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THE INFLUENCE OF SILICON RUBBER AGING ON PARTS OBTAINED IN FLEXIBLE MOLDS

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Abstract: *Silicone rubber flexible molds are used to obtain parts for small volume production. The use of molds, after long periods of time, leads to the possibility that mold material aging influences the parts quality. This paper aim is to analyze how the mechanical properties of the silicone rubber are changing and how the aging influences the quality of the molded parts. Through the presented studies, it is possible to establish until when silicone rubber molds can be used so that the obtained pieces are not influenced by mold material mechanical properties.*

Key words: *Silicon rubber mold, Degradation, Mechanical properties, Surface quality*

1. INTRODUCTION

For manufacturing parts in small volume production, the technology that which is used influences the final price of the parts. The optimal manufacturing technology is choose based on the required quality, material, shape complexity, part manufacturing volume, etc. [1]. If the part has functional surfaces which are requiring a high precision, shape and position small deviations, then a cutting technology will be used [2].

If the part has a complex shape but no specific requirements related to the surface precision, shape and position deviations, then a technology often used in the present could be proper: casting into flexible molds. This technology is used either to obtain resin parts and plastic parts, or even to obtain wax patterns, that are subsequently used in the casting process with light fusible models to obtain metal parts.

This technology is also used for obtaining medical implants [3, 4], wax models [5, 6], resin parts [7,8] and other parts that are used in mechanical constructions.

Usually the material from which the flexible molds are made is silicone rubber, because it has mechanical properties that are suitable for these type of applications: hardness, tensile strength, elongation at break, coefficient of linear expansion and linear shrinkage [9].

One of the silicone rubber molds problems is that the material, in time, undergoes into a degradation process that leads to the loss of mechanical properties. This phenomenon inevitably leads to changes onto the quality of the parts.

The aim of this paper is to evaluate how the silicone rubber molds degradation evolves in time. Also, a model is required to present how the silicone rubber degradation influences the molded parts quality.

2. EXPERIMENTAL SETUP

To achieve the two objectives: the assessment of silicon rubber degrading mode and parts quality modeling due to silicone rubber degradation, Essil 291 silicone rubber, produced by Axon Company, was used. This type of rubber is one commonly used for molds making, as presented in many papers from researches [5, 6, 7, 8, 9].

The main mechanical characteristics of this silicone rubber type are shown in Table 1.

For silicone rubber mechanical properties evaluation, specimens were prepared with the dimensions according to SR ISO 815 + A1: 1995, in a circular disc shape with a diameter of 29,0 ± 0,5 mm and a thickness of 13,0 ± 0,2 mm.

Table 1

MECHANICAL PROPERTIES AT 23°C			
		Unit	**Values**
Hardness	ISO 868 : 2003	Shore A1	38
Tensile strenght	ASTM D412C : 1997	MPa	5
Elongation at break	ASTM D412 : 1997	%	350
Coefficient of linear extension	-	$10^{-4}.K^{-1}$	3
Linear shrinkage	-	%	< 0.1

Seven specimens were made, and the measurements were done on each of them. Subsequently, a statistical processing was made so that all the presented data are equal to average values obtained at the performed determinations. Rubber degradation was naturally performed for five years. The specimens were stored at 25°C in a 50-65% humidity atmosphere without a direct contact with light and after that the measurements were made.

The research methodology is schematically presented in Figure 2.

The 1st stage consists in silicone rubber preparation, after which, in 2nd stage, seven specimens and a silicone rubber mold were manufactured.

The 3rd step was carried out in the first stage of testing, which consisted in determining the specimen's hardness and compression strength and casting seven pieces in the silicone rubber matrix. This step was performed immediately after the silicone rubber crosslinking.

The 4th stage consisted in repeating third round but after a two years period.

The 5th stage consisted in repeating the third round but after a five years period.

The 6th stage consisted in repeating the third round but after a seven years period.

The 7th stage consisted of analyzing and interpreting the data obtained in the testing steps of the specimens.

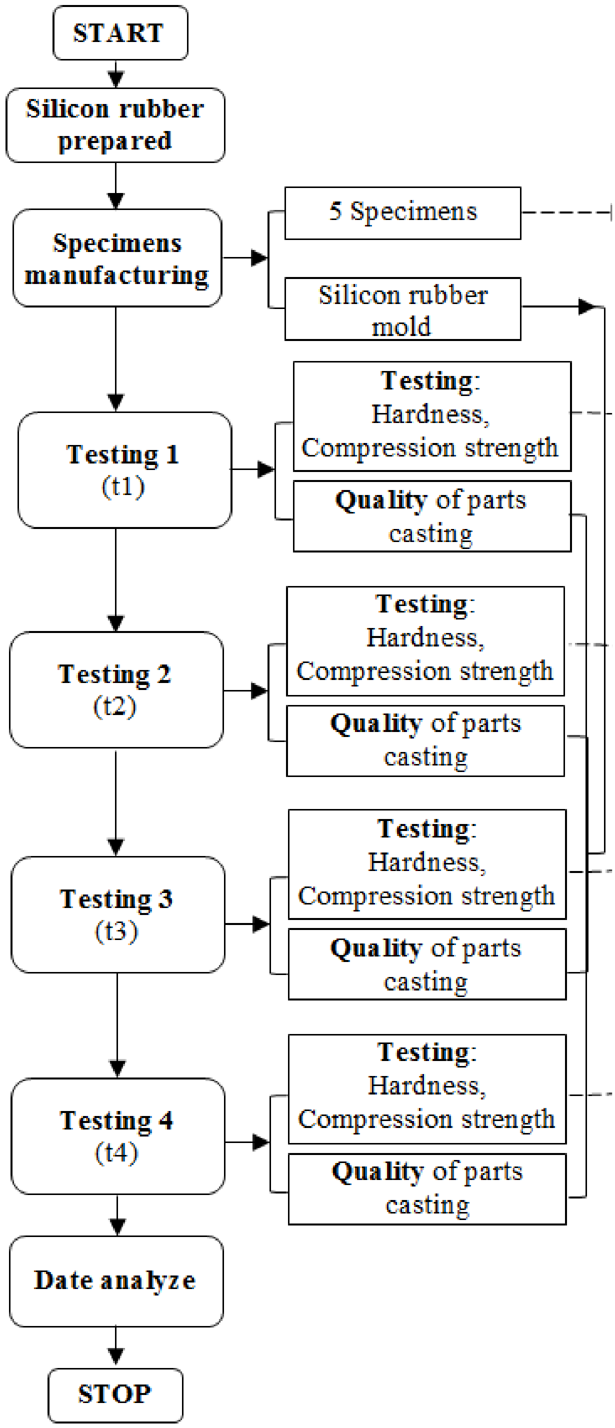

Fig. 1. The working methodology

3. ANALYSIS AND INTERPRETATION OF THE OBTAINED DATA

After collecting the obtained data, a primary statistical data processing was performed to obtain the average values for the hardness, compression strength and parts quality.

3.1 Analysis of samples Hardness

The statistical processing of the obtained data was done using the SigmaStat 3.5 software. Analyzing the measurements, it could be observed that the standard deviation ″Std. dev.″ is between 0.12 ÷1.35, meaning an acceptable variation, and the standard error ″Std. error″ has values between 0.04 ÷ 0.13, representing a weak variation and a good level of homogenization of the obtained values.

Table 2

Influence of aging to hardness.

	Hardness of silicone rubber after			
Aging	**0 year**	**2 year**	**5 year**	**7 year**
Mean	50.2	51.7	53.2	55.2
Std. dev.	0.12	1.19	0.27	1.35
Std. error	0.04	0.07	0.10	0.13

Figure 2 shows the trend of increasing hardness with the silicone rubber aging process.

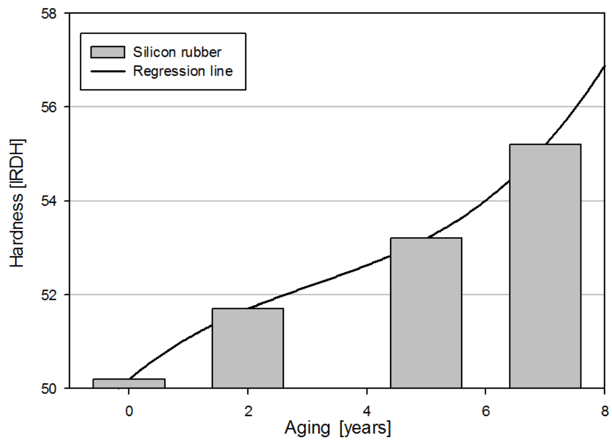

Fig 2. The trend of increasing hardness with the silicone rubber aging

In percent, after two years we have a hardness of 3% higher, after five years we have a hardness 6% higher and after seven years with 10% higher.

3.2 Compression strength analysis

Another aspect that was explored is the way that samples behave under compression, in the case of shortening them by 6 mm (or 50%) using a 10 mm/min compression speed. In this case, the resistance's variation curves were determined, according to the applied force. The results that were obtained after the compression tests were again statistically processed in order to obtain the average for each one of the sample batches' specific deformation. After the statistical data were processed, results that the obtained values are homogeneous and have a high level of representativeness.

Figure 3 shows the variation diagram of the highest force that it is necessary in order to shorten with 50% the height of the sample according to material aging.

Based on the results, shown in Figure 5, it was possible to calculate the percentage of silicone rubber aging. After the silicone rubber preparation, a compressive force of 1363 N is required for 50% compression of the specimen, after 2 years a force of 3% is needed, after 5 years 12% and after 7 years 21%.

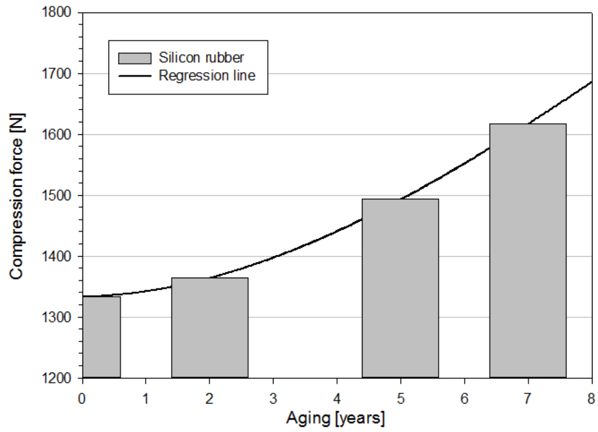

Fig 3. The trend of increasing silicone rubber compressive strength with its aging

4. MATHEMATICAL MODEL FOR SILICON RUBBER AGING

The aging phenomenon results, as we have seen in the increasing of silicone rubber initial characteristics.

Mathematically, in general purpose, it is possible to express the aging phenomenon that affects a certain property of the material through the relationship (1).

$$A(V_0,t) = V_0 + G(t), \qquad G(t) \geq 0, \ \ \forall t \geq 0 \qquad (1)$$

Where: V_0 - represents the initial value of the material property; t - is the time interval and $G(t)$

- a growth factor characteristic to aging, that analytically describes how time influences the material characteristic.

The regression line presented in Figure 2 and Figure 3 is a polynomial curve, therefore the relation (1) can be rewritten by the relation (2), which is the n-grade polynomial equation.

$$A(x) = a_0 + a_1 x + a_2 x^2 + \ldots + a_n x^n \quad (2)$$

For simplifying the notation, let $f(x_i) = A_i$. Substituting each data point into Eq. (2) yields to n + 1 equations (3):

$$\begin{aligned} A_0 &= a_0 + a_1 x_0 + \ldots + a_n x_0^n \\ A_1 &= a_0 + a_1 x_1 + \ldots + a_n x_1^n \\ &\vdots \\ A_n &= a_0 + a_1 x_n + \ldots + a_n x_n^n \end{aligned} \quad (3)$$

There is n + 1 linear equations containing the n+1 coefficients a_0 to a_n. Equation (3) can be solved for a_0 to a_n by Gauss elimination.

Using MathCAD software, equation (2) has been solved, resulting the following polynomial relations, which will be used to approximate hardness evolution in time, equation (4) and strength in compression, equation (5) of the silicone rubber according to the aging process

$$A_H(t) = H_0 + 0.506t + 0.025t^2 \quad (4)$$

where H_0 represents the rubber initial hardness; $t = 0$ years.

$$A_C(t) = C_0 + 8.398t + 4.65t^2 \quad (5)$$

Where C_0 represents the initial compression force of the rubber on $t = 0$ years.

The deviation of the real values obtained from the tests against the theoretical value obtained based on the approximation relations were between 0-0.5% for hardness evaluation and 0-0.3% for compressive force evaluation.

We can say that relations (4) and (5) can be used in practice because they are validated experimentally.

5. DISCUSSION

The aging process is a normal process through which any material passes, but the way each material is affected by this phenomenon is different, both qualitatively and quantitatively. In the case of silicone rubber, following seven-year studies, the following were determined:

- the silicone rubber roughness changes by 10% after seven years.
- the force needed to shorten the specimens by 50% changes with 21% after seven years.

Similar results have been presented in other researches carried out on other elastomeric materials, as it could be seen in literature [10], and [11].

It can be observed that the silicone rubber hardness modification inevitably leads to the change of force required to compress it. Practically from the obtained results, increasing the hardness with 1% and comparing with the initial results it leads to increase the compression force with 2%. This is shown in Table 3.

It is noticeable that in the second year there was a mismatch between the value obtained between the hardness and the compression force. It is possible that in this case the rubber hardness has not been properly established, otherwise the previously released finding is only partially true.

Table 3

Influence of aging to hardness.

Aging	**0 year**	**2 year**	**5 year**	**7 year**
Hardness	0%	3%	6%	10%
Compression force	0%	3%	12%	21%

From this observation results that the hardness and compressive force of a material are interdependent.

6. CONCLUSION

This paper presents how the aging process affects the silicone rubber mechanical and technological properties.

The studies were carried out over a period of seven years, and the measurements were performed immediately after silicone rubber preparation, after 2, 5 and 7 years.

Fallowing the presented results, we can conclude that:

- the hardness and compressive strength increase with the passing of time;
- there is a direct link between the change of hardness and the change of compressive force;
- the hardness changes results in less elasticity of rubber and implies reducing the molds flexibility;
- the mold flexibility is decreasing with aging and this phenomenon has repercussions on how to extract the part from mold;
- the thin wax parts are most affected because they might break because of mold stiffness;
- if the material is injected into the silicone rubber mold, it is advisable to take into account the increasing of the mechanical properties, otherwise the precision of the obtained parts is impaired.

The results presented in this article are obtained only for one type of silicone rubber. For future research, it would be useful to study how aging affects other types of silicone rubber.

Also, the mathematical model presented is necessary to be tested for other types of silicone rubber in order to validate or invalidate it.

7. REFERENCES

[1] Bocanet V., Panc N., *The influence of hole finishing strategies on quality*, MATEC Web of Conferences 137, 03001, 2017.

[2] Panc N., Bocanet V., Bulgaru M., Beldean C., *Research on holes finishing operations performance by cutting*, Acta Technica Napocensis-Series: Applied Mathematics, Mechanics and Engineering, 2014.

[3] Rotaru H., Baciut M., Stan H., Bran S., Chezan H., Iosif A., Tomescu M., *Silicone rubber mould cast polyethylmethacrylate-hydroxyapatite plate used for repairing a large skull defect*, Journal of cranio-maxillo-facial surgery 34 (4), 242-246, 2006.

[4] Berce P., Chezan H., Balc N., *The application of rapid prototyping technologies for manufacturing the custom implants*, ESAFORM Conference, 679-682, 2005.

[5] Bâlc N., PancN., Berce P., *Research on dimensional accuracy of the metal parts made by rapid metal casting*, Academic Journal of Manufacturing Engineering 11 (2), 2013.

[6] Panc N., Radu S.A., Pacurar A., *The simulation of wax solidification process in silicone rubber mold*, Acta Technica Napocensis-Series: Applied Mathematics, Mechanics, and Engineering, 2012.

[7] Radu S.A., Popescu A.C., Balc N., Panc N., *Experimental determination of surface roughness of parts obtained by rapid prototyping*, Proceedings in ARSA-Advanced Research in Scientific Areas, 2014.

[8] Radu S.A., Leordean D.V., Balc N., Nemeş O., *Resin type influence on moulded parts final dimensions*, Studia Universitatis Babes-Bolyai Chemia, 219-228, 2015.

[9] Panc N., Hancu L., Balc N., *Research regarding the improvement of the performance of rubber dies*, Proceedings of the World Congress on Engineering 1, 783-786, 2011.

[10] Li G., Tan J., Gong J., *Degradation of the elastomeric gasket material in a simulated and four accelerated proton exchange membrane fuel cell environments*, Journal of Power Sources, 205: pp. 244–251, 2012

[11] Patel M., Skinner A.R., *Thermal ageing studies on room-temperature vulcanised polysiloxane rubbers*, Polymer Degradation and Stability, 73: pp.399–402, 2001

INFLUENŢA ÎMBĂTRÂNIRII CAUCIUCULUI SILICONIC, ASUPRA CALITĂŢII PIESELOR OBŢINUTE ÎN MATRIŢE FLEXIBILE

Rezumat: Matriţele flexibile din cauciuc siliconic se utilizează pentru obţinerea de piese în volum mic de fabricaţie. Utilizarea matriţelor, după perioade lungi de timp, duce la posibilitatea ca îmbătrânirea materialului din care este confecţionată matriţa, să influenţeze calitatea pieselor obţinute. Acest articol prezintă cercetări asupra modului în care modificarea proprietăţilor mecanice ale cauciucului siliconic, datorat fenomenului de îmbătrânire, influenţează calitatea pieselor turnate în matriţă. Prin studiile de caz prezentate se poate stabili perioada în care se pot utiliza matriţele din cauciuc siliconic, astfel încat piesele obţinute să nu fie influenţate de modificarea caracteristicilor mecanice ale materialului matriţei.

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