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Mechanical Characterization of PDMS with Different Mixing Ratios

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Abstract

Polydimethylsiloxane (PDMS) is a transparent, biocompatible, flexible, simple processing, chemically and thermally stable polymer that has been attracting attention due to its wide range of applications in mechanical, civil and electronic engineering and biomedical field. In order to improve PDMS' properties, many studies have been investigating the effect of the mixing ratios of its components (base polymer and curing agent) on the mechanical properties, once they affect the number of interactions between the polymer chains of the material. With the aim to make a comparison of the mechanical response of pure PDMS (SYLGARD 184) with different ratios of the base elastomer and the curing agent, tensile and hardness tests were performed. The tested mixing ratios were 10:1, 10:2 and 10:3 (base: curing agent). Tensile tests were executed in a universal tester machine, set up with a velocity of 500 mm/min and pre-load of 1 N. An analogical portable durometer type Shore A was used to carry out the hardness test, according to ASTM D2240. The results for the tensile test showed that an increase in the amount of cure agent reduced the tensile strength. The hardness values obtained were 41.7±0.95, 43.2±1.03 and 37.2±1.14 Shore A for pure PDMS with ratios equal to 10:1, 10:2 and 10:3, respectively.

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1. Introduction

Over the last decades, Polydimethylsiloxane (PDMS) has been attracting interest of study due to its properties and wide range of applications, that includes mechanical, civil and electronic engineering and biomedical devices (Adiguzel, Sagnic, and Aroguz 2017; Dalla Monta et al. 2018a; Giri, Naskar, and Nando 2012a; Liu et al. 2017a; Riehle et al. 2018; Rodrigues et al. 2018; Salazar-Hernández et al. 2019; Victor, Ribeiro, and F. Araújo 2019).

PDMS is a silicon-based polymer with low cost, optical transparency, and easy manufacturability, what makes it to have some advantages over other materials (Khanafer et al. 2009; Prabowo, Wing-Keung, and Shen 2015). The main

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properties of PDMS are its transparency (Kacik and Martincek 2017; Lee et al. 2016; Muñoz-Sánchez et al. 2016; Pinho et al. 2019; Yi et al. 2020), biocompatibility (Montazerian et al. 2019; Rao, Zhang, and Liu 2013; Souza et al. 2020), high flexibility (An et al. 2017; Shi et al. 2020), chemical and thermal stability (Dalla Monta et al. 2018; Giri, Naskar, and Nando 2012; Liu et al. 2017).

In order to improve PDMS' properties, many studies have been investigating the effect of the mixing ratios of its components (base polymer and curing agent) once they affect the amount of interactions between the polymer chains of the material (Khanafer et al. 2009; Prabowo, Wing-Keung, and Shen 2015; Flaminio et al. 2021).

In general, the ratio used for PDMS synthesis is 10:1 (w/w) (base:curing agent) and the cure can be carried out either in an oven at highest temperatures, or at room temperature, for different amounts of time, depending on the temperature chosen.

Some studies have shown that the increase of the concentration of curing agent can affect surface properties such as root-mean-squares, Young's modulus (Viola et al. 2012; Wang et al. 2010), and chemical composition (Wang et al. 2010), what changes lubrification behavior (Kim, Wolf, and Baier 2015).

Regarding mechanical properties, Khanafer et. al. (2009) reported that the elastic modulus increases as the proportion of curing agent increases until it reaches the ratio of 9:1 (w/w) (base:curing agent), when the modulus starts to decrease.

Kim et. al. (2011) found out that if PDMS is synthesized with excess of curing agent, stress softening can be observed and under cycle tension tests, a residual strain appeared when increasing the magnitude of the applied strain. Those studies advice that for channel or chamber structures, a rigid PDMS with excess of curing agent is desirable, while in applications that more flexibility is required, PDMS with less curing agent is preferred.

This paper studies how the mixing ratio between curing agent and base polymer when synthesizing PDMS affects the mechanical behavior of the final material, analysing it though tensile and hardness test.

2. Methodology

2.1. Sample Manufacturing

The samples were produced using PDMS Sylgard 184, that consists in the mixture of the base material (silicon) with its curing agent (cross-linker). The ratios used were 10:1, 10:2 and 10:3 (base: curing agent).

The base polymer was weighted, the cure agent added until achieving the desired ratio and both were mixed with a metallic spatula. To remove bubbles that eventually are formed in the material during this process, it went to a vacuum desiccator. Posteriorly, the material was placed in the aluminum moulds, and went again to the vacuum desiccator before the curing process. This last process occurred in room temperature, approximately 25°C, for 48 hours.

The geometries used for the molds were according to ASTM D412 (ASTM 2009) for samples used in tensile tests and ASTM D2240 (ASTM 2015) for hardness tests.

2.2. Tensile Test

A universal tester machine, brand SHIMADZU, with maximum capacity for 10 tons was used to execute the uniaxial tensile tests. The software Trapezium X, version 1.5.1 was used, and the tests were carried out according to ASTM D412 (ASTM 2009) standard. For each mixing ratios, specimens were tested.

As an initial setup, a pre-test was configured with velocity of 5 mm/min until achieving a pre-load of 1 Newton and, since that, the velocity was set up for 500 mm/min until the rupture of the sample. Four thin metal plates with fine particle size sandpaper were attached to the surface of the samples for a better fixation, avoiding the samples slipping during the tests.

2.3. Hardness Test

An analogical portable durometer was type Shore A was used to carry out the hardness tests, that followed ASTM D2240 (ASTM 2015) standard. For each mixing ratio, 2 specimens were used for the test.

The execution of the tests was made in a plane surface and the most plane side of the samples were chosen to execute the measurements in five points. The tests took place in room temperature, approximately 18°C.

3. Results and Discussion

3.1. Tensile Test

Figure 1 shows the graphs of engineering stress versus engineering strains for PDMS with ratios 10:1, 10:2 and 10:3. The results presents that increasing the percentage of curing agent, the tensile strength was reduced. On the other hand, firstly, the Young's modulus followed the behavior proposed by Khanafer et. al. (2009), once the value found were E=1.527 MPa and E=1.334 MPa for 10:1 and 10:2 mixing ratios, respectively. Such behavior can be related and explained with Kim et. al. (2015) studies, which proposed that an excess of curing agent can lead to a less flexible PDMS.

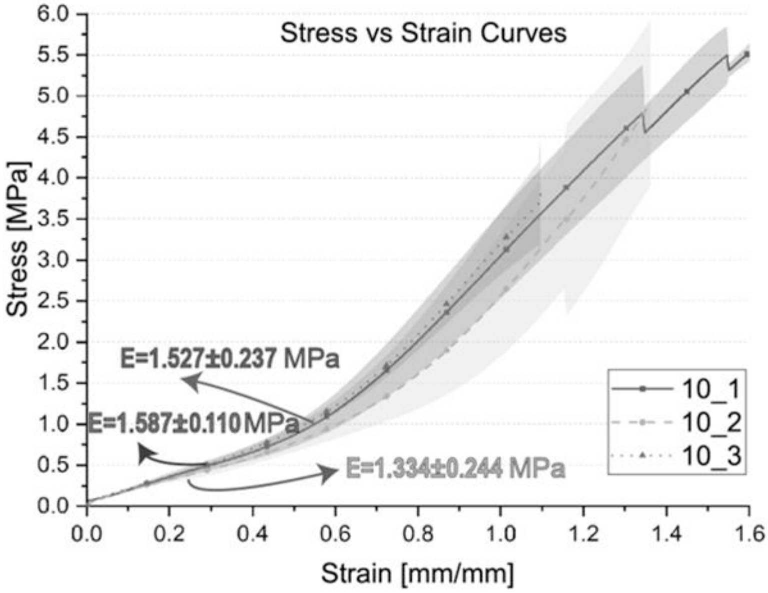

Fig. 1. Engineering stress versus engineering strain curves for PDMS with 10:1, 10:2 and 10:3 mixing ratios.

Regarding PDMS with mixing ratio 10:3, Young's modulus was higher than expected following Khanafer et. al. (2009) and Kim et. al. (2015) studies, as the value obtained was E=1.587 MPa.

3.2. Hardness Test

Figure 2 illustrates the summary of the results obtained from Hardness Test Shore A for PDMS with ratios 10:1, 10:2 and 10:3.

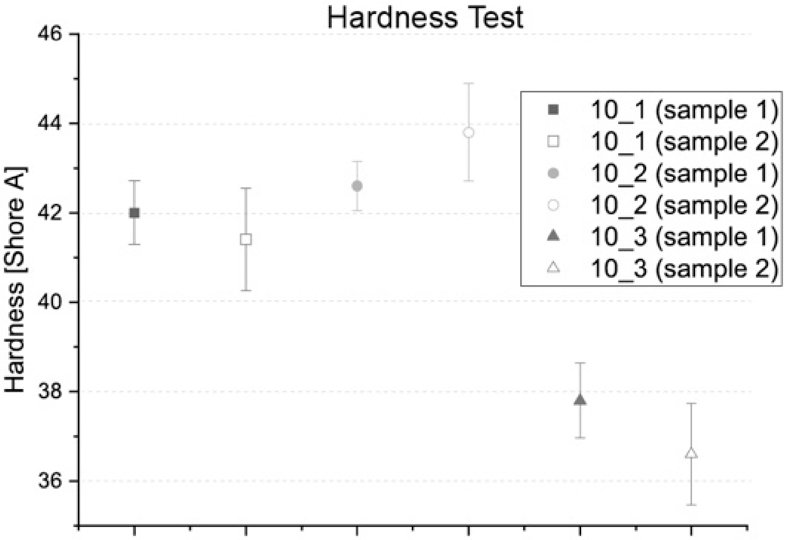

Fig. 2. Summary of results obtained from Hardness Shore A tests.

The hardness average obtained for pure PDMS with 10:1 ratio was 41.7±0.95 Shore A, value close to the declared by the manufacturer, which is 44 Shore A (Dow Chemical Company 2017). It is important to highlight that such ratio is the one recommended by the manufacturer. The measurements obtained are compiled in Table 1. As it can be also seen, the hardness average for PDMS with 10:2 ratio (43.2±1.03 Shore A) was close to the manufacturer's declared value as well.

Table 1. Measurements of Hardness Shore A for PDMS with 10:1, 10:2 and 10:3 mixing ratios.

Hardness - Shore A						
Measurement Point	Pure PDMS 10:1		Pure PDMS 10:2		Pure PDMS 10:3	
	Specimen 1	Specimen 2	Specimen 1	Specimen 2	Specimen 1	Specimen 2
1	42	43	42	43	39	38
2	41	41	43	45	38	36
3	43	42	43	43	37	37
4	42	41	42	43	38	35
5	42	40	43	45	37	37
Average	41.7		43.2		37.2	
Standard Deviation	0.948		1.032		1.135	

Even though the Hardness for PDMS 10:1 was close to the declared by the manufacturer, the relationship between hardness and Young's modulus for the three materials did not follow the general trend. According to many studies, commonly, the tendency is that Young's modulus is proportional to hardness (Lan and Venkatesh 2014; Musil et al. 2002; Sun, Kothari, and Sun 2018).

4. Conclusion

Mechanical properties of PDMS with three different mixing ratios between base polymer and curing agent were studied through tensile and hardness tests in order investigate the influence of the percentage of curing agent in those properties, once the amount of curing agent affects the interactions between the polymer chains of this material. Those studies shows that the tensile strength was reduced when increasing the percentage of curing agent, what can be explained by a possible excess of curing agent that leaded to a material less flexible. Thus, PDMS with 10:3 (w/w) mixing ratio presented the highest Young's modulus. Regarding hardness, the values found for PDMS with mixing ratios 10:1 and 10:2 were 41.7±0.948 and 43.2±1.032 Shore A were close to the one declared by the manufacturer, 44 Shore A, when using 10:1 as mixing ratio.

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