# Comparative study between mechanical properties of silicone catalyzed by tin or platinum and the more effective section.

**Martín-Domínguez, Javier*; de-Cózar-Macías, Óscar D.; Blázquez-Parra, E. Beatriz; Ladrón-de-Guevara-López, Isidro; Ortiz-Zamora, Francisco J.**

* Corresponding author. Tel.: +34-620-803-496. E-mail address: javiermd@uma.es

## Abstract

Nowadays, there is the need and the technical capability to constantly collect data from multiple daily situations to improve measurable activities. An example of this, is the incorporation of sensors over the human body to collect bodily data, whether it be in devices for general activities as running or for specific purposes such as monitoring certain pathologies like diabetes or registering variables in gait. These measurements are provided by sensors adapted to the controlled bodily zone, being able to adapt itself to the organic shape of the body. One of the materials that meets the requirements of strength and malleability is silicone, specifically the one intended for molds. This study questions the viability of the mechanical capabilities of different types of this material through tests of resistance and flexibility, as well as which type of structure is better for its use as a sensor. The collected results indicate which section is most favorable for using silicone in the form of threads and the optimal functions for each type of tested silicone.

**Keywords:** Silicone, Mechanical Properties.

## 1 Introduction and state of the art

The choice of silicone as the material to be tested aims to use it as a base for future body sensors, other materials are being used for this purpose like TPU [1] or smart-textiles [2]. These materials share the common characteristic of being elastic and suitable for long-term use without causing irritation to the user. Their applications are extensive, as they can be adapted to various measurements and can recognize different parameters. In the field of research, they have been utilized in the collection of bodily data, as they can conform to the shape of the human body [3]. Liquid silicone can adapt to the chosen mold's shapes and at the same time is a material that once cured is malleable while being resistant to plastic deformation

[4]. Similarly, being a material that is in a liquid state before taking its final form, it can be mixed with multiple additives that will add properties to the silicone base [5].

In the market, there are two types of differentiated silicones, by the type of catalyst used: those cured by condensation or addition, meaning., those catalyzed by tin or platinum, respectively. This study aims to compare the mechanical properties of both curing forms. They will be subjected to stretching until they break, obtaining the deformation concerning the applied force. As a result, the optimal type of silicone for use as a sensor will be obtained, requiring a balance between resistance and elasticity.

For this purpose, a system capable of testing test pieces is designed, following similar methods used for other similar materials, both the shape of the specimen and the measurements to be performed are conducted in a manner consistent with previous studies [6] [7].The chosen test pieces will be small in size, in order to verify the behavior of this material when stress is applied to very thin sections. At the same time, the most effective section perimeter for each silicone formulation will be tested, comparing a square section with a circular one with a common area of 3.14 mm². The reason for creating specimens of this section is due to an initial approach in obtaining silicone threads capable of being incorporated in body measurement devices [8] , [9], starting with a 1 mm diameter in the circular section specimen. These unconventional testing with non-conventional specimens are conducted to investigate the mechanical behavior of these complex materials under conditions of low cross-sectional areas. In the event of obtaining positive results in this study, sections of smaller sizes will be developed.

## 2 Methodology

The method used to measure the resistance of the test bar consists of a system composed of the elements included in the test bench shown in Figure 1.

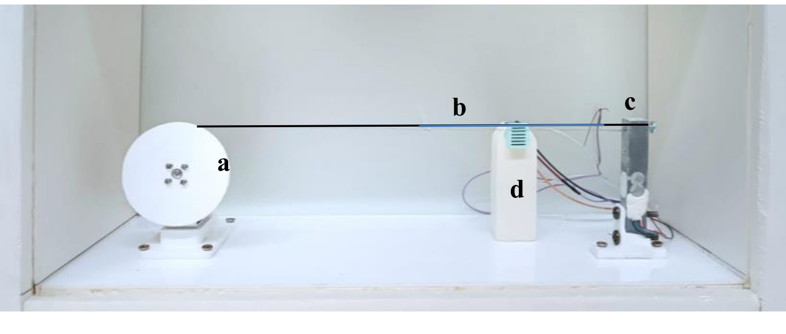

**Fig. 1.** Test bench; (a) pulley; (b) specimen; (c) load cell; (d) STH21.

This test has been carried out using equipment adapted to the needs of testing a material like silicone. Standard tensile testing equipment in property is not suitable for this type of material and dimensions of the specimen, therefore a specific testing bench was developed to meet the required conditions. The test bench is consisted of a system in which the 60 millimeters pulley (a) is connected to a servo motor with a rotation capacity of 20 kilograms. This pulley is linked to a steel wire that connects the silicone specimen (b) to the load cell HX711 (c) that measures the force in kilograms exerted by the tension of the test specimen. The temperature and humidity (d) of the environment will be constantly measured to ensure similar ambient conditions in each test. The pulley transmit the rotate grades that later will be transform into distance travelled. All inputs from this system are transmitted to the data processing program through an ESP32 Arduino board.

The components of the system were carefully chosen to achieve accurate results. The servo motor used in the system has a precision of ± 1°, which, considering the pulley's radius of 30 millimeters, results in an error margin of ± 0.5 millimeters. The load cell used in the system provides an error margin of ± 0.4 grams and is calibrated using precision weights.

To obtain the silicone specimens, one of the previously mentioned properties, the liquid state of the material prior the component mixing, is utilized. Therefore, specific molds have been designed to reproduce identical geometries among the different samples. To achieve this, molds have been designed using 3D modeling software and printed on 3D printers. The molds consist of two differentiated parts, as shown in Figure 2: the material pouring zone (a) where the desired shape is obtained, and the lid (b). Both are joined by screws to prevent any type of leakage (Figure 3). The molds have been fabricated on the Ultimaker S5 printer with a layer thickness of 0.1 millimeters to obtain the highest precision on the specimens, specifically for the tubular geometry, that requires a good transition (Figure 4). Figure 5 shows two kinds of specimens used in this study.

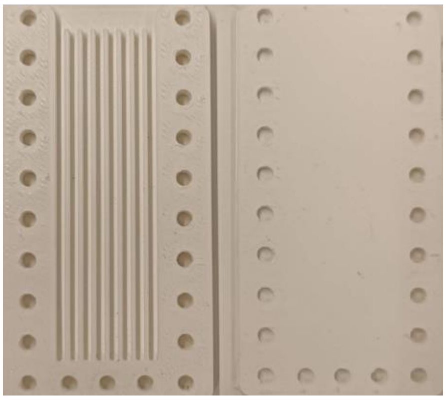

**Fig. 2**. The two parts of the mold.

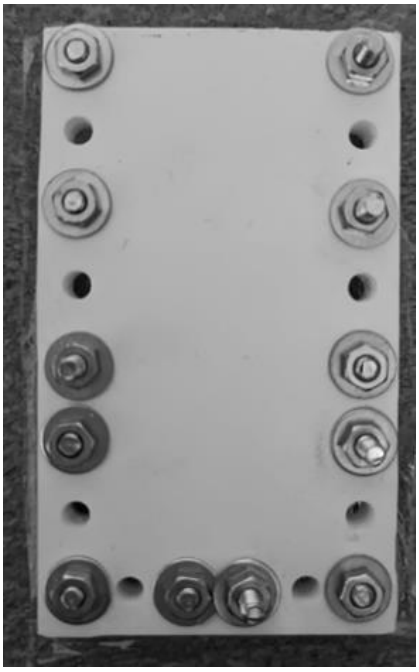

**Fig. 3**. Ensembled mold.

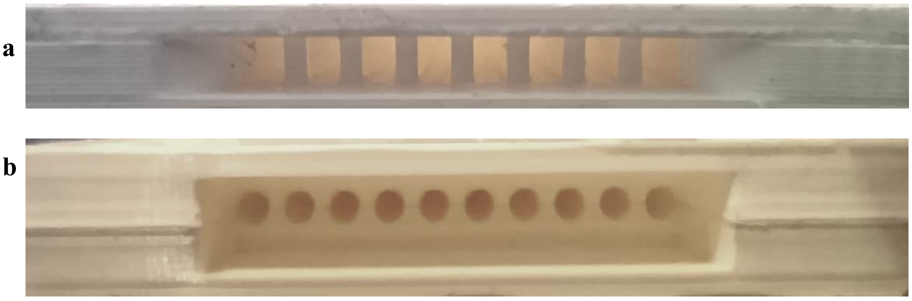

**Fig. 4**. Comparison between prismatic and tubular entrance molds; a, prismatic; b, tubular.

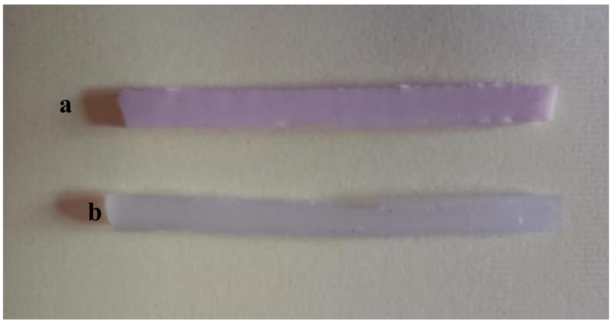

**Fig. 5**. A, prismatic tin specimen. B, tubular platinum specimen.

In the market there are multiple purchasing options for liquid silicone from various brands and hardness levels. To ensure maximum objectivity in the study, it is used silicone catalyzed by both tin and platinum from the same brand, “Feroca”, and with the same hardness level, Shore 30. This approach ensures that neither the supplier nor the hardness of the silicone will cause falsity in the comparison of the two components.

## 3 Results.

The tests are carried out on the testing bench shown above, with the specimens attached to the steel thread and to the load cell.

Prior to the tests, a visual check is performed to identify any existing differences between the two kind of specimens, circular and prismatic. Both the tin-catalyzed and platinum-catalyzed silicone produce better results in the tubular specimens. The difference is the presence of trapped air bubbles within the square mold, with several bubbles having a size of less than 1 millimeter in diameter or interruptions in the filling of the specimen due to a large air bubble. This condition will be crucial in selecting a more effective section, as it is expected that air inclusions will adversely affect the mechanical strength of the specimens. The incomplete specimens are dismissed.

The test results are presented in the following four graphs, where the horizontal axis represents the elongation (equation 1) of the specimen, and the vertical axis represents the force in grams measured by the load cell. The average of five measurements has been taken for each type of specimen.

$$elongation = \frac{lenght\ (mm) - initial\ length\ (mm)}{lenght\ (mm)}$$

**Equation 1**. Elongation.

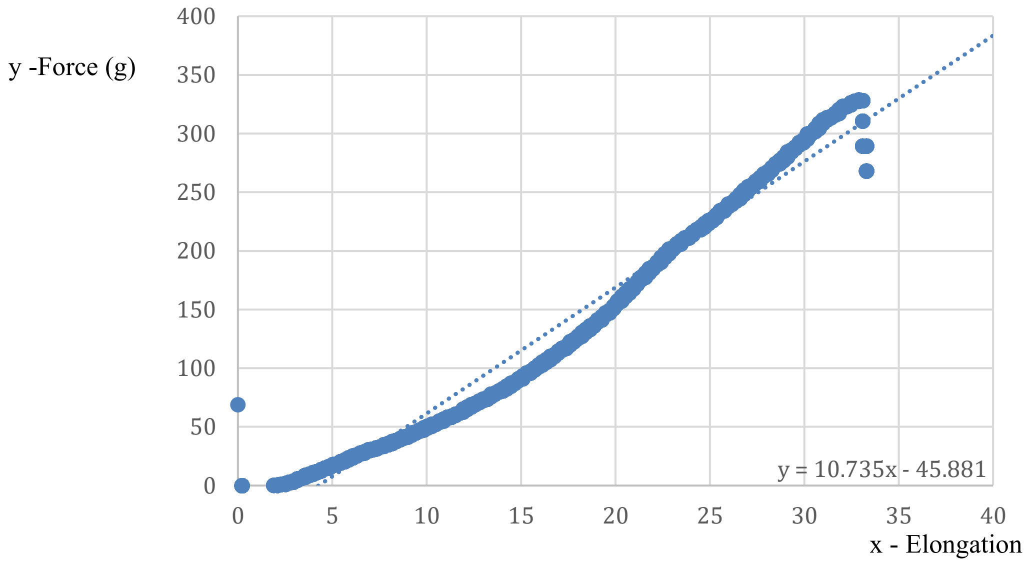

**Fig. 6.** Tin-catalyzed, circular specimen. Elongation produced in relation to applied force.

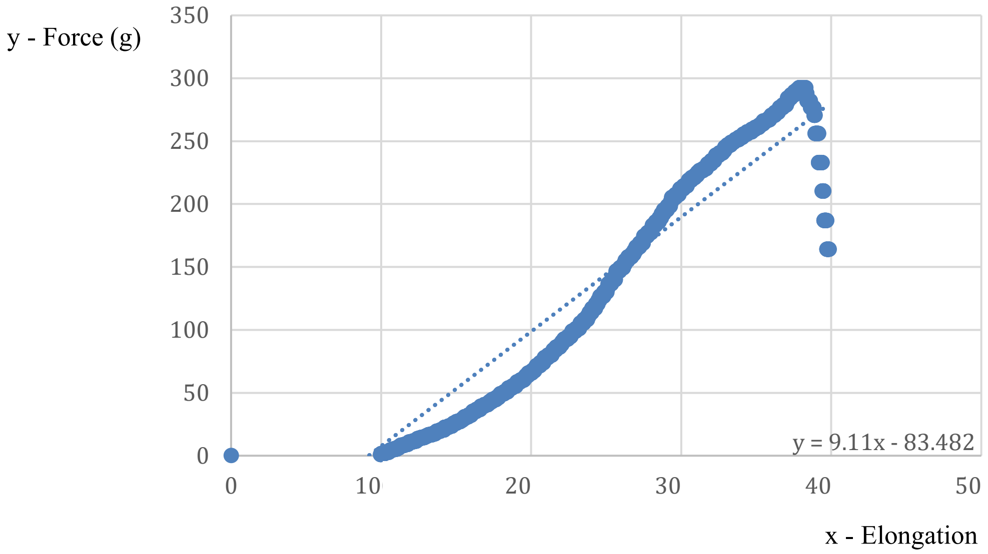

**Fig. 7.** Tin-catalyzed, square specimen. Elongation produced in relation to applied force.

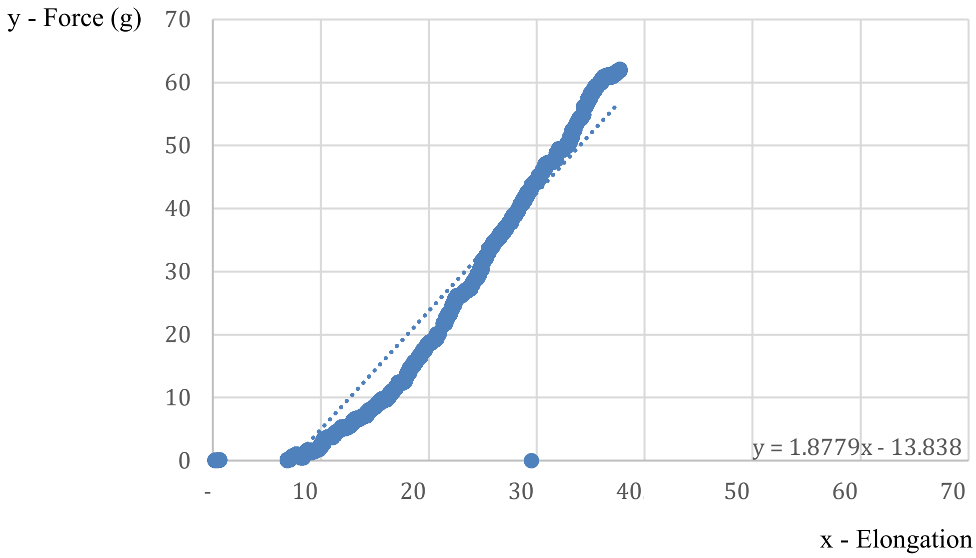

**Fig. 8.** Platinum-catalyzed, circular specimen. Elongation produced in relation to applied force.

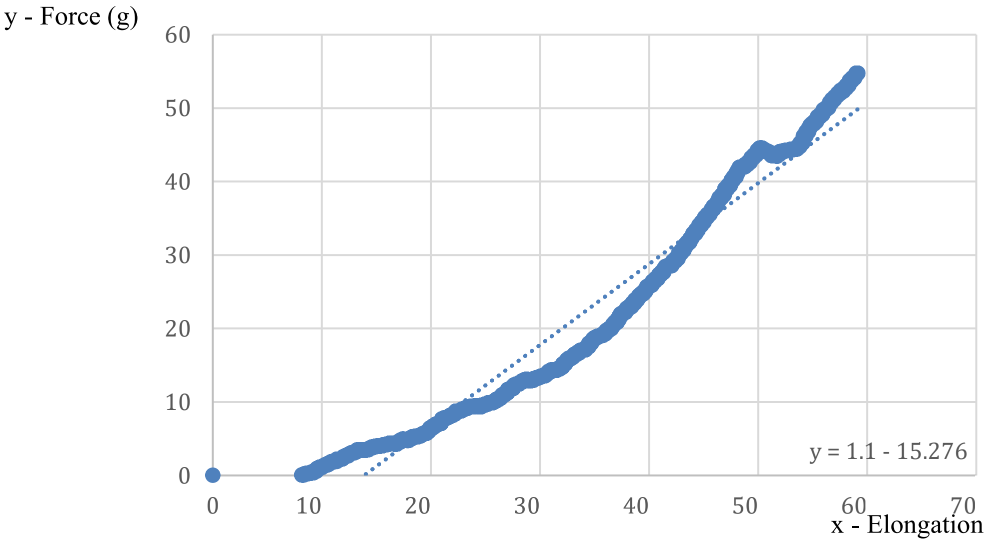

**Fig. 9.** Platinum-catalyzed, squared specimen. Elongation produced in relation to applied force.

The graphs visually display the differences between the two types of materials and sections. Regarding the cross-sectional areas of the specimens, Figures 6 and 7 show variations in the maximum force achieved and the elongation produced. Due to better material compaction in the circular specimens, they exhibit higher strength as air entrapment is minimized. A similar trend can be observed in Figures 8 and 9, comparing the square and circular sections of platinum-catalyzed silicone. The circular section demonstrates better stress resistance. Table 1 provides a comparison of the maximum values obtained for each group. It reflects a bigger contrast between the two sections in tin-catalyzed silicone compared to platinum-catalyzed silicone, with a difference of 36 grams. This can be attributed to the higher viscosity of the platinum-catalyzed silicone, which creates greater stress concentrations at the mold edges, leading to larger air bubbles compared to the smaller ones formed in the prism-shaped specimens. Circular specimens do not exhibit these air inclusion issues.

Furthermore, there are differences in elongation. Figures 7 and 9 show longer elongation curves compared to Figures 6 and 8, indicating the effects of the air intrusions. Due to the irregularities caused by air intrusions in the prism-shaped molds, circular specimens will be considered and used in future experiments.

Figures 6 and 8 illustrate the elongation and force graphs of the two materials used with tubular specimens. The differences lie in the variations of elasticity observed. The platinum-catalyzed specimen offers less resistance to stretching, resulting in higher levels of elongation with lower applied forces. This condition also causes the tin-catalyzed silicone to rupture at a lower elongation compared to the platinum-catalyzed silicone.

The complementarity between the two units studied depending on the material used can be visually observed in the graphs. The tin-catalyzed specimens show better results in terms of tensile strength, while the platinum-catalyzed ones are more efficient in elongation, although they allow for less traction.

**Table 1.** Maximum force and elongation of each specimen.

| *Material* | *Maximun Force* | *Maximun Elongation* |
|---|---|---|
| *TIN - CIRCULAR* | *329 g* | *32* |
| *TIN – SQUARE* | *293 g* | *38.5* |
| *PLATINUM – CIRCULAR* | *62 g* | *37.07* |
| *PLATINUM - SQUARE* | *54 g* | *58.3* |

## 4 Conclusions and future research.

The conclusions reached will serve as a reference point for the construction of future body sensors.

In the manufacturing and quality section of the final piece, it is found that generating circular threads is much more effective than with square section threads due to the air bubbles that form during the silicone curing process. It is suspected that these bubbles form more easily in prismatic threads due to the existing edges in the mold that offer areas of higher internal stress that easily cause the bubbles to attach to the walls. Circular section molds will be designed for efficiency and effectiveness.

Regarding the silicone to be used, it will vary depending on the function it serves. That is, for cases where the material is intended to withstand aggressive elongations but with little applied force, the platinum-catalyzed silicone will be used. In cases where a material more resistant to traction is required, the tin-catalyzed silicone will be chosen.

Both silicones are compatible for use in body sensors, each being used for different conditions.

In future experiments, the objectives will focus on obtaining the most efficient section, trying to make the thread as thinner as possible, for use as a body sensor and observing the performance of the materials under constant stress cycles to verify their durability. Other experiments will explore the necessary additives for using silicone as a sensor and incorporate them into efficient prototypes that provide real-time data on the wearer's activity.

## References

1. H. Liu *et al.*: Electrically Conductive Thermoplastic Elastomer Nanocomposites at Ultralow Graphene Loading Levels for Strain Sensor Applications Electrically conductive thermoplastic elastomer nanocomposites at ultralow graphene loading levels for strain sensor applications (4), 157,( 2015).
2. C. C. Vu and J. Kim,: Highly elastic capacitive pressure sensor based on smart textiles for full-range human motion monitoring, *Sens Actuators A Phys(314),* (2020).
3. X. Lin and B. C. Seet,: Battery-Free Smart Sock for Abnormal Relative Plantar Pressure Monitoring, *IEEE Trans Biomed Circuits Syst*(11), 464–473 (2017).
4. S. C. Shit and P. Shah,: A Review on Silicone Rubber, National Academy of Sciences, (2013).

5 K. G. Princy, R. Joseph, and C. Sudha Kartha,: Studies on Conductive Silicone Rubber Compounds, Journal of Applied Polymer Science(69), 1043-1050 (1998) .

6. M. Aurilia, F. Piscitelli, L. Sorrentino, M. Lavorgna, and S. Iannace,: Detailed analysis of dynamic mechanical properties of TPU nanocomposite: The role of the interfaces, *Eur Polym J* (47), 925–936 (2011).
7. C. Dils, L. Werft, H. Walter, M. Zwanzig, M. Von Krshiwoblozki, and M. Schneider-Ramelow,: Investigation of the Mechanical and Electrical Properties of Elastic Textile/Polymer Composites for Stretchable Electronics at Quasi-Static or Cyclic Mechanical Loads, Materials (12), (2019).
8. M. Amjadi, K. U. Kyung, I. Park, and M. Sitti,: Stretchable, Skin-Mountable, and Wearable Strain Sensors and Their Potential Applications: A Review, *Advanced Functional Materials* (26), 1678–1698 (2016).
9. P. Eizentals et al,: Gait analysis by using Smart Socks system, CONFERENCE 2019, AITAE, vol.242, IOP Publishing (2019).