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Analysis of the Effect of Vacuum Pressure Variations on the Fluidity, form Ability, Hardness, and Density of the RTV 10A Silicon Rubber Composites with 30% Talc

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ABSTRACT

RTV 10A silicone rubber composites have many applications in forming many medical products and one of the recent applications is for orthotic insoles. This is because the RTV silicon rubber has excellent flexibility, elasticity, and resistance against splitting. However, these mechanical properties still need improvement when applied in certain medical applications. One way to improve mechanical properties is by adding talc. The process of mixing silicon rubber with talc requires special techniques to prevent the formation of porosity that may lead to unexpected mechanical properties. This porosity occurs due to trapped air during the mixing process or pouring into molds. Efforts to eliminate this porosity include vacuum die casting (VDC) techniques. This study presents the mechanical properties improvement of RTV 10A silicon rubber composite with the addition of using 30% talc. The objective is to achieve a more convenient orthotic insole to reduce the pain in human foot joints during walking due to planar stress. This study aims to reduce the porosity and minimize the trapped air by adding 30% talc into RTV 10A silicone rubber composite using VDC. In the experiment, the pressure variation was determined at -0.04 MPa, -0.06 MPa, -0.08 MPa, and -0.1 MPa through a mold size of 45 mm in diameter and thickness of 7 mm. Fluidity, density, porosity, and hardness were tested during the experiment. The results show that by decreasing vacuum pressure, the density and the hardness increase. This is because the size and distribution of porosity are decreased and more homogeny. Furthermore, it also produces higher fluidity. However, the porosity of the specimen after vacuum casting is not partially filled.

Keywords: casting, composite, silicone rubber, talc, vacuum.

INTRODUCTION

Silicone rubber is an elastomer based on high-molecular-weight linear polymers, polydimethylsiloxane (PDMS) with a Si-O main chain and two methyl groups on each silicone. The silicon oxide (Si-O) main chain bonds are more stable than the silicon-silicon (Si-Si) bonds. The arrangement in the main chain Si-O provides a high degree of resistance to ozone, oxygen, heat (up to 315 °C), UV rays, humidity, and general weather effects, which are often used as a protective layer [1]. There are two types of silicone rubber with a heating vulcanization system and room temperature vulcanization (RTV) silicone rubber. Silicone rubber with a heating vulcanization system is more expensive. In contrast, RTV silicone rubber is cheaper but has a lower hardness value

when compared to silicone rubber by heating vulcanization. Nevertheless, the hardness of RTV silicone rubber can be improved by adding reinforced powder, i.e., talc, to form composite materials [2]. RTV Silicone rubber composites have many applications to form many medical products for example orthotic insoles via casting process with or without pressure [3, 4, 5]. The success of the casting process is determined by means fluidity tests, which indicates the fluid's ability to flow and fill the mold cavities. Fluidity is determined by factors such as viscosity (resistance to flow) and molecular interactions within the substance and usually presented as fluidity index [6]. To determine fluidity of material, the fluidity testing is required. The specific method can vary depending on the substance being tested and the desired parameters such as viscosity measurements, flow rate measurements, rheology tests, spiral flow testing, etc. The characteristics of fluid flow in the fluidity test are greatly influenced by viscosity and the design of the mold used in the test apparatus. The presence of solid particles in the fluid also greatly affects the viscosity of materials. The higher the percentage of solid particles present in the fluid, the lower the viscosity, and the lower the fluidity index. Another factor that affects the fluidity index is the use of pressure. The flow of fluid in fluidity testing can be generated by gravity or pressure. The application of positive and negative pressure/vacuum pressure tends to increase the fluidity index as it becomes higher [7]. In our previous study, combining silicone rubber RTV 10A which is a very soft silicon rubber type with 30% talc has mechanical properties which suitable as an insole material. However, the manufacture of shoe insoles using the gravity casting method results in a product with a rough surface, non-homogeneous hardness and high presence of porosity. Mixing RTV silicone rubber with hardener and talc by stirring causes porosity due to the presence of trapped air bubbles within it [2]. Trapped gas is the main source of porosity in conventional gravity castings. The porosity provokes a significant decrease in the overall mechanical properties. One method to minimize the occurrence of air bubbles is through the vacuum die casting (VDC) process.

In the VDC process, the gas is discharged through a vacuum valve by a vacuum pump [8]. Vacuum casting is characterized by a controlled vacuum pressure to extract gas from the mold cavity. The application of vacuum pressure can reduce gas entrapment associated with filling and facilitate solidification due to increased heat transfer between the fill and the die, reduced the amount and size of trapped gas and decreased porosity.

This study was conducted to provide information about the improvement of the manufacturing process composite silicone rubber RTV with talc by means VDC to avoid rough surfaces, porosity and produce hardness homogeneity. However, the effect of vacuum pressure on the fluidity of composite silicone rubber RTV 10A with 30% talc must be evaluated. This paper also studies its effects on the vacuum pressure on the mechanical properties i.e. hardness and density.

MATERIALS AND METHODS

Materials

A detailed specification of the silicon rubber RTV 10A used in the experiment is presented in Table 1 and a detailed specification of talc used in the experiment is presented in Table 2 and the photo of talc in presented in Figure 1. The silicone rubber composites with talc were conducted by weighing the RTV 10A silicone rubber according to the need and then weighing 30% of the mass of the silicone rubber talc. Stirring was carried out using a stirrer at a velocity of 600 rpm for 20 minutes before 3% of the hardener was added and stirred for 2 minutes on that mixture. The mixing is done at room temperature. Furthermore, the composite (in liquid form) is placed in a vacuum chamber and degassed at a pressure of -0.8 bar for 2 minutes to reduce air trapped during stirring and minimize porosity. After the degassing is complete, the fluidity test is then carried out. The experiment was repeated three times for each vacuum pressure variation.

Fluidity test

The fluidity test was carried out by vacuum method. The liquid silicone rubber composite with talc was placed in a composite container. Transparency hose with 6 mm inner diameter and 2000 mm long as fluidity measurements test was connected into composites chamber and vacuum chamber. The variations of the vacuum pressures test of -0.4 bar, -0.6 bar, -0.8 bar, and -1 bar in the vacuum chamber were produced by controlling the pressures of a vacuum pump. The schematic vacuum fluidity test conducted in the

Table 1. Specification of silicone rubber RTV 10A [7]

Mechanical properties	Value (unit)
Mixed viscosity	23,000 cps
Specific gravity	1.07 g/cm^3
Specific volume	25.8
Cure time	30 min – 5 h
Shore a hardness	10A
Tensile strength	475 psi
Shrinkage	<0.001 in./in.

Table 2. Specification of talc [8]

Item specification	Value/Description
Density (g/cm^3)	2.7–2.85
Oil absorption	30–55
Solubility in H_2O	Not dissolved
Appearance	White powder, ash
Smell	No smell
Mohs scale hardness	1.0–1.5
pH	8.4–9.4
Crystallography	Flat
Hegman grind	3–6

Figure 1. Photo of talc

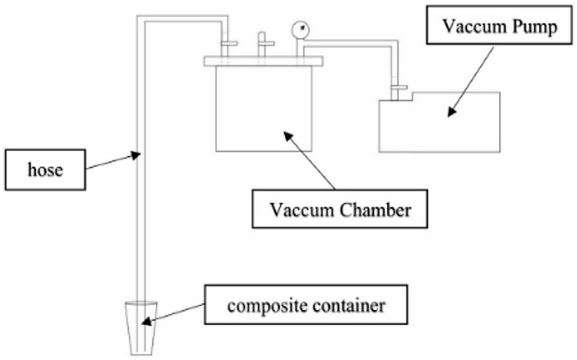

Figure 2. Fluidity test schematic

experiments is presented in Figure 2. During the vacuum fluidity test for vacuum pressure variation, the height and duration of silicone rubber composites with talc until they can flow were measured. Fluidity testing gives the maximum height in cm which is the length of silicone rubber composites with talc flow across the transparence hose. Here the total volume of silicone rubber composites can be calculated by multiplication the cross-section area with the total height. Another result of the fluidity test is flow velocity. The flow velocity test aims to obtain the information regarding the time of silicone rubber composites with talc start to flow until the maximum length was counted as travel time. The average flow velocity can be calculated by total height divided by travel time. The flow velocity indicated how fast the cavity was filled by silicone rubber composites with talc.

Form ability test

The next test is the formability test, which assesses the ability of the silicone rubber-talc composite to fill the mold cavities. A disc mold, as shown in Figure 3, was used to evaluate the effect of vacuum pressure at -0.04 MPa, -0.06 MPa, -0.08 MPa and -0.1 MPa on how fully the mold cavities were filled. The mold is coated with acrylic inside to reduce the frictional force. At the same time, a seal is given to the edge of the mold to prevent leakage. The disc mold has a cavity with a diameter of 45 mm and a thickness of 7mm, where the thickness of the specimen to be cast refers to the ASTM D2240 silicone hardness test. Specimens in the mold are left for 24 hours and removed for hardness, density, and porosity measurement. After 24 hours the curing process was finished, and the disc mold was opened. The disc sample of silicone rubber composites with talc was then characterized. The first characterization was conducted by visual inspection to obtain how much the cavity was filled the texture of the outer surface and the porosity. Visual observation is done by observing the sample using a stereo microscope. During visual observation, a lamp is placed at the bottom of the sample to see the inside appearance. The disc sample without a vacuum process was produced to compare the results between those treated and those not.

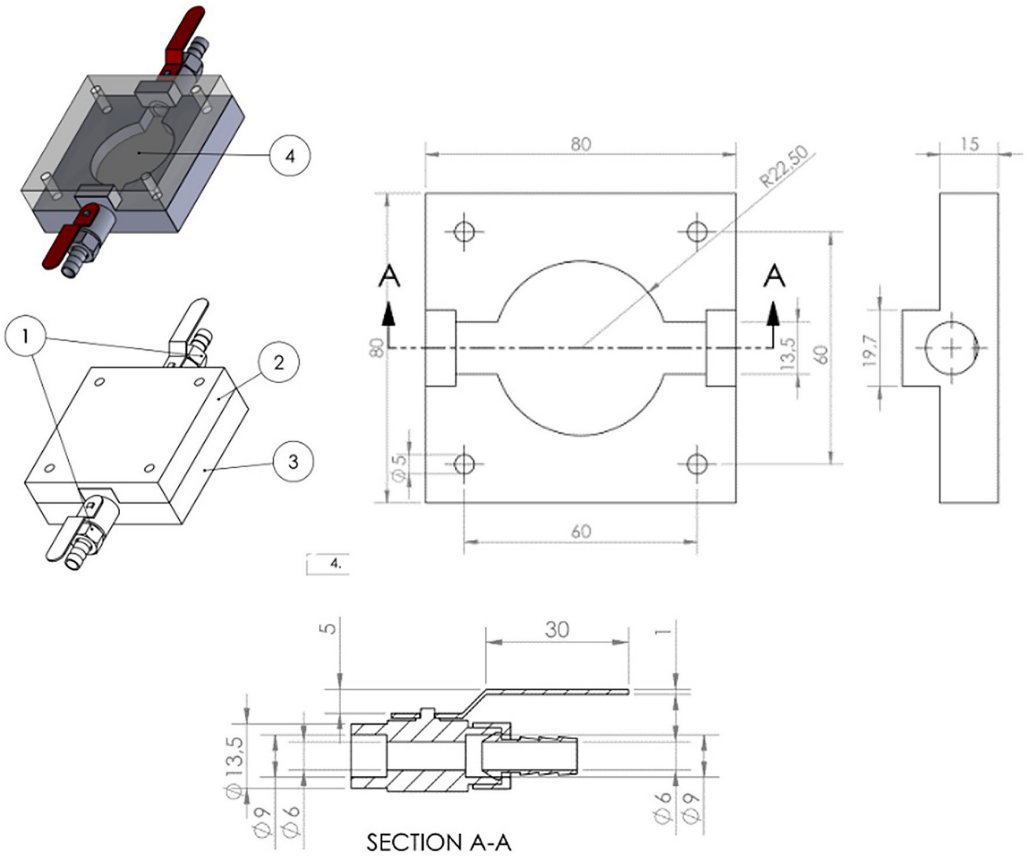

Figure 3. Specimen molds

RESULTS AND DISCUSSION

Fluidity test results

The correlation of vacuum pressure on the fluidity, total volume, travel time, and velocity is presented in Figure 4. Figure 4a shows the decrease the vacuum pressure the maximum height is increased. The lowest height value is at 43.67 cm with a pressure of -0.04 MPa, and the highest value is at 107.17cm, with a pressure of -0.1 MPa. At the same time of observation, the lowest time stood at 221.33 s with a pressure of -0.04 MPa, and the highest time stood at 333.33 s with a pressure of -0.1 MPa as presented in Figure 4b. Furthermore, the lowest volume stands at 49.36 cm^3 with a pressure of -0.04 MPa, and the highest stands at 121.14 cm^3 with a pressure of -0.1MPa as shown in Figure 4c. Moreover, as presented in Figure 4d, the lowest velocity value is at 0.23 cm/s with a pressure of -0.04 MPa, and the highest value is at 0.35 cm/s with a pressure of -0.1 MPa.

Result of form ability test

A result of the disc sample produced by and without vacuum pressure is presented in Figure 5. The sample prepared with and without vacuum casting show a different surface appearance. The disc samples without vacuum pressure Figure 5a show the surface was not as smooth as the vacuumed samples. Nevertheless, the surface of the vacuumed sample at -0.04 MPa, -0.06 MPa, -0.08 MPa, and -0.1 MPa as presented in Figures 5b–5e respectively has the same surface appearance.

The condition inside the disc sample both with and without vacuum pressure was observed by illuminating the bottom side of the stereo microscope with a lamp. Figure 5 shows the image captured by the following procedure. Silicone rubber has the property of transmitting light, thus the information regarding porosity in the disc sample can be obtained by comparing the brightness of the image. The dark side shows the section of the disc sample more filled than the bright side. The disc sample produced without vacuum pressure in Figure 6a, shows there was no bright side. It indicated that there was no porosity. Figure

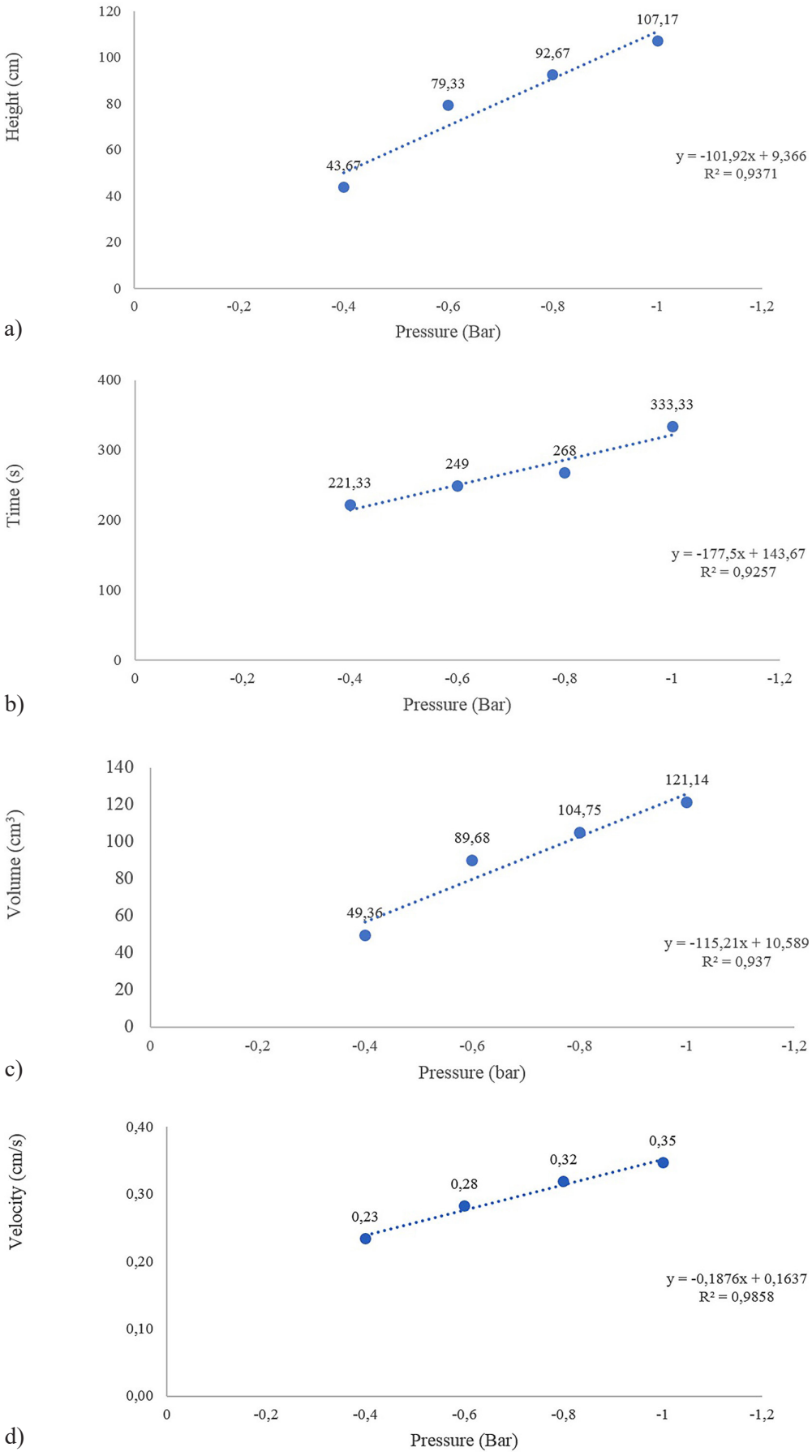

Figure 4. Fluidity test results: (a) pressure vs. height; (b) pressure vs. time; (c) pressure vs. volume; (d) pressure vs. velocity

Figure 5. Results of specimens' preparations: (a) without vacuum; (b) to (e) with a vacuum

6b–e shows the disc sample prepared with vacuum casting -0.04 MPa, -0.06 MPa, -0.08 MPA, and -0.1 MPa respectively, showing the dark and bright sides. The bright side indicates that there not filled by silicone rubber composites.

For each vacuum pressured variation, three specimens were made with a total of 12 specimens formed, none of which experienced perfection and had casting defects. In disc samples that were not subjected to vacuum pressure, small pox formed, and voids on the surface were seen spreading on the surface and in deep areas. The surface of the specimen without vacuum die casting also looks rough with bubbles and hollows on the surface. This occurred because the gas was still trapped in the composite mixture. Meanwhile, in 12 specimens with vacuum pressure, there was a large cavity inside the specimen/ porosity. This occured because the void occurred in the middle and above, with the edge of the cavity still covering the composite. This is related to the ability of the composite to fill the cavity. The shape of the cross-sectional channel in specimen printing is shown in Figure 7.

Figure 7 shows that the composite flow moves through a hose with a diameter of 6 mm and then enters the cavity with a diameter of 45 mm and a thickness of 7 mm. Not filled side occurs in the upper (1/2 up from the molded part). Silicone rubber is an RTV material where the curing period is influenced by the time at room temperature so that during curing time the viscosity increases. The silicone rubber composite with talc is included in the non-Newtonian dilatant fluid based on the type of fluid. Non-Newtonian fluids are fluids in which the shear stress is not directly proportional to the strain rate but follows the power law [12]. Dilatant is a non-Newtonian fluid in which this fluid's viscosity and shear stress tend to increase [13]. According to [9, 10] a study of the non-Newtonian fluid flow of iron sand flowing through a straight pipeline and an elbow pipe channel was carried out, and the results revealed that the wall shear stress that occurs increases with each increase in the strain rate. Both on the straight pipe and the elbow pipe. The wall shear stress in the elbow pipe is greater than the wall shear stress in the straight pipe. In addition, the viscosity also increases with each increase in the strain rate both in straight pipes and in elbow pipes, where the viscosity of elbow pipes is greater than in straight pipes. Based on these data, it can be assumed that the channel in the specimen mold with a curved wall has higher shear stress than the shear stress in the pipe section. As a result of the vacuum pressure that occurs, the composite continues to rise towards the outlet due to the presence of this vacuum pressure and the high shear stress on the channel wall, and a void is formed in the center of the specimen due to the lower shear stress in the middle than the wall. Due to a defect in the specimen, the density test was carried out twice where the test specimen was divided into two types, namely printed specimens and cut specimens. Test specimens are presented in Figure 8. The printed specimen is the whole specimen from the casting, while the cut specimen is part of the specimen, which is filled with composite. Using a density meter, the results of the printed specimen test are presented in Figure 9. Figure 9 indicates that the mass that fills the mold forms a descending linear graph where the lower the pressure, the lower the mass was 11.71 g, and the lowest was 9.73 g. It filled into the mold with the largest mass at a pressure of -0.06 MPa. This value is lower than the mass of the specimen without vacuum die casting, which is 13.91 g. The volume formed also forms a downward linear graph where the lower pressure and the lower volume can be formed. The largest volume value was at -0.06 MPa pressure with a volume of 9.59 cm^3, and the lowest was at -0.1 MPa pressure with a volume of 8.01 cm3. The percentage of filled volume indicates the ability of the vacuum die casting to fill the mold, and the highest percentage is obtained at a pressure of -0.06 MPa with 86.26%. A comparison of the

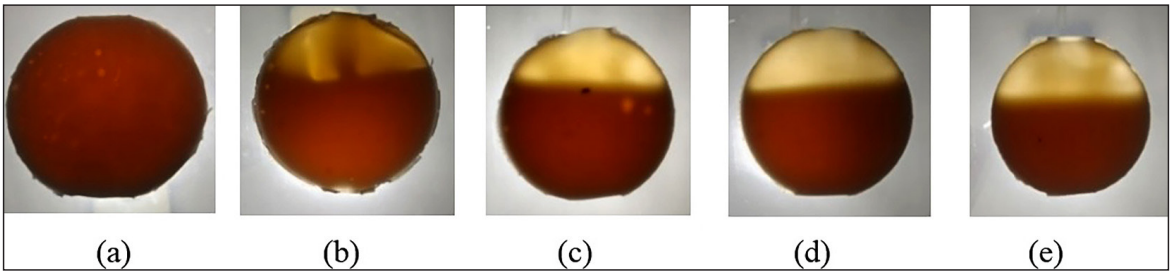

Figure 6. Results of specimens' preparations: (a) without vacuum; (b) to (e) with a vacuum

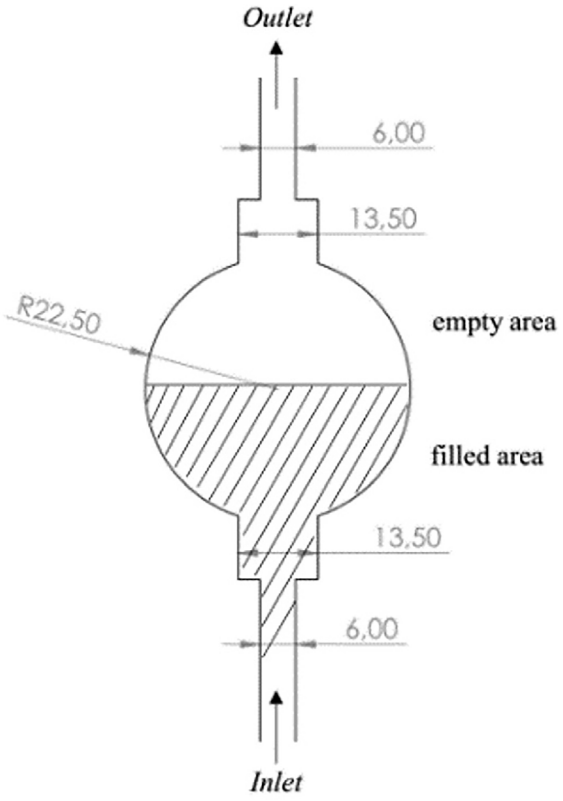

Figure 7. Specimen mold cross-section

density values of printed specimens and cut specimens is presented in Figure 10. The density value is formed by dividing the mass/volume. According to Figure 9, the pressure of 0 bar shows the density value of the specimen without vacuum pressure. The density of the printed specimen forms a descending linear graph with the highest density values at a pressure of -0.04 MPa and -0.08 MPa at 1.23 g/cm^3, and the lowest at -0.06 MPa and -0.1 MPa pressure of 1.22 g/cm^3. This value is lower than the specimen value without vacuum die casting, in which the density is 1.28 g/cm^3. The graph cut specimens form an ascending linear line with a density value higher than the specimen without vacuum die-casting with the highest density value at -0.06 MPa pressure of 1.33 g/cm^3. The density value from specimen testing using a density meter is used to find the porosity of the specimen by comparing the theoretical density of silicone rubber composites with talc with the density of the test results. Figure 11 shows the comparison percentage of porosity between print and cut specimens. There is an example of the porosity present in the specimens as indicated in white dots in Figure 11. The white dot is appeared when light is applied to the bottom part of the specimen, if there is porosity, the surface of the upper part will appear brighter than its surroundings. Microscopy testing is used to see the air bubbles trapped in the specimen. The microscope test results are presented in Figure 12. It conveys that the porosity of the printed specimen is higher than that of the cut specimen, with the lowest porosity in the printed specimen is 21.86% at a pressure of -0.04 MPa. This value is greater than that of the specimen without vacuum die casting, which is 19.16%. In addition, for the cut specimen, the smallest porosity is 16.72% at a pressure of -0.04MPa. The lower the vacuum pressure applied, the higher the porosity that occurs. In specimens without vacuum die casting, the bubbles formed have large and largest dimensions, while in specimens with vacuum die casting, the bubbles formed tend to be smaller (like spots) and scattered. At a pressure of -0.06 MPa, fewer bubbles formed in accordance with the specimen porosity value of -0.06 MPa, where the value is the lowest. Whereas in the -0.1 MPa specimen, the bubbles formed tend to be more in accordance with the porosity graph where the porosity value of the -0.1 MPa specimen is the highest as presented in Figure 11. Hardness testing was carried out using a shore a durometer. The results of the hardness test are presented in Figure 13 and the increasing percentage of hardness is shown in Table 3. According to Figure 13, the hardness value is increased linearly as the vacuum pressure decreases. The highest increase in the percentage of hardness value is obtained at a pressure of

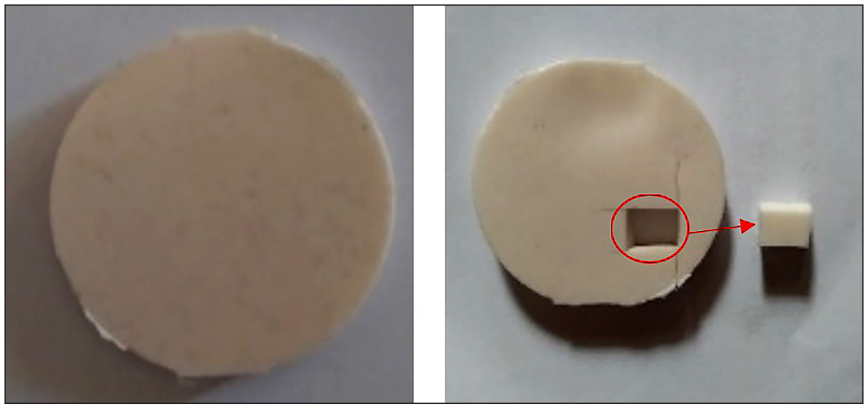

Figure 8. Test specimen: (a) print; (b) cut

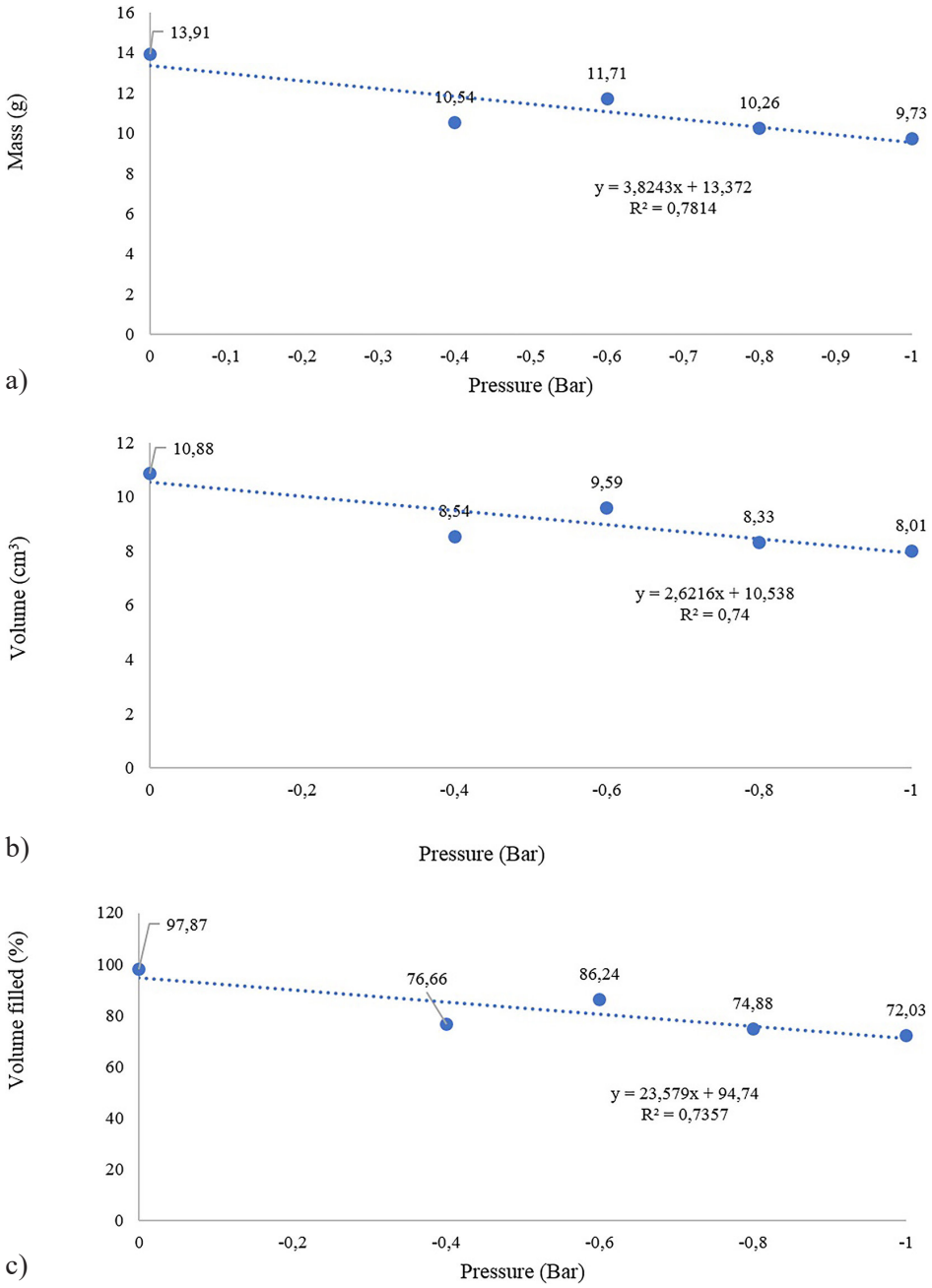

Figure 9. Test of printed specimens: (a) pressure vs. mass; (b) pressure vs. volume; (c) pressure vs. volume filled

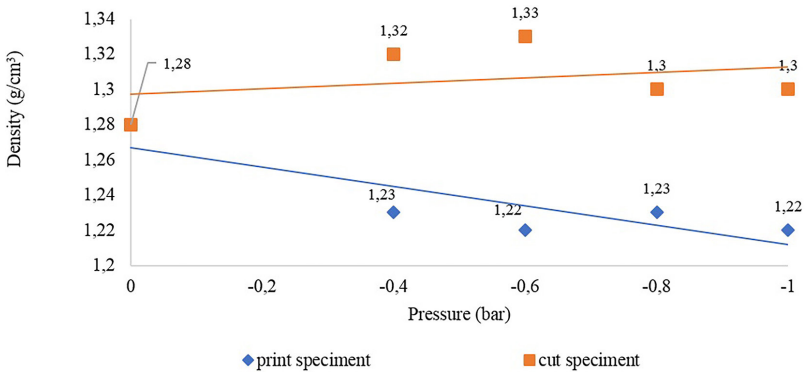

Figure 10. Print and cut specimen density

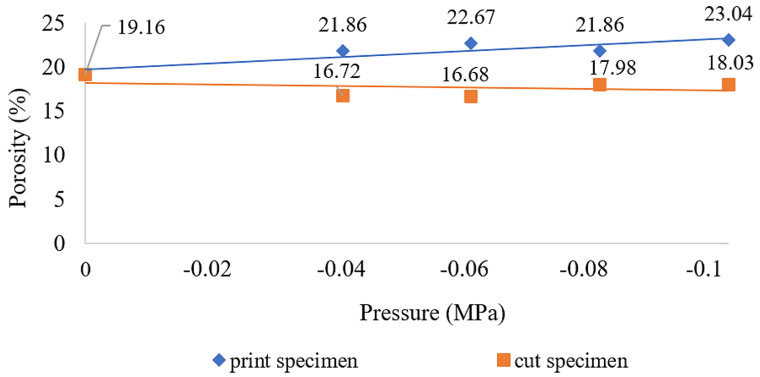

Figure 11. Porosity calculation results

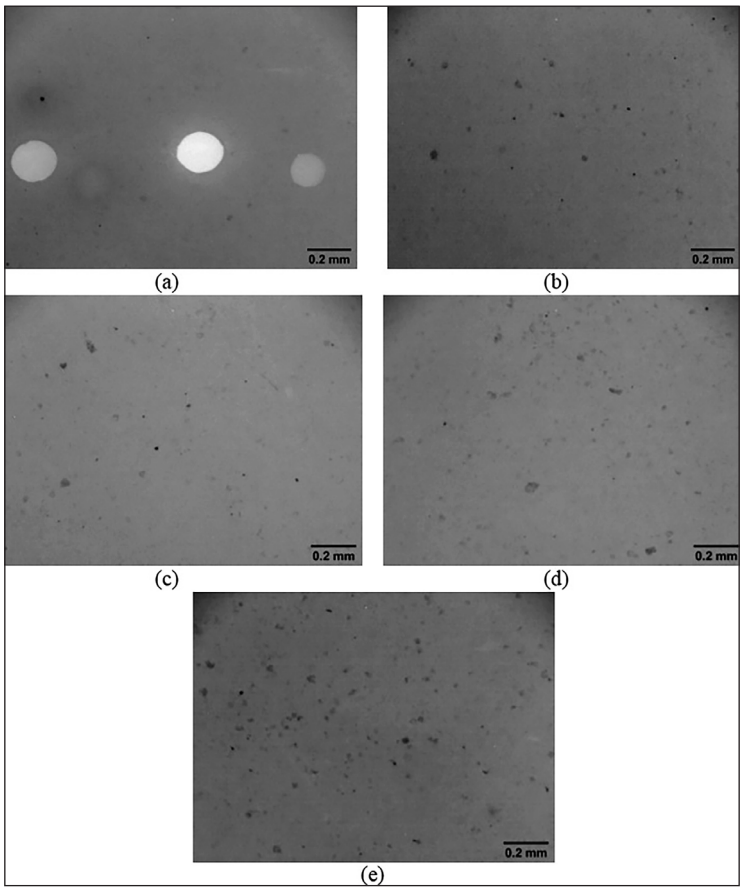

Figure 12. Macrograph of specimens: (a) specimen produced without vacuum casting and (b)–(e) specimens produced by vacuum casting.

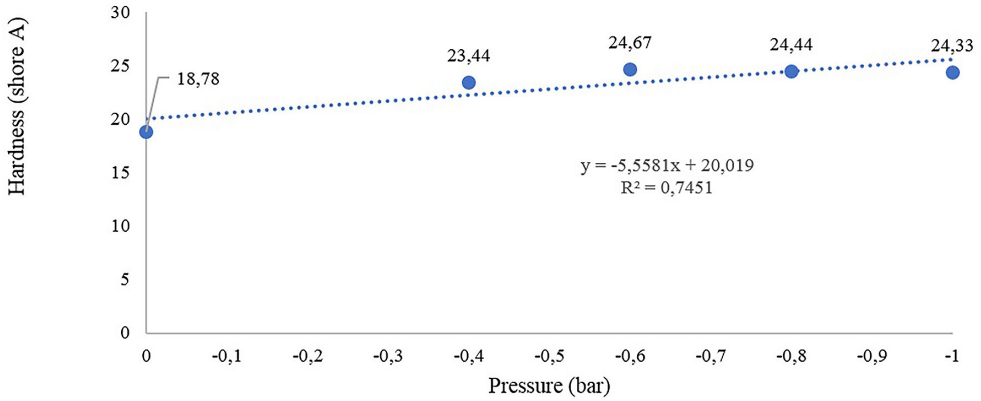

Figure 13. Hardness test. A pressure of 0 bar indicates a specimen produced without vacuum casting.

Table 3. Increased hardness

Pressure	Increased hardness (%)
-0.4	24.81
-0.6	31.36
-0.8	30.14
-1	29.55

-0.06 MPa with the addition of a hardness value of 31.36% from specimens without vacuum die casting. The lower vacuum pressure results in higher density, and therefore increasing the hardness. Disc sample produced by non-vacuum pressure has a lower hardness than vacuum-pressure disc samples. The addition of talc increased the hardness of the silicone rubber composites with talc even though hardness is also influenced by the density. Vacuum pressure of the silicone rubber composites with talc is an effective method to enhance the mechanical properties of the silicone rubber composites with talc.

CONCLUSIONS

The testing to determine the effect of vacuum pressure on the VDC process of silicon rubber composite with talc has been successfully conducted. The conclusions obtained are as follows:

1. With the increasing vacuum pressure, the density and hardness decrease due to the decreasing size and distribution of the porosity. The density and hardness are also more homogenous.
2. In the fluidity test, the flow rate and height of hoses increase with the increase in vacuum pressure.
3. None of the specimens were produced by VDC using the proposed mold design. It is proof that the test is able to fill the cavity.

Future works of this study will study porosity observation by utilizing photo processing techniques to obtain an information regarding the size, distribution, and locations of pores.

Acknowledgment

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