Optimization of Handling Process in Silicone Rubber Room Temperature Vulcanizing in Reducing Defects of Silicone Molded Products

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Abstract

There is a defect in the form of air bubbles (bubbles) after the mixing process in the molding process of silicone Rubber Room Temperature Vulcanizing (RTV) 228 which can reduce product quality. The post-mixing handling process is carried out through the vacuum degassing method with variations in vacuum pressure (30 cmHg, 50 cmHg, and 70 cmHg) and degassing duration (2 minutes, 4 minutes, and 6 minutes). Assessment of the effectiveness of the parameters used was based on the value of the mass difference between the actual mass and the target mass and through analysis of the elemental composition obtained by the X-Ray Fluorescence (XRF) method. The most optimal combination of parameters in the vacuum degassing process was obtained at a vacuum pressure of 70 cmHg with a degassing duration of 2 minutes, where the combination obtained the smallest mass difference value. The results of the XRF testing carried out did not or could not show the effect of vacuum degassing, which only showed the composition of the elements contained in each specimen used.

Keywords: Silicone Rubber RTV 228; Vacuum Degassing; Bubble; X-Ray Fluorescence

1. Introduction

Silicone is a synthetic polymer composed of cross-links between silicone and oxygen atoms (-Si-O-Si-), and is equipped with organic groups that allow this material to be available in liquid to solid form [1]. One particularly prevalent type is Room Temperature Vulcanizing (RTV) silicone, which is capable of vulcanizing at room temperature without additional heating. RTV silicone is a material that exhibits advantageous properties, including flexibility, thermal resistance, and chemical stability. These properties have led to its extensive utilization in a variety of applications, including medical, industrial, and household fields [2].

It has been demonstrated that air bubbles have the potential to develop as a consequence of the mixing process, which consequently leads to a decline in mold quality [3,4]. The presence of bubbles is a result of the entrapment of air during the mixing process. In the vacuum degassing method, the pressure surrounding the mixture is reduced, thereby enabling the bubbles to rupture and escape [5,6].

The primary issue identified in this research pertains to the prevalence of post-mixing bubbles in silicone blends. Accordingly, the objective of the present analysis is to assess the parameters of vacuum pressure and degassing duration, with the aim of identifying the most optimal combination of parameters to achieve a reduction in the number of bubbles.

2. Materials and Methodology

The research focused on the identification of the most optimal combination of parameters to minimize the number of bubbles in the vacuum degassing process. The determination of research variables and the preparation of tools and materials were carried out in the implementation of the research. As demonstrated in Table 1, the research apparatus comprises a series of independent variables, dependent variables, as well as control variables.

Table 1. Table of Research Variables

Variable Types	Name of Variable	Description or Tested Values
Independent	Vacuum pressure	30 cmHg, 50 cmHg, 70 cmHg
variable	Degassing time	2 minutes, 4 minutes, dan 6 minutes

Variable Types	Name of Variable	Description or Tested Values
	Mixing time	1 minute
Dependent variable	Actual mass	Mass measurement of silicone molding products after solidification.
Control variable	Silicone type	Silicone Rubber RTV 228 Clear FG with a mix ratio of 1:1
	Room temperature	25°C-27°C
	Mixing speed	Constant
	Shape and dimensions of the mold	The mold is of the "beam" variety, with specimen dimensions measuring 20x13x8.5 millimeters.
	Curing time	5 hours

2.1. Tools and materials

In this research study, a variety of tools and materials were utilized, including silicone rubber RTV 228 clear FG, an Orion VP-RS-1 vacuum pump connected to a vacuum chamber, molds, analytical scales, mixing media, instruments for measuring time, and X-Ray Fluorescence (XRF) machines.

2.2. Research procedure

The research process is initiated by the amalgamation of silicone part A (base) and part B (curing agent) in a 1:1 ratio. This mixture is subjected to a constant speed for a duration of one minute. The formed bubbles underwent a handling procedure that involved the vacuum degassing process, which utilized varying levels of vacuum pressure (30, 50, and 70 cmHg) and degassing durations (2, 4, and 6 minutes). Subsequent to the vacuum degassing process, the mixture is to be poured into the mold, with a maximum allotted time of three minutes. It has been determined that the curing of the silicone mixture should be avoided during this period.

2.3. Data processing and analysis

The determination of the optimal parameter combination is based on the mass difference value obtained. It should be noted that calculations [1] and [2] were used to obtain target mass data with RTV silicone density ($\boldsymbol{\rho}$) $= \mathbf{1,1}\ {}^{\boldsymbol{g}}/_{\boldsymbol{cm^3}}$.

$$\boldsymbol{v = p \cdot l \cdot h} \quad (1)$$

$$\boldsymbol{m_t = v \cdot \rho} \quad (2)$$

The specimens were weighed, and the mean mass was determined through calculation [3].

$$\boldsymbol{\bar{m}_a = \frac{m_{a_1} + m_{a_2} + \cdots + m_{a_n}}{n}} \quad (3)$$

The calculation of [4] was used to obtain the mass difference value.

$$\boldsymbol{s = m_t - \bar{m}_a} \quad (4)$$

The mass difference value is indicative of the number of bubbles contained in the specimen. It is evident that as the mass value obtained decreases, the number of bubbles present in the specimen also diminishes.

X-ray fluorescence (XRF) testing was also conducted to ascertain the potential alterations in elemental composition that might be associated with the quantity of bubbles present. It is hypothesized that the observed fluctuations in elemental composition are indicative of the quantity of bubbles present within the specimen.

3. Results and Discussion

3.1. Evaluation of vacuum degassing method

Through the research procedure, the silicone prints (specimens) shown in Figure 1 were obtained. Visual observation of the specimens indicates variations in the number of bubbles present, contingent on parameters of vacuum pressure and degassing duration.

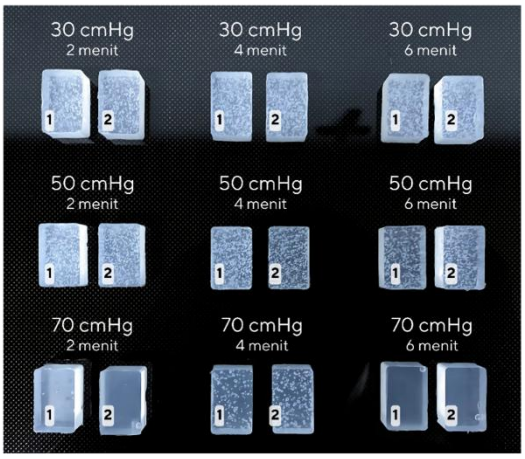


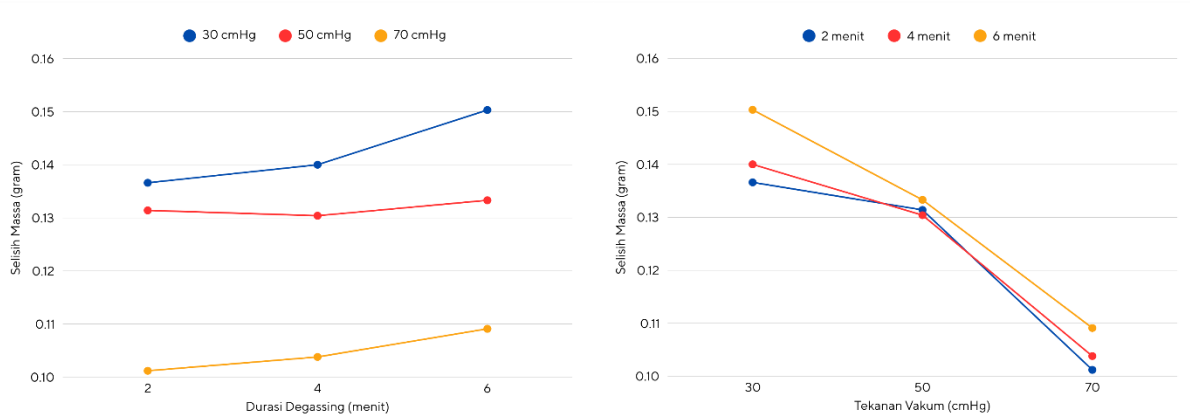
Figure 1. Specimens Based on Each Parameter Variation

The process of handling bubbles in the mixture can be accomplished by alternative methods, including centrifugal degassing, thermal degassing, and ultrasonic degassing. The research conducted by Lee et al. employed the centrifugal degassing method, which utilizes centrifugal force to separate air from the silicone mixture. This method is effective for large-scale industrial applications; however, it is not suitable for precision applications and requires complex equipment [7]. Tanaka et al. used thermal degassing to heat silicone, reducing its viscosity and accelerating air release. The application of this thermal degassing method requires a significant investment of energy, as well as an additional period to facilitate cooling [8]. In their study, Kim and Park implemented the ultrasonic degassing technique. This method involves the use of vibration waves to induce micro-breaking of the bubbles. The utilization of this method carries the potential risk of compromising the structural integrity of the silicone polymer chain [9].

In this study, the vacuum degassing method was employed, entailing the implementation of a multifaceted approach encompassing a combination of vacuum pressure parameters and a predetermined degassing duration. The utilization of the vacuum degassing method has emerged as a more reliable and cost-effective approach when compared to previous research methods. The vacuum degassing method can be carried out on a small research scale, and it does not require the use of heat energy or vibrating equipment.

3.2. Effect of vacuum pressure and degassing duration on mass difference

Subsequent evaluation of the vacuum degassing process entailed measurement of the mass discrepancy between the target mass and the actual mass for each combination of predetermined independent variables. The mass difference is used as an indicator of assessment regarding the success of bubble reduction in the specimen. It has been established that the smaller the mass difference value in a specimen, the smaller the number of bubbles in the specimen. The results of the mass difference values are presented in Figure 2 in graphical form.



(a) (b)

Gambar 2. Comparative Effectiveness: (a) Degassing Time against Mass Difference and (b) Vacuum Pressure against Mass Difference

As demonstrated in Figure 2, the value of the mass difference in the specimen is found to be significantly influenced by the appropriate condition of the independent variable parameters. The present study demonstrated that elevating the vacuum pressure and reducing the duration of degassing enhance the efficacy of the vacuum degassing process when implemented as a post-mixing handling procedure. It can be concluded that the combination of high vacuum pressure and brief degassing duration is the most effective parameter to obtain the minimum mass difference value.

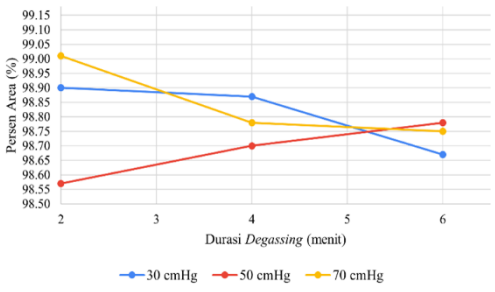
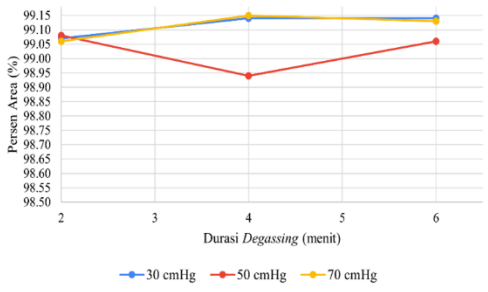
In Christiono's research, an evaluation of silicone degassing was performed based on vacuum duration. This evaluation focused on a visual assessment of defects [10]. Arifin et al. conducted research related to the effect of vacuum pressure on mold surface quality [11].

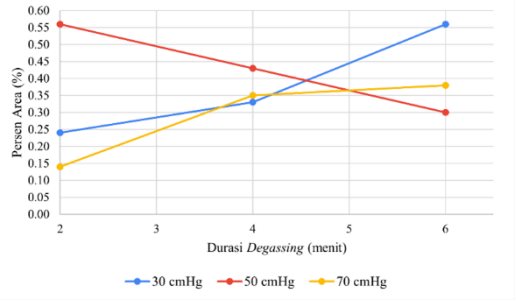
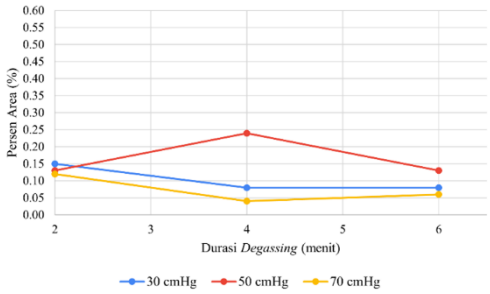
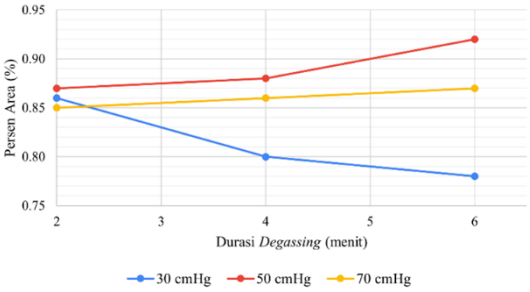
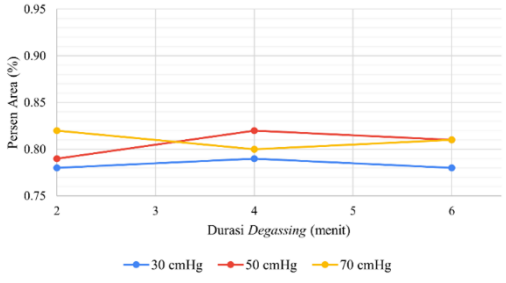
In this study, the mass difference calculation was used as a quantitative approach to assess the number of bubbles in the specimen. In the preceding studies, the quantitative approach was conspicuously absent in the evaluation of the number of bubbles trapped in the specimen.

3.3. Effect of vacuum degassing on chemical element composition based on xrf test

X-Ray Fluorescence (XRF) analysis was conducted in order to determine the impact of the vacuum degassing process on the elemental composition of the specimens. The composition of each specimen was analyzed and compared in terms of the dominant elements silicone, calcium, and ruthenium. The results of this analysis are presented in the form of line diagrams, as shown in Table 2.

Table 2. Comparison of Elemental Composition of Specimens through XRF Testing

Element Composition	Concentration Chart on Specimen 1	Concentration Graph on Specimen 2
Silicone(Si)		

Element Composition	Concentration Chart on Specimen 1	Concentration Graph on Specimen 2
Calsium (Ca)		
Ruthenium (Ru)		

As indicated by the findings in Table 2, there is an absence of a comparable trend across all the specimens examined, as well as within the groups of specimens. It is thus evident that the elemental composition of the specimen cannot be discerned through XRF testing alone, as it merely quantifies the elemental composition present. The presence of bubbles in the silicone molding process does not affect the elemental composition, thus precluding the identification of the bubbles in the XRF test.

The utilization of XRF tests on silicone materials has been previously investigated in various studies conducted in disparate contexts. In the research conducted by Qiao et al., the XRF test was used to map the distribution of filler elements in polymer composites [12]. In the research conducted by Siah et al., the XRF test was utilized for the analysis of chemical element changes in RTV silicone due to the aging process [13].

In the present analysis, the XRF test was utilized to assess the distribution of elements within silicone following the vacuum degassing process. The experimental phase of the study incorporated XRF testing, which was utilized to establish a direct correlation between variations in vacuum pressure and degassing duration with changes in the concentration of each element.

4. Conclusion

The results of the vacuum degassing study indicated that vacuum pressure was the most significant parameter in reducing the number of bubbles in the specimen. It has been determined that increasing the vacuum pressure results in a decrease in the mass difference value between the target mass and the actual mass. This finding indicates a higher effectiveness in the degassing process. Conversely, variations in degassing duration exhibited that a duration of 2 minutes yielded the most optimal mass difference value. The discrepancy in values at 4 and 6 minutes is not statistically significant. This is due to the minimal variation observed in only three decimal digits. The variation can be attributed to variations in mold dimensional tolerances and the limited precision of the measuring instrument.

XRF analysis was conducted to compare the elemental composition of the specimens. However, it was found that the percent area data obtained could not be used to definitively identify the effect of vacuum degassing on the number of

bubbles. In conclusion, the optimal parameter configuration for minimizing bubble formation was determined to be a pressure of 70 cmHg in conjunction with a degassing duration of two minutes, a configuration that proved to be both technically and economically viable. This approach obviated the necessity for prolonging the degassing duration, a strategy that was found to have a negligible impact on the outcome.

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