Tear Resistance Evaluation of Room Temperature Vulcanizing Silicone Rubber: A Comparative Study

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ABSTRACT

Room Temperature Vulcanizing (RTV) silicone cures at room conditions, providing tear resistance and flexibility to a wide range of industries. Yet, its mechanical performance improvement continues to be difficult when it is filled and catalyzed. In this work, the tear resistance of three RTV materials—RTV 48, RTV 683, and RTV M4503—is investigated with different talc (2–4 wt.%) and catalyst (40–60 wt.%) formulations. Tear resistance testing per ASTM D624 yielded average and standard deviation values for material consistency determinations. Comparative analysis is also given in the research to ascertain the effect of over-cross-linking on elasticity and structural morphology. RTV 48 experienced a dramatic decrease in tear strength at high catalyst content due to over-cross-linking and the loss of elasticity. RTV 683 experienced initial improvement through the addition of talc, but excess catalyst caused premature cure and reinforcement loss. In contrast, RTV M4503 showed significant tear resistance enhancement as talc and catalyst were compounded optimally, maintaining structural integrity and reinforcement efficacy. Results demonstrate the crucial role of filler and curing agent concentration interaction in modulating silicone mechanical properties. RTV M4503 featured the optimal tear resistance and stable performance among the compositions assessed, indicating its potential use in applications requiring enhanced durability. This research provides a guide to optimization of additive ratios in RTV silicone formulations, guiding materials and process conditions selection for industrial applications that demand reproducible mechanical strength.

Keywords: *RTV, silicone rubber, talc-catalyst, tear resistance.*

I. Introduction

Silicone rubber is one of the important materials used in modern engineering and industrial applications, as its unique combination of mechanical, chemical, and thermal properties is utilized in a wide range of applications. Among various silicone rubbers, RTV silicone is one of the most general-purpose and high-performance materials. RTV is an acronym for a type of silicon rubber that vulcanizes or cures at room temperature without any additional heat. RTV silicone rubbers are widely applied in a variety of uses, including gasketing, sealing, and molding, for dynamic loads, cutting edges, and cyclical stresses. Here, RTV silicone rubber tear strength is among the most significant performance measures that have a direct influence on the ability of this material to retain its functionality and integrity when environmental conditions are extreme. In automotive applications, RTV silicone rubber is used in sealing engine components. The ability of this material to resist tearing is critically crucial in maintaining the consistency of performance with repetitive mechanical vibration and thermal cycling during engine running [10]. This resistance to

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tearing improves not only the life of the seals but also minimizes the possibility of leaks that could lead to catastrophic failures. In medical care, RTV silicone rubber is commonly applied to prosthetics and medical molds. In these uses, tear resistance is a very important attribute because the materials must take care of being handled and moved constantly without losing their structural strength [7].

Besides, dynamic viscoelasticity of RTV silicone rubber is critical to its application. Viscoelasticity in silicone elastomers has been shown to impact tear resistance, especially in the case of cyclic stress conditions [22]. Material dissipation of energy upon deformation would prevent the formation and growth of tears, thereby prolonging its lifespan. Among the different kinds of RTV silicone rubber, three RTV 48, RTV 683, and RTV M4503 are used more extensively because of their different mechanical properties and suitability in certain special applications. These grades have been formulated to meet certain performance needs and are thus usable across a wide range of industrial applications. RTV 48 is especially known for its mechanical strength and ease of manipulation, which makes it so widely employed in so many applications in which it needs to offer consistent performance over the long term. Its average elongation at break, combined with outstanding tear resistance, further adds to its usefulness in mold making and industrial sealing situations. The mechanical characteristics of RTV 48 are due to its unique composition, usually containing reinforcing fillers that raise its tensile strength and toughness [9].

The included fillers not only add to the tear strength of the material but also significantly add to its overall lifetime when exposed to severe conditions [6],[20]. RTV 683, nonetheless, has an exceptionally high elongation at break, reflective of high toughness and flexibility. This effectively qualifies RTV 683 as an ideal candidate for applications with high deformation levels, such as dynamic seals and flex components. The high value of elongation at break is strongly required where the material should deform upon movement and should not break as a result of the consequential change in mechanical stress [27]. The new recipe of RTV 683 contains particular cross-linking agents that give it higher elasticity, thus making it ideal to function properly in dynamic applications [23],[14]. RTV M4503, on the other hand, possesses superior tensile strength capable of withstanding mechanical stress. The new recipe is particularly useful in engineering applications involving resilience as well as stiffness. The higher tensile strength of RTV M4503 is typically realized with advanced cross-linking techniques and addition of certain fillers that enhance its stress structure during strength [21]. RTV M4503 is thus most suitable for use in the aerospace and automotive industries, where the materials experience gigantic mechanical stresses [24]. The most important property of RTV silicone rubber is resistance to tearing, which would have a substantial effect on the application performance of the material in a wide range of applications, particularly in applications where mechanical stress and dynamic loading are involved.

Tear resistance can be defined as the propensity of the material to resist further elongation of an initial tear, and it plays a vital part in product durability and reliability when made by RTV silicone rubber. RTV silicone rubber tear resistance is a multifaceted property, and it is governed by the selection of fillers, cross-linking agents, curing conditions, and overall molecular structure of the material. On-going research work is focused on detailed examination of tear resistance of three industrially important grades of RTV silicone rubber, viz. RTV 48, RTV 683, and RTV M4503. The testing will be carried out by tear strength testing, a technique involving the application of the test specimens to a tensile force load in opposite directions while noting the resulting values of tear resistance and the extent of the tears until failure. The tear resistance properties of these materials are an important aspect for their application in prosthetic legs, which are expected to withstand substantial mechanical stress and deformation.

II. Material and Methods

1. Materials

The RTV rubbers were mixed with catalysts and talc to create uniform samples, ensuring consistent thickness and curing. The following materials were used in this study:

- RTV silicone rubber variants: RTV 48(Matapel Chemicals, Indonesia), RTV 683(Matapel Chemicals, Indonesia), and RTV M4503(Wacker Chemie AG, Indonesia).
- Catalysts(Wacker Catalyst T-14, Indonesia): provided in recommended ratios by manufacturers (2–4% by weight).
- Talc(Haichen Talc Powder, Indonesia): added as a filler at concentrations of 40%, 50%, and 60% by weight.

2. Sample Preparation

In this study, the sample preparation process involved mixing RTV silicone rubber with talc and catalyst according to predetermined ratios. The rubber mixture was then poured into molds. After pouring, the samples were cured at room temperature for 48 hours,

1. Mixing

   RTV silicone rubber was mixed with talc and catalyst according to predetermined ratios. Specimen composition is shown in Table 1. A vacuum chamber was used to remove air bubbles, ensuring sample integrity. The vacuum chamber used in this study can be seen in Figure 1. Vacuum chamber specifications are: Chamber dimensions: 135 x 135 x 400 mm; Material: Clear Acrylic Sheet and PVC with AW Class type; Maximum pressure: 100 kPa; Refrigerant vacuum pump rotary vane single stage air vacuum Pump, 220 V: 50 L/min; Degassing time: 5 minutes.

Table 1. Silicon rubber test specimen composition

No.	Composition of Silicon Rubber	Catalyst (gram)	Talc Powder (gram)
1	RTV 48 2% 40%	8.4	120
2	RTV 48 2% 50%	9	150
3	RTV 48 2% 60%	9.6	180
4	RTV 48 3% 40%	12.6	120
5	RTV 683 2% 40%	8.4	120
6	RTV 683 2% 50%	9	150
7	RTV 683 3% 40%	12.6	120
8	RTV 683 3% 50%	13.5	150
9	RTV 683 3% 60%	14.4	180
10	RTV M4503 3% 40%	12.6	120
11	RTV M4503 3% 50%	13.5	150
12	RTV M4503 4% 50%	18	150

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Fig. 1. Vacuum chamber

2. Molding and Curing

The RTV silicone rubber mixtures (RTV 48, RTV 683, and RTV M4503) were poured into stainless-steel molds measuring 200 mm × 150 mm × 8 mm (length × width × thickness), machined to ISO 34-2016 Method A specifications. The cast sheets were cured at room temperature for 48 hours, then post-cured at 60 °C for 4 hours to ensure complete crosslinking.

C. Testing Protocols

The test was conducted based on the ISO 34-2016 standard, which is an international standard for measuring the tear strength of materials. This standard is suitable for various types of rubber, including RTV, and has been widely used by other researchers, so the results can be compared between laboratories and manufacturers. Based on this standard, method A was the method that was adopted. Method A was used because it provides more precise and accurate tear test values than other methods. Such precision and accuracy are of crucial importance in giving test results that are consistent and reliable [5]. Additionally, method A is simpler in terms of monitoring the last observation of the test samples subjected to tear testing. In this manner, researchers can readily identify and examine the regions of material failure. The selection of an approach is to provide the most representative data regarding the tear strength of the material, so that the research results can be used as a true reference in material and product development.

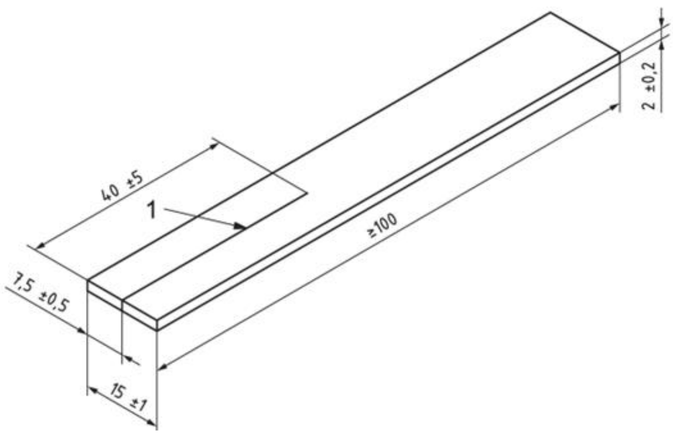

Fig. 2. Mold dimension of test sample

Fig. 3. Test sample after press cutting

Preparation of test sample material involves preparing 3 test samples, i.e., RTV 48 silicone rubber, RTV 683 silicone rubber, RTV M4503 silicone rubber with catalyst and talc blended together into one sheet of rubber, 8 mm thick. After that, the rubber sheet was printed in accordance with ISO 34-2016 standard method A. Printing was carried out using a Gester cutting press (GT-KD20, Gester Instruments Co., Ltd., Taiwan, capacity 4T). The dimensions of the mold used in the test sample can be seen in Figure 2. The test sample after the cutting process is shown in Figure 3.

Fig. 4. Zwick Roell Z020 tear tester

Testing was carried out using the tear tester (Zwick Roell Z020, Germany, max. Load of 20 kN as shown in Figure 4), at a constant crosshead speed of 500 mm/min. Prior to testing, the standard tear-test fixture was mounted and its height adjusted to match the specimen's cut length. Each test sample was then clipped securely at both ends in the fixture that can be seen in Figure 5, ensuring no slippage during the test. The test was initiated by pressing the start button and allowed to run uninterrupted until the sample was completely torn apart. Upon separation, the tester automatically recorded the required data, after which

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the next specimen was prepared and tested. Once all formulations had been evaluated, the collected data were compiled for subsequent analysis.

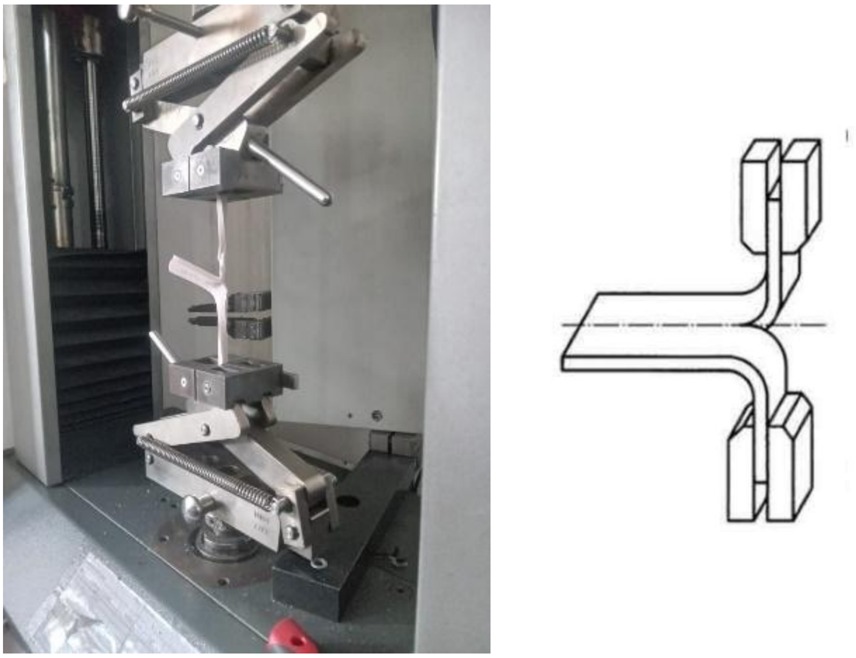


Fig. 5. Tear testing on test sample

Data analysis was performed by identifying the maximum and average values obtained for each parameter across all RTV formulations. The parameters assessed comprised Initial Tear Length (AO), which reflects tear resistance as the maximum force applied per unit length of tear; Maximum Force (Fmax), denoting the highest load required to initiate material rupture; Fracture Index (FI), measuring the material's resistance to stress-induced cracking or tearing, with higher FI values indicating greater durability; Fracture Work (X-fw), representing the total energy absorbed to propagate a crack, where larger X-fw values correspond to stronger materials; and Breaking Force (Fbreak), the ultimate force needed to completely sever the specimen, directly indicating overall material robustness.

III. Results and Discussions

The tear resistance test data of silicone rubber materials RTV 48, RTV 683, and RTV M4503 are presented in Table 2. The average X-fw values of each material are summarized in Table 3, Table 4, and Table 5. These results provide insight into the effect of catalyst and talc variations on the tear resistance of silicone rubber.

In Table 3, it can be seen that material manufacturing process failures occurred at certain compositions, such as 3% 50%, 3% 60%, 4% 40%, 4% 50%, and 4% 60%. Excessive catalyst accelerates the cross-linking reaction rate, which causes the material to harden before the molding process is completed [11],[4]. According to the theory of polymerization kinetics, the acceleration of the reaction rate due to excess catalyst can lead to over-cross-linking, which results in a brittle material and decreases its elasticity [8],[19]. This excessive cross-linking process can affect the mechanical properties of the material. This is in line with findings showing that materials with overly dense cross-link networks can suffer mechanical failures, such as cracking or breaking, when subjected to loads [12].

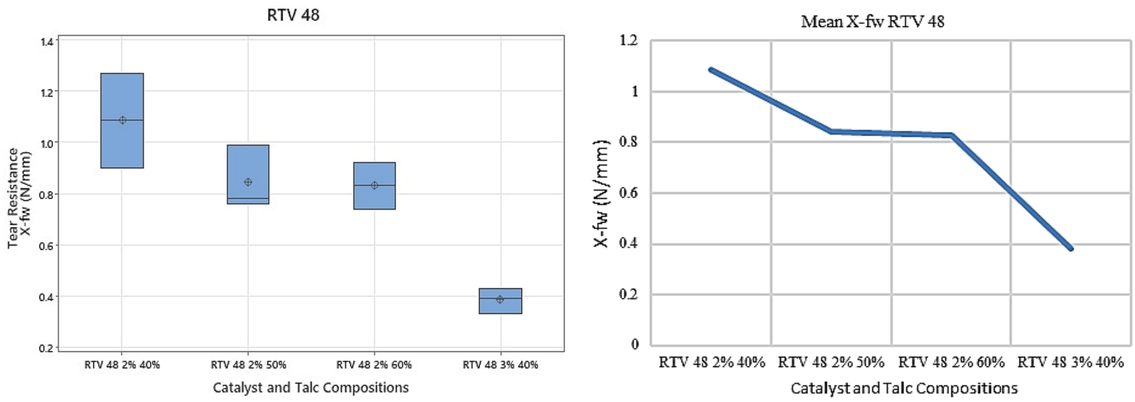
Table 2. Silicon rubber tear testing data collection results

Rubber			FI	X-Fw	Fbreak
Silicon	Catalyst	Talc Powder	N/mm		
RTV 48	2%	40%	1.26	1.27	-
			1.22	0.9	1.19
			1.16		0.47
	2%	50%	-	0.78	-
			0.79	0.76	0.65
			1.03	0.99	1.33
	2%	60%	0.75	0.74	1.05
			0.92	0.92	1.35
			0.9		5.28
	3%	40%	0.51	0.43	1.69
			0.36	0.33	0.4
			0.39	0.39	0.33
RTV 683	2%	40%	0.90	0.9	0.8
			1.02	0.81	1.05
			0.98	0.82	0.74
	2%		1.44	1.02	1.22
		50%	1.06	0.91	7.81
			0.92	0.87	6.51
				0.77	
	3%	40%		0.86	
				0.81	
			0.79	0.74	3.22
	3%	50%	1.08	0.98	1.26
			0.78	0.77	0.81
	3%	60%	1.01	0.92	1.36
			0.82	0.75	5.17
			0.91	0.91	0.8
RTV M4503	3%	40%	0.64	0.64	4.46
			0.81	0.71	0.33
			0.67	0.64	0.42
	3%	50%	1.23	0.78	1.61
			0.73	0.73	5.12
			0.76	0.75	0.84
	4%	50%	1.1	1.1	0.81
			0.77	0.76	0.42
			0.7	0.68	-

Table 3. Average value of X-fw RTV 48

RTV 48	
	Mean
2% 40%	1.085 N/mm
2% 50%	0.843 N/mm
2% 60%	0.83 N/mm
3% 40%	0.383 N/mm

In Figure 6, it can be seen that the addition of talc and catalyst to RTV 48 generally decreased the tear resistance value. The 3% talc and 40% catalyst sample showed a tremendous decrease in reduction. This is because the reason of extra catalyst brings an over-cross-linking effect. The process decreases the energy-absorbing ability of the material before cracking, thereby decreasing the tear resistance [12]. An extra catalyst in the polymer can lead to an acceleration of the cross-linking reaction and thereby form an extremely tight network. This ductility loss is particularly detrimental where flexibility is required, since they cannot be able to absorb energy like it is desired under stress. Previous studies have shown that the addition of talc can serve as a reinforcing agent, but at certain concentrations, talc can also lead to higher stress concentrations, which contribute to a decrease in tear resistance [26]. Furthermore, the interaction between talc and the polymer matrix also plays an important role in determining the mechanical properties of the composite. Talc can act as a filler that increases the strength and modulus of the material, but if used in excessive amounts, it can cause a decrease in mechanical properties due to the formation of more stress concentration points [3].



(a) (b)

Fig. 6. Boxplot (a) and Graphic (b) X-fw composition silicon rubber RTV 48

In the context of material manufacturing, particularly involving catalyst materials with varying concentrations of talc and catalysts, the manufacturing outcomes can be significantly impacted. Observations indicate that when using 3% talc in conjunction with 60% catalyst content, failures arose during the manufacturing process that can be seen in Table 5. This may be related to the high catalyst concentration exceeding optimal levels conducive to stable processing. Similarly, in a scenario with only 2% talc and 60% catalyst, no standard deviation value was obtained due to testing errors that prevented the acquisition of multiple datasets. The absence of multiple data points in this case does not permit any measure of variability, ultimately rendering the assessment of process stability ineffective.

The implications of high standard deviation values are noteworthy. A greater standard deviation in manufacturing processes suggests a wider spread of data from the mean, indicating potential instability within the process [15]. Composite materials will generally exhibit this manner due to intrinsic complexities of structural properties of composite materials and their interactions during processing. In case of failure of manufacturing, material mechanical and thermal properties must be considered as they become dominant function of the process parameters governing their behavior during fabrication [16].

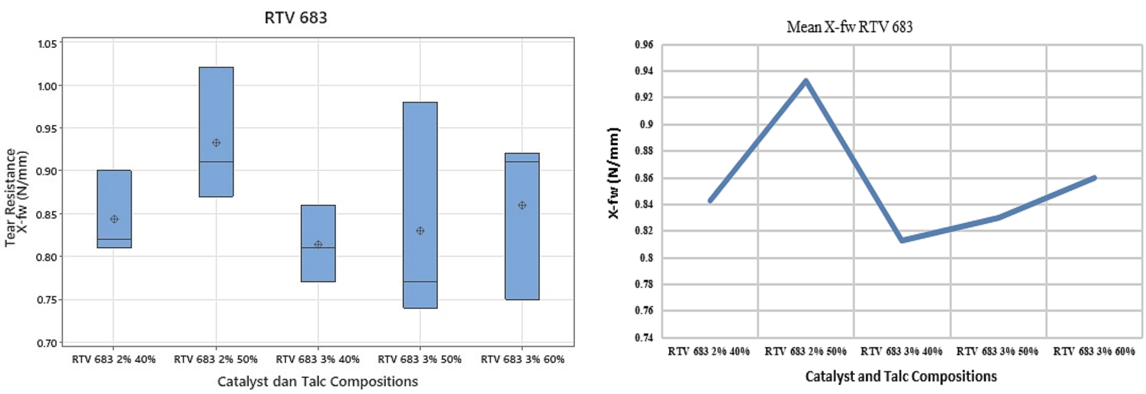
Research has also established that process variability, catalyst composition, and inter-material interaction all have critical roles to play in the production outcome. High catalyst content can potentially disrupt the quality and uniformity of the final product. It has been established that manufacturing methods introducing excessive variability in processing conditions can lead to premature failures, as seen in polymer composites and their thermal/microstructural responses [17],[18]. Hence, catalyst composition control remains paramount for improving material manufacturing stability and reliability.

Moreover, the process environment and subsequent defects must be accurately monitored and analyzed. Techniques such as predictive modeling and online monitoring are essential to predict imminent failures ahead of time, which suggests a highly developed correlation between manufacturing process technology advances and material quality manufactured [19].

Table 4. Average value X-fw RTV 683

RTV 683	
Variations	Mean
2% 40%	0.843 N/mm
2% 50%	0.933 N/mm
3% 40%	0.813 N/mm
3% 50%	0.83 N/mm
3% 60%	0.86 N/mm

The combination of talc content and catalyst concentration in RTV 683 silicone rubber significantly influences the tear strength of the product. Precisely, addition of talc has been found to enhance the tear strength of silicone rubber, while an increase in the catalyst content decreases the property. When the catalyst level was 3%, the average tear strength was less than that using 2% catalyst, as it can be observed from Figure 7. This reduction in tear resistance can be attributed to the impact of excess catalyst on the curing reaction; an overly accelerated reaction may inhibit the full molding of the silicone, leading to a weak and unimproved structure [15],[16].



(a) (b)

Fig. 7. Boxplot (a) and Graphic (b) X-fw composition silicon rubber RTV 683

Excessive catalyst tends to accelerate the curing process excessively, resulting in incomplete polymerization or cross-linking. This incomplete reaction inhibits the establishment of optimal molecular arrangements within the silicone matrix, reducing the overall structural integrity [4],[20]. Consequently, the benefits that talc—known to improve mechanical stability, crystallinity, and tear resistance—should normally bring to the silicone may be undermined when high catalyst levels induce rapid curing [12],[21]. The result is a weakened material whose performance fails to meet desired standards in applications requiring robust tear resistance.

Moreover, previous studies have documented the reinforcing capabilities of talc, demonstrating how its incorporation into silicone composites can result in enhanced tensile strength and tear resistance due to improved crystallinity [22],[23]. However, when used in conjunction with high catalyst concentrations, as documented when combining 3% talc with 60% catalyst, the anticipated mechanical benefits of talc may be severely compromised. This is a direct consequence of the rapid curing induced by the excess catalyst, hindering the necessary alignment and bonding of polymer chains that are critical for optimal material performance [24],[25].

In examining the effects of catalyst percentages on manufacturing processes of materials utilizing RTV composites, particularly at higher catalyst concentrations such as 4% with 40%, 50%, and 60%, as can be seen in Table 6, a clear tendency towards manufacturing failure has been observed. This is because many factors are associated with the curing reaction and also with the physical properties of materials involved in the production process. When catalysts are incorporated into the RTV material system, they are intended to accelerate silicone rubber curing. However, excessive catalyst content can create too rapid a reaction, which adversely affects the polymer chain alignment and adhesion in the structure of the material, causing incomplete forging and a consequent loss of structural integrity [15],[16]. Failure at the manufacturing level at the indicated percentages implies that while catalysts are needed to initiate and promote curing, their excess may undermine the expected enhancement in mechanical and thermal properties that would otherwise result from successful vulcanization.

In addition, the use of standard deviation in this case is helpful in explaining the variability of data acquired from the manufacturing processes. Even though high percent catalyst values are related to failures, the standard deviation informs us about the extent to which variations in the processing parameters impact tear resistance and other material properties. In this respect, a bigger standard deviation suggests a larger spread of data around the mean value, which could be a sign of high process instability and inconstancy during manufacturing [18],[19].

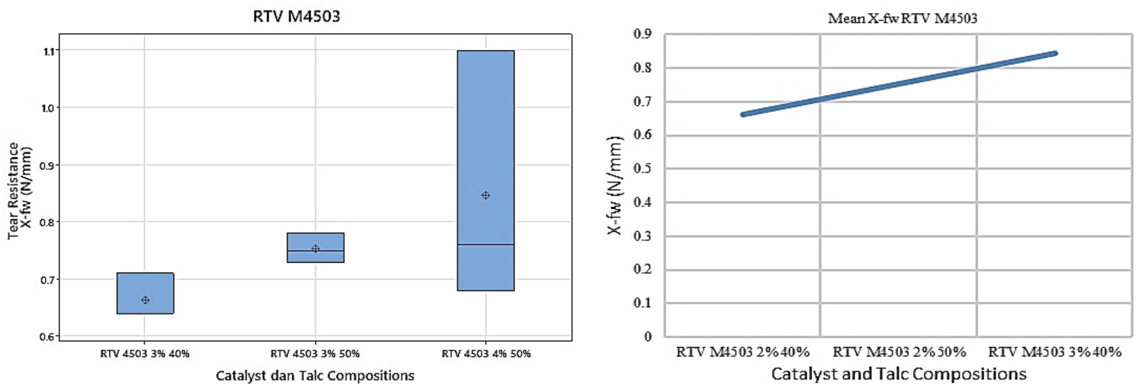
Furthermore, the incidence of failure at different catalyst contents indicates a critical materials design factor; it shows the importance of catalyst level optimization. A balance between sufficient catalytic activity and maintenance of physical properties of the RTV silicone rubber is crucial. As it is, empirical studies towards catalyst concentration optimizations can go a great way in enhancing the reliability of material performance with fewer incidences of failure. This relationship between process parameters and observed outcomes underscores the need for rigorous quality control measures throughout the manufacturing sequence [4],[20].

In Figure 8, it can be seen that the addition of talc and catalyst to RTV M4503 tends to increase the tear resistance value. The addition of talc increases the mechanical strength of the material through matrix reinforcement of silicone rubber. Notably, the introduction of excess catalyst can lead to undesirable effects such as agglomeration and self-cross-linking, which adversely affect mechanical performance, particularly when the percentage of the catalyst surpasses critical thresholds [9]. This indicates that while catalysts are necessary for effective curing of RTV silicone, too high a proportion can create complexities that result in compromised material integrity.

Table 5. Average value of X-fw RTV M4503

RTV M4503	
Variations	Mean
3% 40%	0.663 N/mm
3% 50%	0.753 N/mm
4% 50%	0.846 N/mm

According to composite material theory, talc functions as a filler that increases stiffness and resistance to deformation, resulting in a material that is more resistant to tearing. It helps to stretch the polymer chains and facilitate a denser cross-linking network without the drawbacks of excessive over-cross-linking, which can reduce mechanical performance [17]. Correlating the impact of talc content with the catalyst percentages reveals that while talc serves to enhance specific properties, there remains a delicate balance, if not proportioned carefully, as noted in studies indicating that excessive additive proportions can yield heterogeneous distributions that counteract the intended effects of reinforcement [16],[25].



(a) (b)

Fig. 8. Boxplot (a) and Graphic (b) X-fw composition silicon rubber RTV M4503

IV. Conclusions

Each type of RTV silicone rubber demonstrated a distinct peak in tear resistance following formulation optimization. RTV 48 reached the highest average fracture work of 1.085 N/mm with 2% catalyst and 40% talc. RTV 683 achieved 0.933 N/mm at 2% catalyst and 50% talc, while RTV M4503 peaked at 0.846 N/mm with 4% catalyst and 50% talc. Deviations from these optimal ratios led to a tear resistance drop of up to 65%, indicating that even minor changes in catalyst and filler content can significantly impact mechanical performance. These findings offer clear formulation guidelines to achieve maximum tear resistance, providing a practical reference for manufacturing RTV silicone components with high durability in demanding industrial environments.

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