Effect of the cure time on the Mechanical Properties of Silicone Rubber used as Socket Liners

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Abstract. This work is focused on the upper part of the prosthesis which is called a socket, it is in contact connect with the amputated part. The shear force between skin and socket, local pressure, sweating, and bacteria generation, all lead to skin inflammation and a bad smell. Consequently, the prosthesis became uncomfortable for a patient. To address this issue silicone rubber liners is proposed to use because it can absorb moisture, stress distribution, and antibacterial. The curing time and temperature are important factors for determining crosslink density, from the results obtained, can be noticed that, the cross-link density can greatly affect the silicone rubber properties, it can have a direct effect on the tensile strength, modulus of elasticity, percentage of elongation as well as the water absorption, and the cure time (15 min.) shows the best result. As a result, using it making the prosthesis more comfortable and acceptable to the patient. In this paper, the effect of cure time on physical properties was studied.

Keywords: Silicone rubber, cure time, mechanical properties, water absorption.

1. Introduction:

Large numbers of people suffer from the amputation of one or both lower limbs, which directly affects their lives[1]. These disabilities can increase in number dramatically for several reasons, including wars, the incidence of diabetes, vascular diseases, and cancer [2]. The lower limb prostheses are an important device for amputees to recover missing functions, and to reduce other activities problems [3]. The interfaces between socket and stump are an important element for lower limb orthoses and prostheses, which provides proper contact between the prosthetic lower limb and the amputated part[4]. Amputees feel uncomfortable from the prosthesis, due to several reasons, such as, the pressure on specific areas, the shear between the skin and the socket, and the generation of bacteria due to the lack of absorption of sweat [5, 6]. The socket should be achieving good load distribution, stability, and control for mobility. Principles of residual limb anatomy and interaction biomechanical between the socket and the stump are fundamental to the improvement of socket properties. These improvements are intended to provide a good load distribution around the residual limb [7].

The slipping between the skin and the socket leads to the deformation of the stump tissues. The discomfort resulted not from the local pressures, but the increase in interface temperature and sweating inside the socket [8-10]. So, should be avoided this disadvantages by using comfortable liners as the interface between the skin and the socket [11].

The silicone rubber has special features such as high chemical stability, heat resistance, abrasion, and environmental resistance. In recent years, interest has increased in the production and development of
silicone rubber and its use in many applications, including medical applications [12]. So it was appropriate to choosing silicone rubber as the socket liner. At the same time, the silicone lining can cause some problems for the patient if it is not of good properties [13]. The interface will be formed during walking between the liner and the skin, which can cause frictional force that will affect residual limb tissues, which leads to blisters and ulceration forming. This is associated with the accumulation of sweat and the appearance of bacteria, which increases tissue damage and the patient's inability to continue wearing the prosthesis [14, 15].

2. Material and experiments:
The silicone rubber (NBO-102016) was available locally, the samples were prepared by hand casting, as sheets were made by dimension (130x30x6)mm. Samples were cut according to the ASTM D638 Type IV specimen dimensions as shown in Figure 1. The cure time (0, 15, and 30) min. at 60 °C. The machine used for the testing of tensile properties is a microcomputer-controlled electronic universal testing machine model (WDW-5E). Shore A durometer was used for hardness measurements according to ASTM D-2240 [16] and water absorption was performed according to ASTMD-570-98 [17]. In all tests, three samples were used for each examination and the average readings were taken.

3. Water absorption measurements:
Water absorption measurements are done to have an idea about sweat absorption. The water absorption behavior of silicon rubber of the dried and pre-weighed. Then, was immersed in 50 ml of deionized water at 37 °C in an incubator. The immersed specimens were withdrawn from the water after 30 minutes, intervals, and their wet weight was determined after first blotting with a filter paper to remove the surface water and immediately weighing specimens. The water absorption percent is calculated by using the equation:

\[ W = \left( \frac{W_w - W_d}{W_d} \right) \times 100\% \]  

(1)

Where W is water absorption percent, \( W_d \) is the dry weight, and \( W_w \) is the wet weight.

4. Results and discussions:
The cross-link density can greatly affect the silicone rubber properties, it can have a direct effect on the tensile strength, modulus of elasticity as well as the percentage of elongation. Curing time and temperature are important factors for determining crosslink density. In addition to the fact that the curing can improve the mechanical properties, it can also avoid any change in the dimensions or properties during the period of use due to aging, this results in the interconnection of the remaining free radicals with the used time [18, 19]. Sample (c) shown the highest tensile strength was obtained as in Figure 2, compared to the sample (b) with 15 min. cure time and sample (a) without curing, this is due to the heating work as a catalyst for bonding. the tensile strength increased from 0.81 to 0.96 MPa.
The elongation percentage at breaking was also affected by the curing time, so can notice, an improvement in the elongation value with the increase in curing time. The increase in elongation at 30 minutes of care time may be due to the breaking of some bonds formed, a similar process that happens
in rubber when it is vulcanized at a temperature and time more than the specified, causing devulcanization[20], shown in Figure 4.

![Graph showing elongation % for different samples](image)

**Figure 4.** Effect of cure time on elongation  a) 0, b) 15, and c) 30 min.

Curing time did not show a significant effect on the hardness of silicone rubber, as shown in Figure 5. This is a good indicator of the elasticity of the samples.

![Graph showing hardness Shore A for different samples](image)

**Figure 5.** Effect of cure time on hardness  a) 0, b) 15, and c) 30 min.

The objective of polymers curing is to complete cross-linking and interaction of components with each other to avoid aging, which can occur in samples during storage or use. Because the reaction at room temperature can leave some non-reacting radicals that can react when appropriate conditions are
available and this leads to change in polymer properties and dimensions. Figure 6, shows the effect of cure time on the water absorption, at 15 minutes’ cure time, the water absorption increase, this due to the release of gases resulting from the reaction, leading to the formation of some pores in the sample, which can increase the water absorption percent. But at the 30 minutes cure time, the water absorption decrease, this refers to an increase in the cross-linking density [21], which can close part of those formed pores. The percentage of absorption remains greater than the sample without any heat treatment, and this is suitable for the socket lining to increase the ability to absorb sweat, and the socket becomes more comfortable for the patient.

[Figure 6. Shows the effect of cure time on water absorption.]

5. Conclusions:

Silicone is mainly used as a lining in the lower limbs prosthetics, specifically the socket that represents the upper part of the prosthesis. The aim of it is to prevent friction between the skin and the socket as well as to prevent the formation of bacteria by absorbing moisture, thus it can prevent the formation of infections and the prosthetic is more comfortable and acceptable to the patient. The curing time and temperature are important factors for determining crosslink density, from the results obtained, can be noticed that, the cross-link density can greatly affect the silicone rubber properties, it can have a direct effect on the tensile strength, modulus of elasticity, percentage of elongation as well as the water absorption.
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