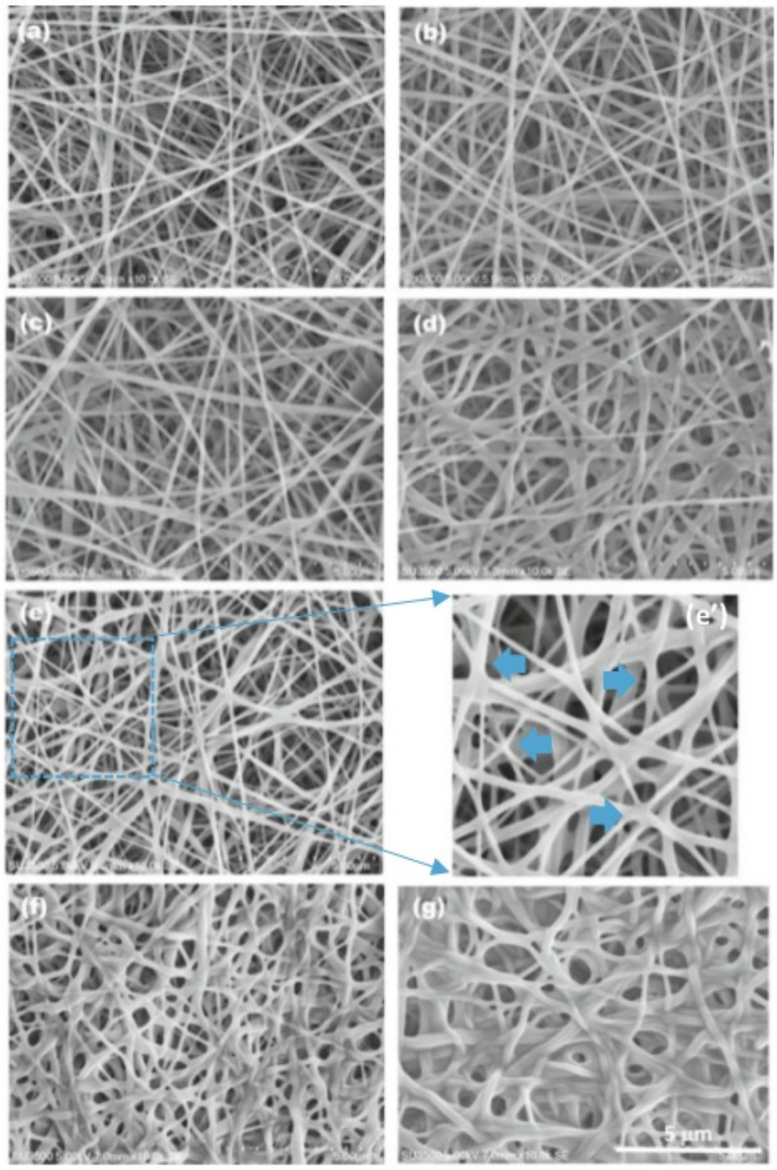


**Fig. 1** SEM images of the electrospun nanofiber membranes of neat PVA (**a**), AVF-10/PVA (**b**), AVF-20/PVA (**c**), AVF-30/PVA (**d**), AVE-1/AVF-30/PVA (**e**), a magnified image of a square area marked in Fig. 1e (e'), AVE-3/AVF-30/PVA (**f**) and AVE-5/AVF-30/PVA (**g**)

The average fiber diameter of this membrane of 124 nm with the use of a low Mw of PVA (22,000 g/mol) is competitive with a fiber diameter of the produced membrane using high Mw of PVA (85,000–124,000 g/mol), namely 123 nm [4]. These results inform an essential point that is not a correlation effect between Mw of the polymer and fiber size of the produced nanofiber membrane. As mentioned above, the differences in electrospinning process parameters are the cause.

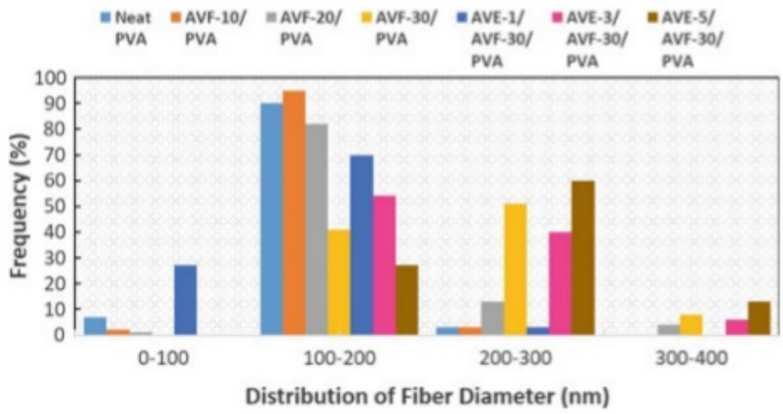


**Fig. 2** Distribution of fiber diameter formed in the AVF/PVA and AVE/AVF/PVA membranes

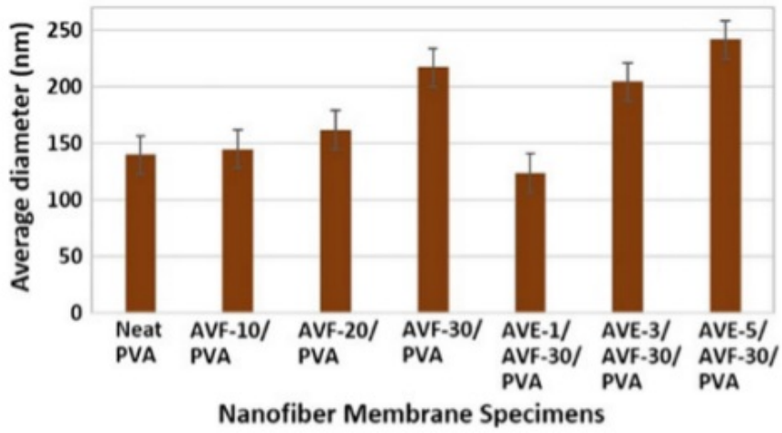


**Fig. 3** Average fiber diameter of the AVF/PVA and AVE/AVF/PVA membranes

In this case, changes in the fiber diameters and structures are affected by the physical properties of the spinning solution. They also provide an impact on the mechanical property of the membranes discussed below.

## 3.2 *Tensile Properties of the AVF/PVA and AVE/AVF/PVA Membranes*

The tensile properties of all membrane specimens (Fig. 4) show that both tensile strength and tensile modulus of AVF/PVA are slightly higher than those of neat PVA. The maximum tensile strength of AVF-30/PVA membrane (3.58 ± 0.58 MPa) is lower than that of the natural skin (5–30 MPa), although the tensile modulus of 17.72 ± 1.58 MPa included in that indicated by the natural skin (4.6–20 MPa). Its

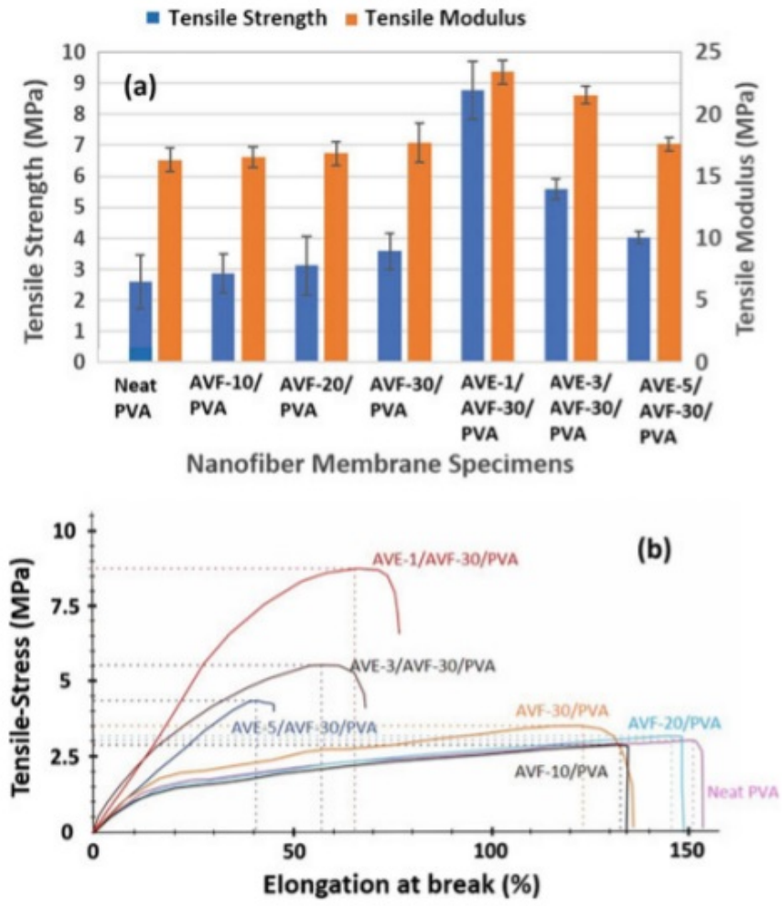


**Fig. 4** Tensile strength and modulus (**a**), and tensile-stress versus elongation at break (b) of AVF/PVA and AVE/AVF/PVA membranes with different AVF and AVE concentrations.

elongation at break (135 ± 7.10%) is higher than that of the natural skin (35–115%) [7]. Therefore, the AVF/PVA membranes from this study are not recommended for wound dressing application owing to its comparatively low tensile strength.

Efforts to improve the tensile strength, which is balanced with the tensile modulus as the natural skin properties seemed to be complicated. Introducing a small amount (1%) of AVE in the AVF-30/PVA significantly improves the tensile strength from 3.58 ± 0.58 to 8.78 ± 0.94 MPa. The tensile modulus also increases from 17.72 to 23.39 MPa, but the elongation at break decreases from 135 ± 7.10 to 7575 ± 18.83% (Fig. 4a, b). Thus, comparing with the properties of the natural skin, tensile strength and elongation at break of AVE-1/AVF-30/PVA are included in the range of the natural skin properties, but the tensile modulus is slightly higher. An increase of AVE concentration noticeably reduced the tensile properties, but the elongation values are comparable, although they are limited.

The tensile properties of the AVE-1/AVF-30/PVA membrane, however, are higher in comparison with our previous works [4, 11]. The best values obtained from AV (4%)/PVA were 6.38 MPa, 34.75 MPa, and 125% for tensile strength, tensile

modulus, and elongation at break, respectively [4]. The properties resulted from a hybrid nanofiber membrane of PVA_AV/CSNe with 15% concentration chitosan nano-emulsion (CSNe) were $6.18 \pm 0.15$ MPa, $21.9 \pm 9.88$ MPa and 97%, for tensile strength, tensile modulus, and elongation at break, respectively [11]. The combination of AVF and AVE powder seems to be comparable with that of AVE powder and CSNe for reinforcing materials of PVA.

Besides, the influence of fiber structure on the alteration of tensile properties of the membranes played a more prominent role rather than that of fiber diameter. It can be seen in Fig. 1 that the membranes have straight oriented fibers with relatively uniform fiber size in the entire areas (Fig. 1a, b, c). Those fiber structures tended to be lower tensile and modulus strengths in comparison with the membrane (Fig. 1d), having many cross-link fibers that tightly bound, even though the fiber diameter is slightly larger. Furthermore, by comparing the fiber structure formed in the membranes in Fig. 1d, f, g, the fiber structures built in the membrane (Fig. 1d) exhibits lower density of cross-link fibers that tightly bound compared to that present in the membranes in (Fig. 1f, g), resulting in higher tensile properties of the membranes in (Fig. 1f, g), even though they have larger fiber size. Therefore, the highest tensile properties achieved by the membrane with the fiber structure having a high density of cross-link fibers that tightly bound as depicted in Fig. 1e, e'.

Therefore, the highest tensile properties achieved by the membrane with the fiber structure having a high -volume fraction of cross-link fibers that tightly bound as depicted in Fig. 1e, e'.

A similar trend is shown in a study of the AV powder/PVP and AV acetate/PVP nanofiber membranes [3]. SEM micrographs of all membranes revealed the fiber structure with a straight-oriented fiber and having smaller fiber diameter compared to that of this work. However, the tensile strength resulted from that membranes is much lower than that of the present results.

## 4 Summary

The electrospinning technique has succeeded in fabricating the nanofiber membranes of PVA combined with AVF and AVE. The use of AVF shows a comparatively low tensile strength of the membrane, whereas adding small amounts of AVE improves the tensile properties significantly. Incorporation of 1% AVE powder with 30% AVF in PVA solution produces the nanofiber membrane with the tensile properties included to that of the native skin: i.e., $8.78 \pm 0.94$ MPa, $23.39 \pm 0.94$ MPa and $75 \pm 18.83$% for tensile strength, tensile modulus and elongation at break, respectively, which is recommended as a candidate for a wound dressing material. A significant finding from the current research is the fiber structure built in the nanofiber membrane has provided a prominent effect on the tensile properties rather than the fiber diameter, especially the fiber structure having a high density of cross-link fibers that tightly bound. This finding could be useful information related to nanofiber technology.

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