CHAPTER V

RESULTS AND DISCUSSIONS

5.1 EFFECT OF TYPES OF SILICONE RESIN ON THEIR MECHANICAL PROPERTIES

5.1.1 Tensile Properties

The effects of the commercial RTV silicone resin types on the mechanical properties of silicone elastomers are investigated in this section. Four types of commercial RTV silicone resins, i.e. RTV 585, RTV 300, RTV 3480 and RTV 4503 were studied.

In the case, aging had sustained effect on tensile strength and modulus during the entire experiment. The time-dependent mechanical properties of the silicone elastomers have been studied by investigating the tensile strength as a function of time up to four weeks while the sample was stored under room condition. The results are displayed in Figure 5.1, 5.2, 5.3 and 5.4, respectively.

From Figures 5.1, 5.2, 5.3 and 5.4, they are evident that the mechanical properties of silicone elastomer changed with time. The specimens' moduli increase rapidly with the time at the beginning of the experiment and become stable within 2 weeks. This time-dependent phenomenon of the elastomer mechanical properties may be driven by the further curing process or the relaxation of the polymeric chains [19-21]. However, from Figure 5.4, it is not showed the effect of curing agent concentration 1.0 phr because it can not form to be silicone elastomer. It can be determine that curing agent, amounts 1.0 phr, is not enough to curing for RTV 4503.

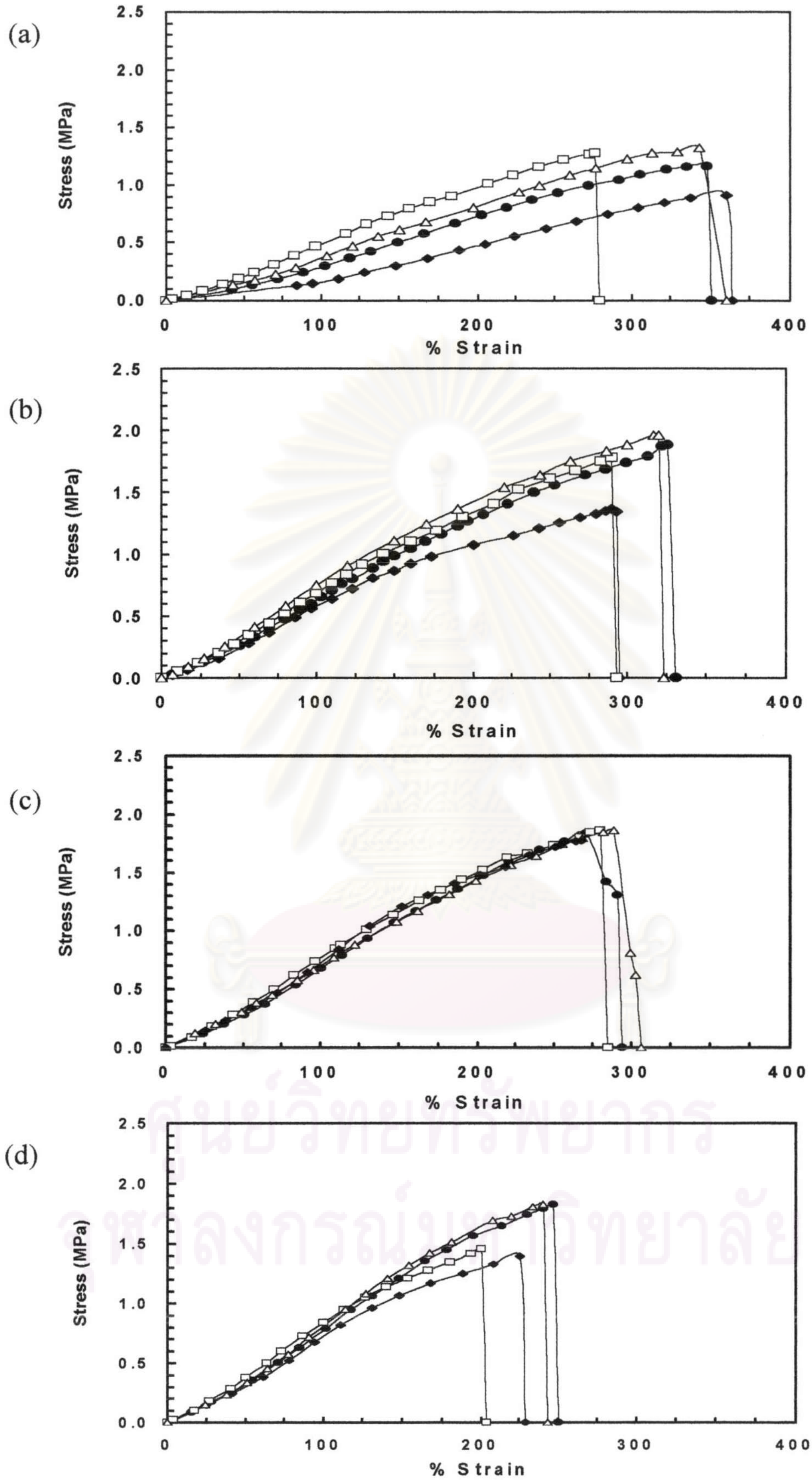


Figure 5.1 The time-dependent mechanical properties of silicone resin, RTV 585, at curing agent concentration of (a) 1.0 phr (b) 1.5 phr (c) 2.0 phr (d) 2.5 phr (—◆—1 week), (—●—2 weeks), (—□—3 weeks), (—△—4 weeks)

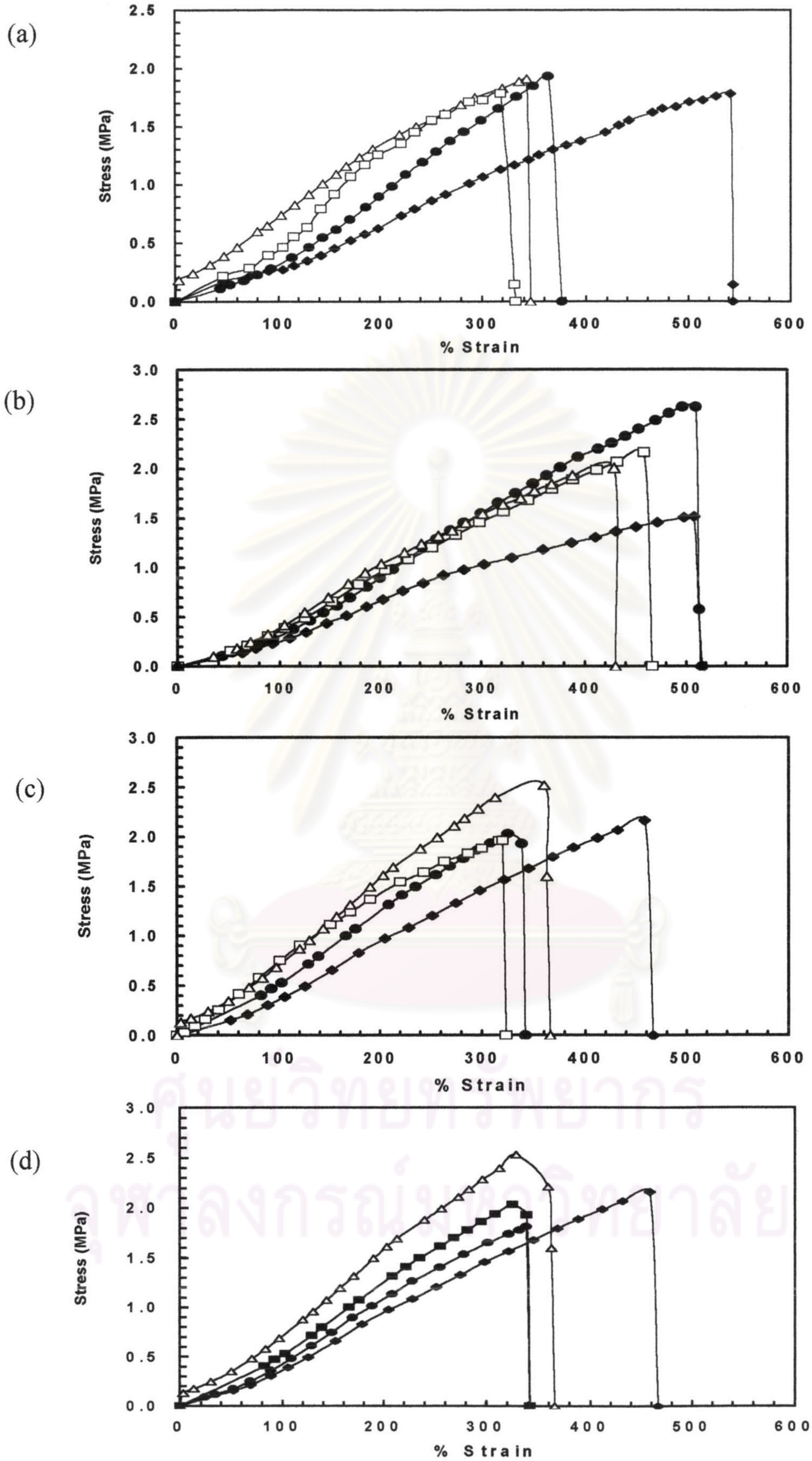


Figure 5.2 The time-dependent mechanical properties of silicone resin, RTV 300, at curing agent concentration of (a) 1.0 phr (b) 1.5 phr (c) 2.0 phr (d) 2.5 phr

(—◆—1 week), (—●—2 weeks), (—□—3 weeks), (—△—4 weeks)

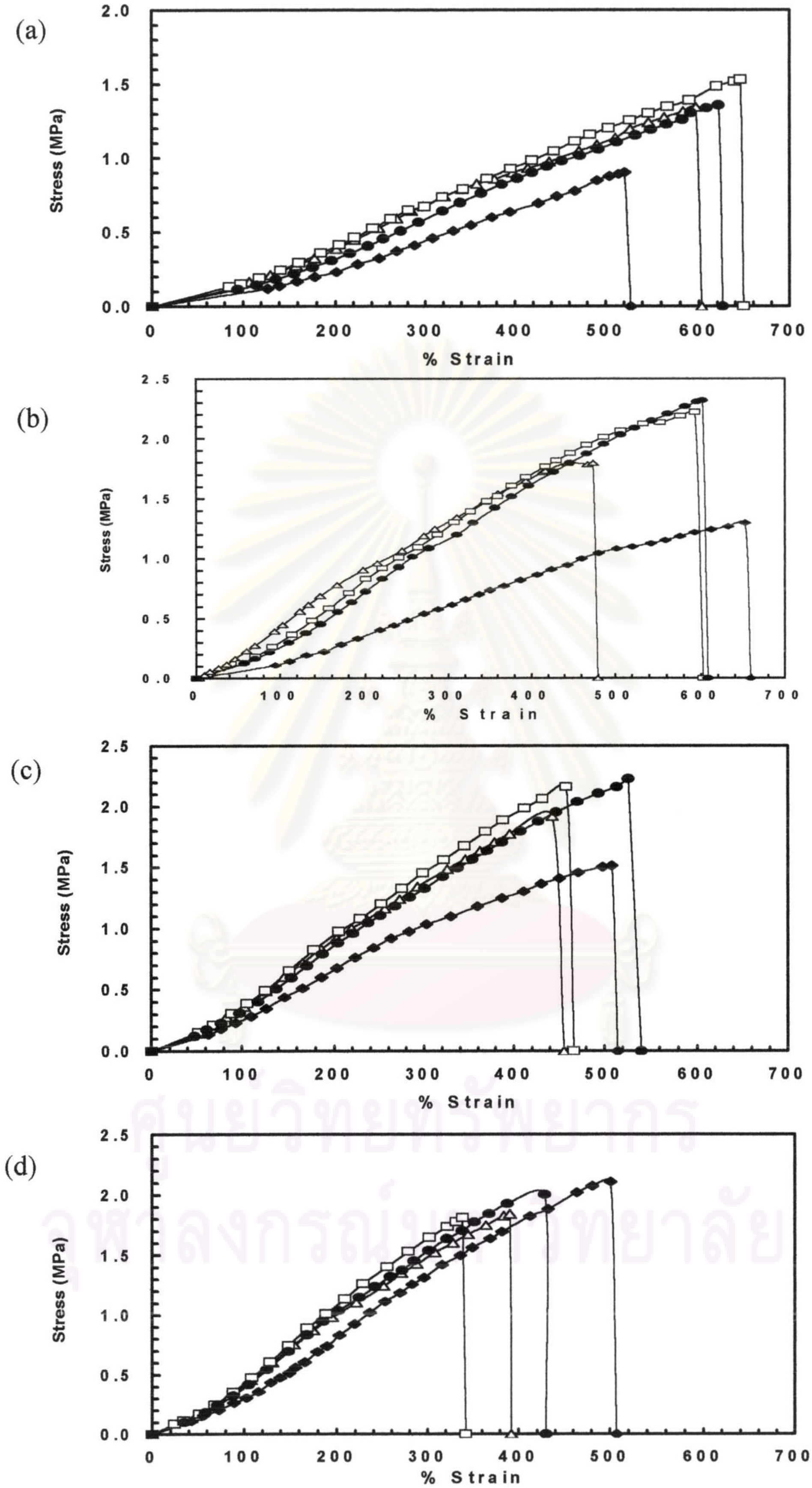


Figure 5.3 The time-dependent mechanical properties of silicone resin, RTV 3480, at curing agent concentration of (a) 1.0 phr (b) 1.5 phr (c) 2.0 phr (d) 2.5 phr (–◆–1 week), (–●–2 weeks), (–□–3 weeks), (–△–4 weeks)

(a)

(b)

(c)

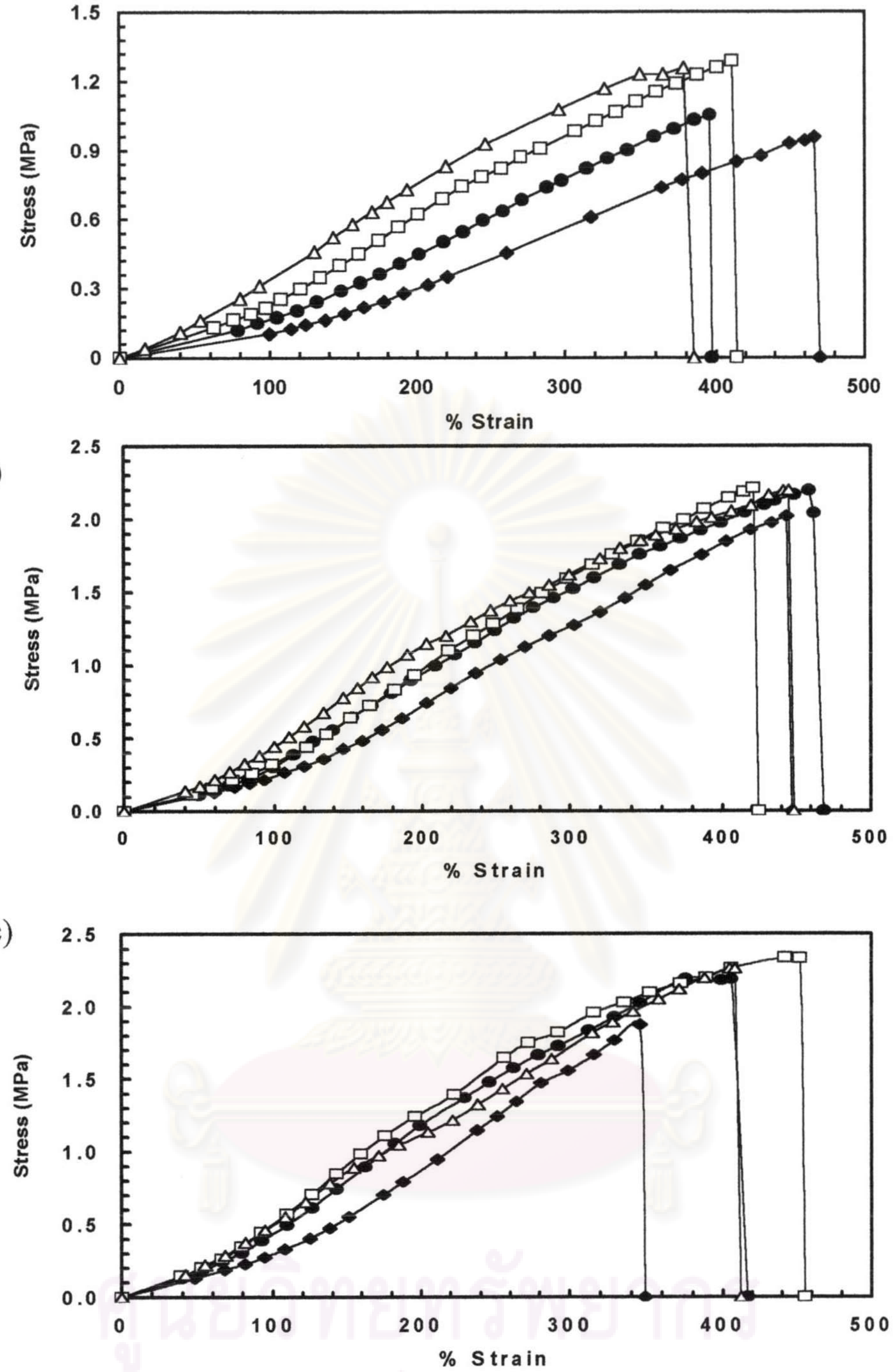


Figure 5.4 The time-dependent of mechanical properties of silicone resin, RTV 4503, at curing agent concentration of (a) 1.5 phr (b) 2.0 phr (c) 2.5 phr

(—◆—1 week), (—●—2 weeks), (—□—3 weeks), (—△—4 weeks)

Table 5.1 Tensile properties of different silicone resin types in this investigation (3 weeks)

Curing agent concentration (phr)	Tensile properties	RTV 585	RTV 300	RTV 3480	RTV 4503
1.0	Maximum tensile strength (MPa)	1.35	2.75	1.37	-
	% Elongation at break (%)	713.71	950.63	602.99	-
	Tensile modulus (MPa)	0.19	0.29	0.23	-
1.5	Maximum tensile strength (MPa)	3.32	2.72	1.80	2.59
	% Elongation at break (%)	897.21	775.28	479.66	550.12
	Tensile modulus (MPa)	0.38	0.35	0.38	0.33
2.0	Maximum tensile strength (MPa)	2.63	2.27	1.96	2.69
	% Elongation at break (%)	695.16	688.26	455.37	1069.44
	Tensile modulus (MPa)	0.41	0.34	0.43	0.49
2.5	Maximum tensile strength (MPa)	2.78	2.58	1.84	2.26
	% Elongation at break (%)	635.89	627.63	391.85	884.96
	Tensile modulus (MPa)	0.45	0.43	0.47	0.56

From previous results, it was shown that mechanical properties become stable within 2 weeks. Thus, in this investigation presents the mechanical properties up to 3 weeks for complete crosslink developing as shown in Table 5.1 which presents the tensile properties of the different silicone resin types as a function of curing agent concentration. Figure 5.5 shows effect of silicone resin types on tensile modulus at curing agent concentration of 1.5 phr and Figure 5.6 shows tensile modulus of silicone resin RTV 585 at curing agent concentration of 1.5 phr as a function of time .

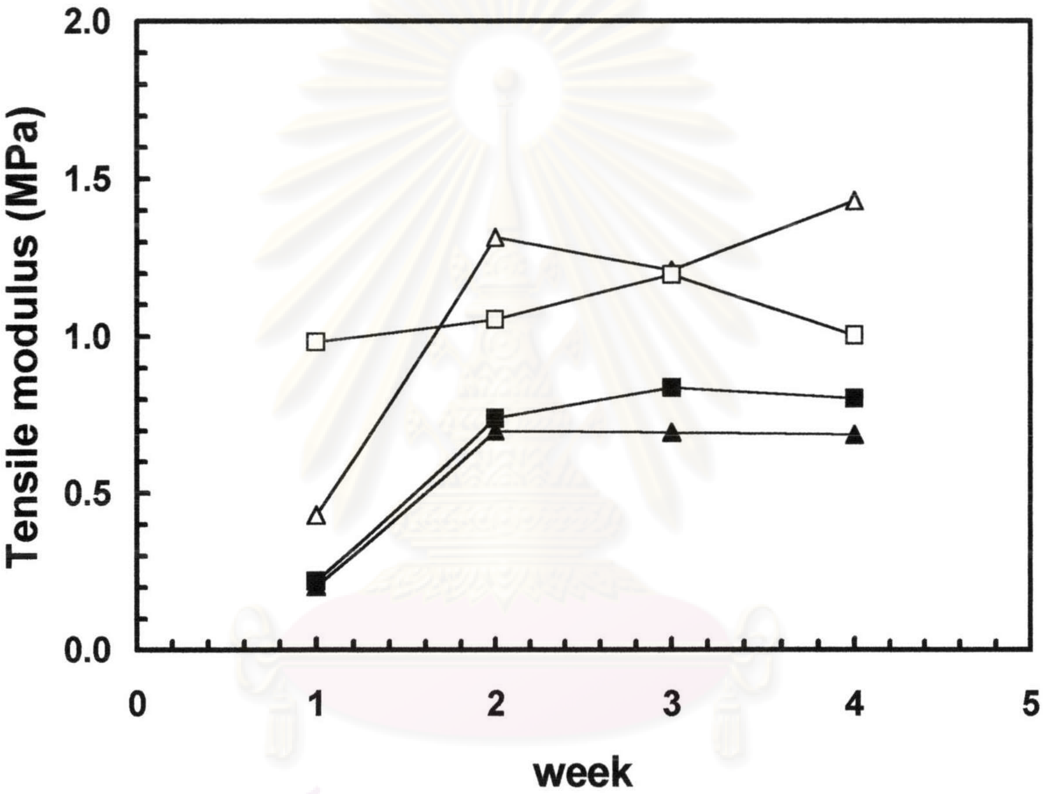


Figure 5.5 Effect of silicone resin types on tensile modulus at curing agent concentration 1.5 phr (△ RTV 585), (□ RTV 300), (■ RTV 3480), (▲ RTV 4503)

Figure 5.5 shows the effect of silicone resin types on tensile modulus at the same curing agent concentration of 1.5 phr. It is observed that the tensile modulus increases with time and becomes stable within three weeks in all types of silicone resin. It is clearly seen that RTV 585 is the highest modulus when observes after two weeks. From this result, it can be confirmed that the optimal period for develop mechanical properties of silicone elastomer is up to three weeks.

Figure 5.6 exhibits tensile modulus of silicone resin RTV 585 at various amounts of curing agent. It shows effect of curing agent concentration on tensile modulus (example silicone resin RTV 585). It was observed that the tensile modulus sharply increases with the curing agent content and curing time at room temperature in the first two weeks. Thus, bond strength develops as the RTV curing proceeds and this requires up to 2-3 weeks. It is the curing time for system that composes of resin and curing agent. However, it is clearly seen from the figure that rate of curing reaction is not dependent on the amount of the curing agent used.

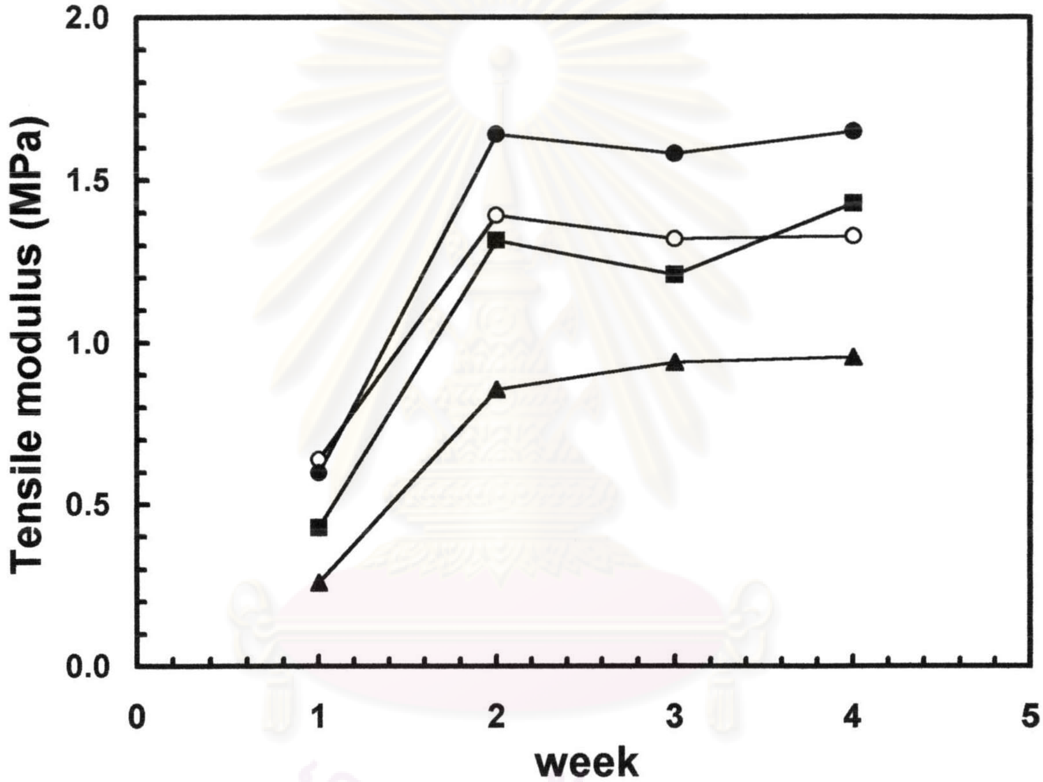


Figure 5.6 Tensile modulus of silicone resin RTV 585 as a function of curing agent concentration (—▲— curing agent 1.0 phr), (—■— curing agent 1.5 phr), (—○— curing agent 2.0 phr), (—●— curing agent 2.5 phr)

Figure 5.7 shows the effect of curing agent concentration on tensile strength of each type of silicone resin. It was observed that tensile strength of each silicone resin was different. For RTV 3480 and RTV 4503, the tensile strength increases with an increasing of curing agent concentration and becomes stable at 2.0 phr of the curing agent. On the other hand, RTV 585 and RTV 300 show higher tensile strength comparing at the same curing agent concentration.

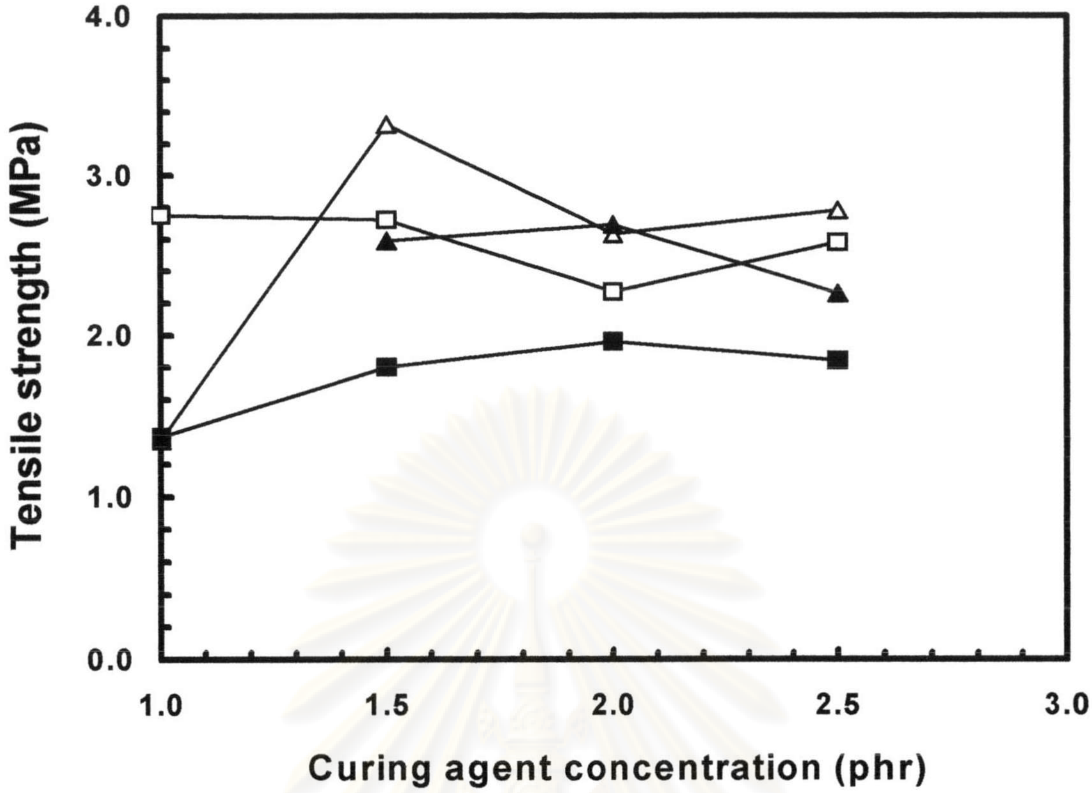


Figure 5.7 Tensile strength of each silicone resin as a function of curing agent concentration (–△– RTV 585), (–□– RTV 300), (–■– RTV 3480), (–▲– RTV 4503)

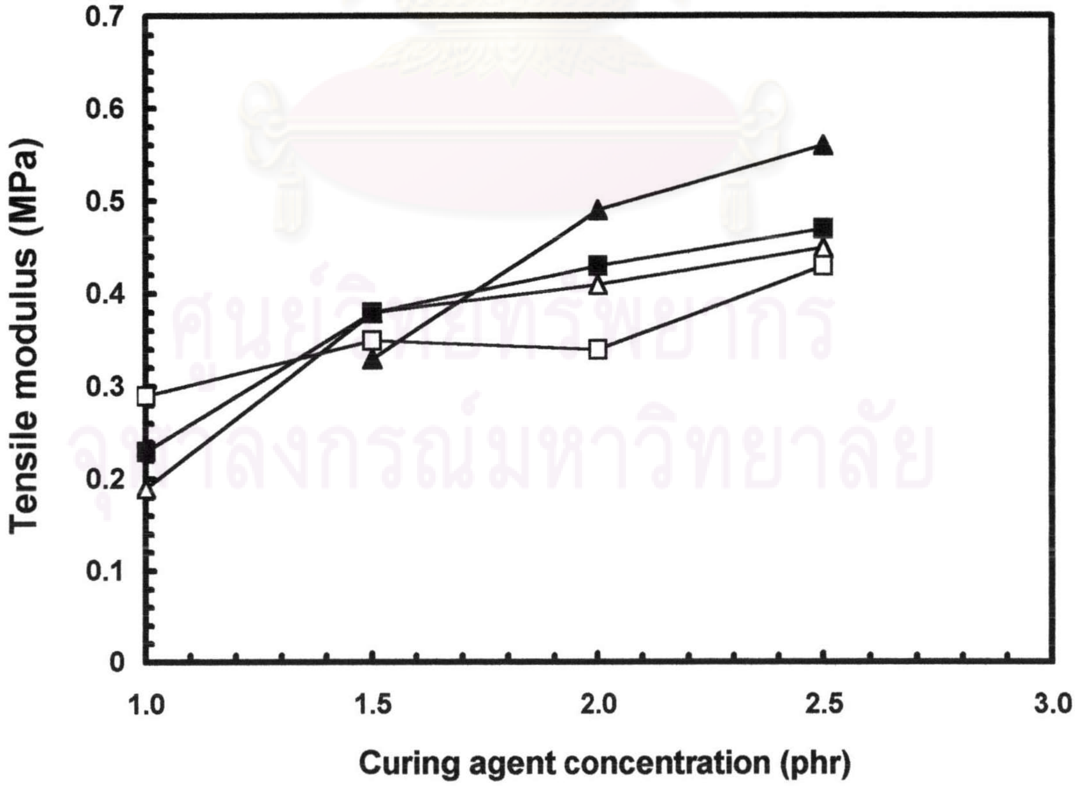


Figure 5.8 Tensile modulus of four different silicone resins as a function of curing agent concentration (–△– RTV 585), (–□– RTV 300), (–■– RTV 3480), (–▲– RTV 4503)

Figure 5.8 shows the tensile modulus of each silicone resin as a function of curing agent concentration. The tensile modulus tends to increase in all types of silicone resin when curing agent concentration increases. This means that all studied curing agents significantly improve strength by increasing cross-link junctions of the resulting cured elastomers, therefore, the tensile modulus increases rapidly [22].

From Figure 5.5-5.7, they can conclude that the rate of curing reaction is not depend on the amount of the curing agent used and the optimal period for develop mechanical properties of silicone elastomer is up to three weeks. Thus, the properties comparison of silicone resin for use to imitate breast model is shown in Figure 5.9. It presents the effect of silicone resin types on stress-strain behaviors at constant curing agent concentration of 1.5 phr after 3 weeks. It can observe that the tensile strength and percentage of elongation of RTV 585 are slightly higher than RTV 300, but it is clearly seen that the mechanical properties of RTV 4503 and RTV 3480 are worse than RTV 585 and RTV 300. However, RTV 3480 shows the worst mechanical properties so it is not suitable for breast model material.

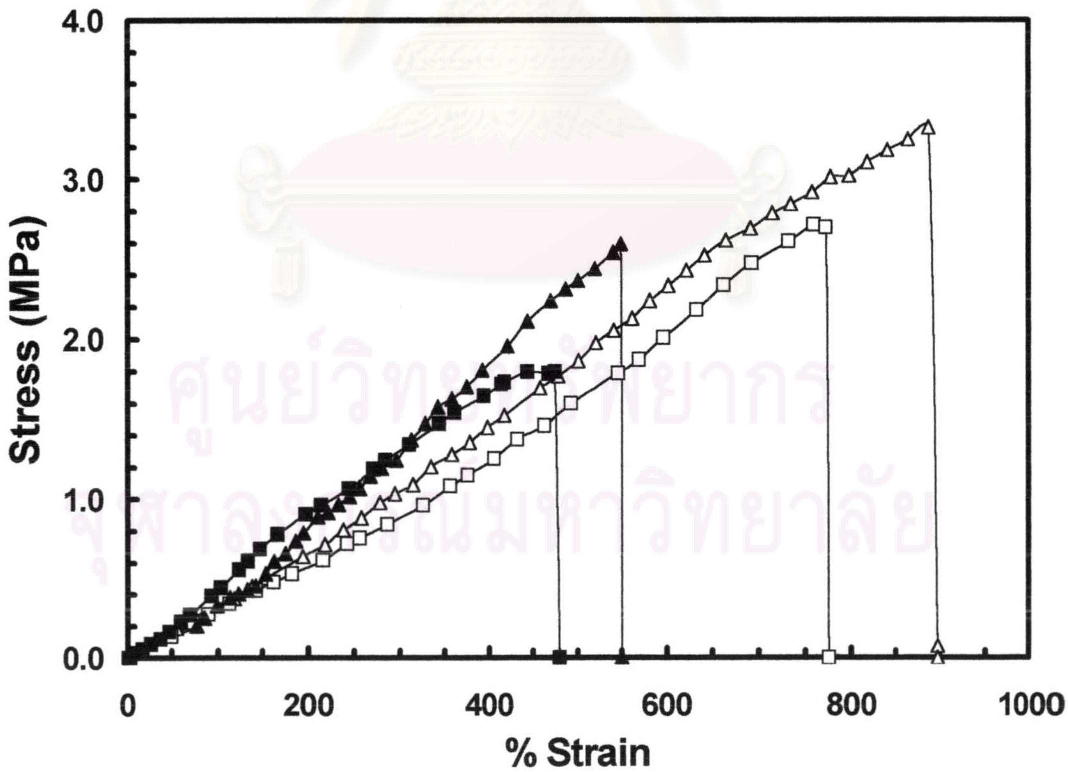


Figure 5.9 Effect of silicone resin types on stress-strain behaviors at constant curing agent concentration of 1.5 phr after three weeks (-△- RTV 585), (-□- RTV 300), (-■- RTV 3480), (-▲- RTV 4503)

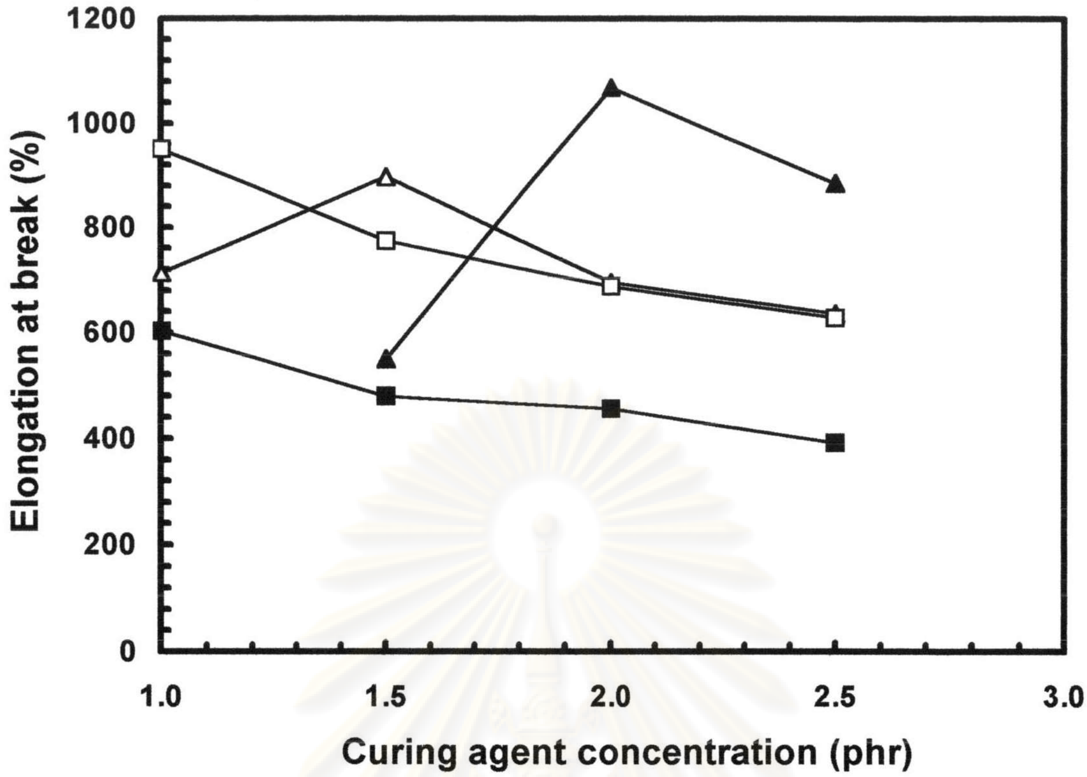


Figure 5.10 Percent elongation at break of each silicone resin as a function of curing agent concentration (RTV 585), (RTV 300), (RTV 3480), (RTV 4503)

Figure 5.10 depicts the percentage of elongation at break of each silicone resin as a function of curing agent concentration. It reveals that the effective of curing agent concentration can increase the stiffness of the elastomer. The characteristics of the percentage of elongation at break trends to decrease when more curing agents are added. The results show that decreasing the amount of curing agent leads to the softening and toughening of the elastomer. Nevertheless, it is observed that percentage of elongation at break of RTV 585 at curing agent amounts of 1.5 phr is out of trend. It can imply that the amount of curing agent 1.0 phr is not enough for chemical crosslinking so the result shows increasing of percentage of elongation at break at curing agent amounts 1.5 phr. As the same way of RTV 4503, it can imply that the suitable of curing agent concentration is 2.0 phr. Thus, the increasing of percentage of elongation at break is also corresponding to the sharp increasing of tensile strength and tensile modulus at curing agent concentration of 1.5 phr in Figure 5.7 and 5.8, respectively.

From Figure 5.9 shows effect of silicone resin types on stress-strain behaviors at constant curing agent concentration of 1.5 phr after three weeks, it can also be concluded that the most appropriate silicone resins for fabricating breast-training model are RTV 585, RTV 300 and RTV 4503 due to the relatively high elongation obtained.

5.1.2 Hardness

Hardness measurement derives from small deformations at the surface. The effect of curing agent concentration on the hardness of silicone resins is shown in Figure 5.11. The result showed that both RTV 585 and RTV 300 gave significantly higher hardness values than RTV 4503 in all cases as the curing agent concentration was increased by 0.5 from 1.0 to 2.5 phr. i.e. it increases with curing agent concentration. This is maybe due to an increase in crosslink density as explained in the previous results. Moreover, the curing agent concentration of 1.5 phr of RTV 585 presents the mechanical properties closely to the human skin. So, RTV 585 was selected to imitate the skin layer.

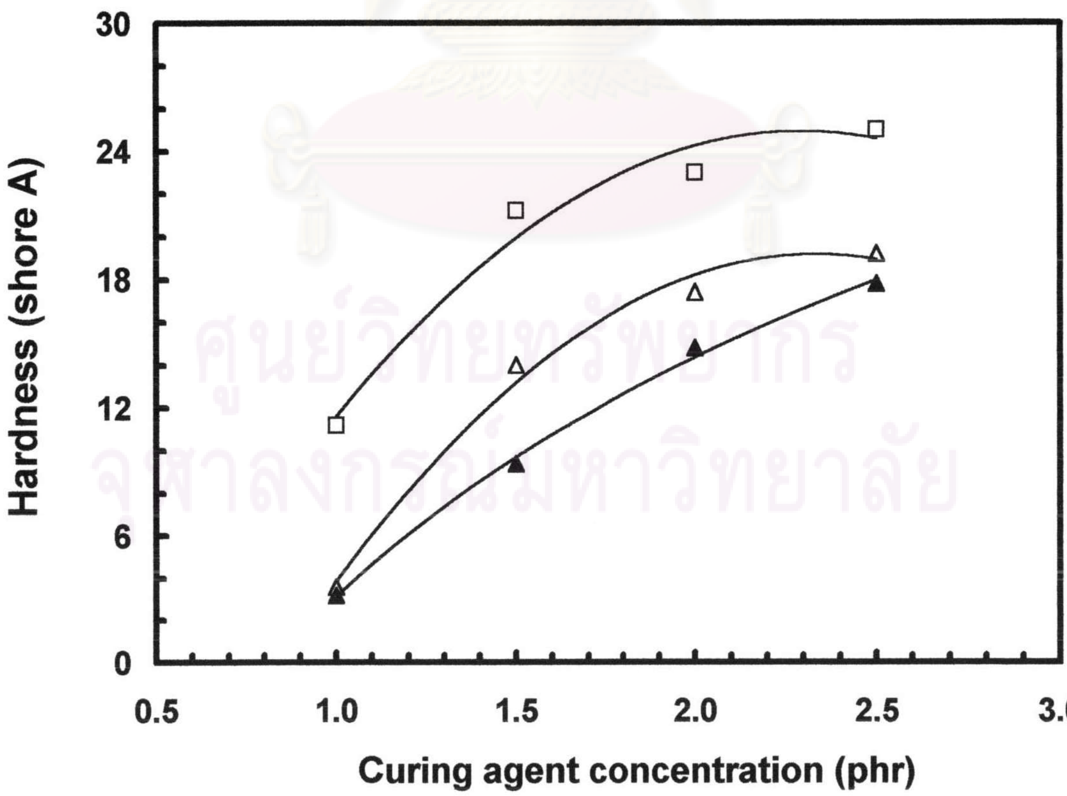


Figure 5.11 Effect of curing agent concentration on silicone elastomer hardness of different silicones (-△- RTV 585), (-□- RTV 300), (-▲- RTV 4503)

5.1.3 Tear Strength Properties

One major shortcoming of the currently used breast model is the ability to resist tear. From the previous results, tear strength was; therefore, in the three types of silicone resins. Figure 5.12 shows the elastomer's examined tear strength as a function of percentage of elongation at three kinds of silicone resin on curing agent concentration 1.5 phr. It is found that tear strength of RTV 585 is the highest value with 32.4 N/mm. and percentage of elongation at break is 234.3 %. So it can confirm that RTV 585 is suitable for imitating skin layer. On the contrary, RTV 4503 is softer and tougher than RTV 585 and RTV 300 as seen from the low tensile modulus.

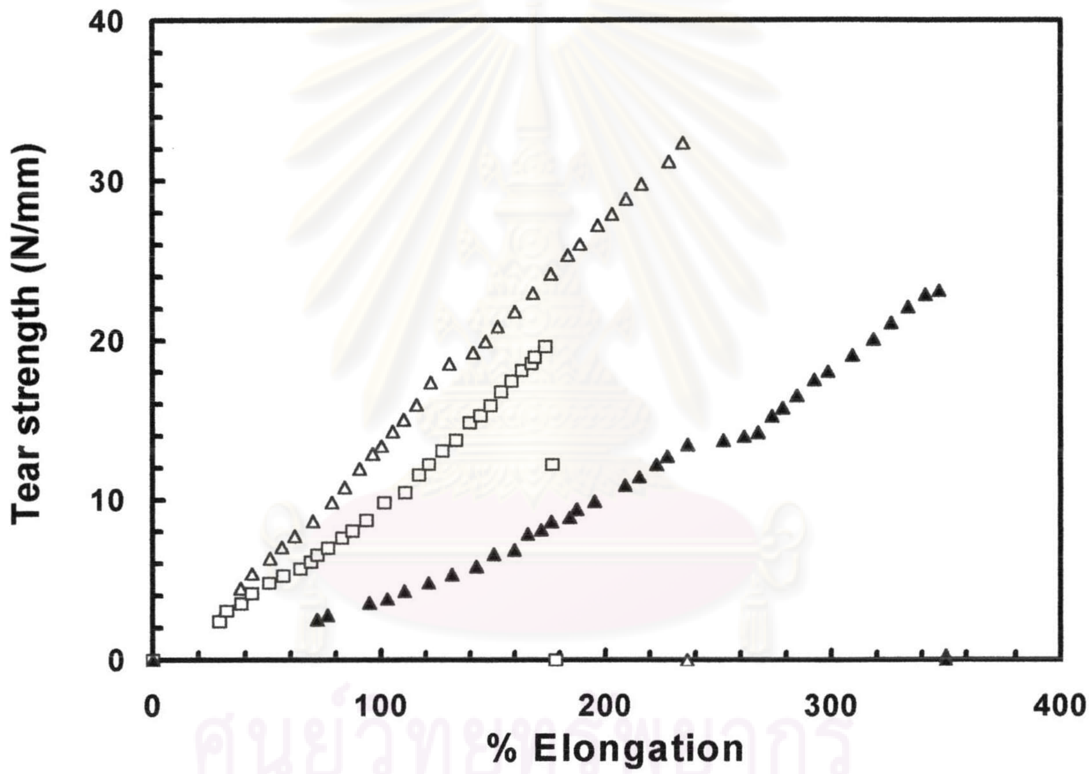


Figure 5.12 Variation of tear strength as a function of percentage of elongation of three kinds of silicone resins at curing agent concentration of 1.5 phr (△ RTV 585), (□ RTV 300), (▲ RTV 4503)

From results of hardness and tear strength, both show that RTV 4503 is not suitable for fabricating breast-training model. Another important property evaluated via the mechanical test is the crosslink density and molecular weight between crosslink.

5.1.4 Determination of Crosslink Density

Crosslink density, typically given as the average molecular weight between crosslinks(M_c), is an important factor governing the physical properties of cured thermoset resins. However, the absolute crosslink density can only be obtained when accurate values of the Flory-Huggins polymer-solvent interaction parameter are available. For thermosets one frequently employed method is to calculate M_c by using the value of modulus in the rubbery plateau region.[23,24].

According to *Rubber Elasticity Theory* the crosslink density and molecular weight between crosslinks can be calculated by the use of the relationship shown in Equation 5.1 and 5.2 [25,26]

$$\nu = \frac{G}{RT} = \frac{E}{3RT} \qquad \text{.......................................(5.1)}$$

$$M_c = \frac{\rho}{\nu} \qquad \text{...(5.2)}$$

M_c is the number-average molecular weight of the chain between two junction points, ρ is the density of silicone resin. For highly crosslinked networks, chain entanglements are not present and, under small deformations, the relationship between crosslink density and the equilibrium elastic modulus can be expressed by using the kinetic theory of rubber elasticity (Equation (5.1)). Here G = E/3 is used [27].

where E = modulus

ν = average crosslink density, mole/cm^3

R = gas constant

T = temperature, Kelvin

The effect of silicone resin types on crosslink density and molecular weight between crosslink at curing agent concentration of 1.5 phr as a function of time are shown in Figure 5.13 and 5.14

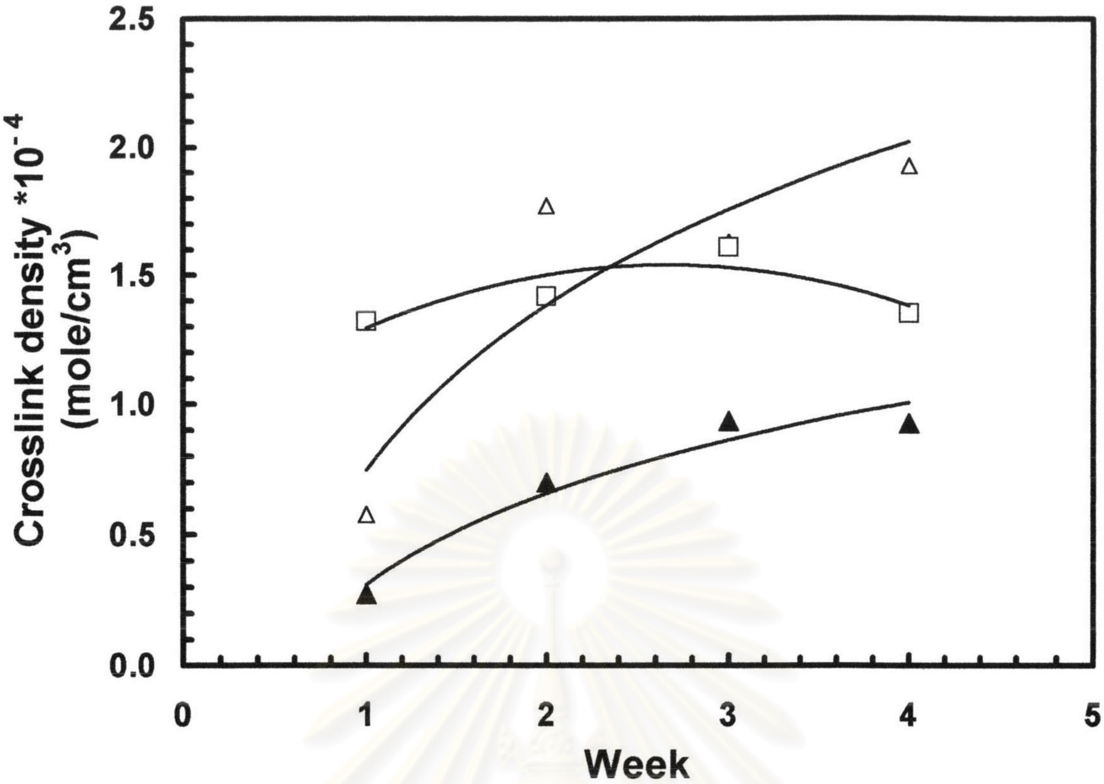


Figure 5.13 Effect of silicone resin types on crosslink density at curing agent concentration of 1.5 phr as a function of time (△ RTV 585), (□ RTV 300), (▲ RTV 4503)

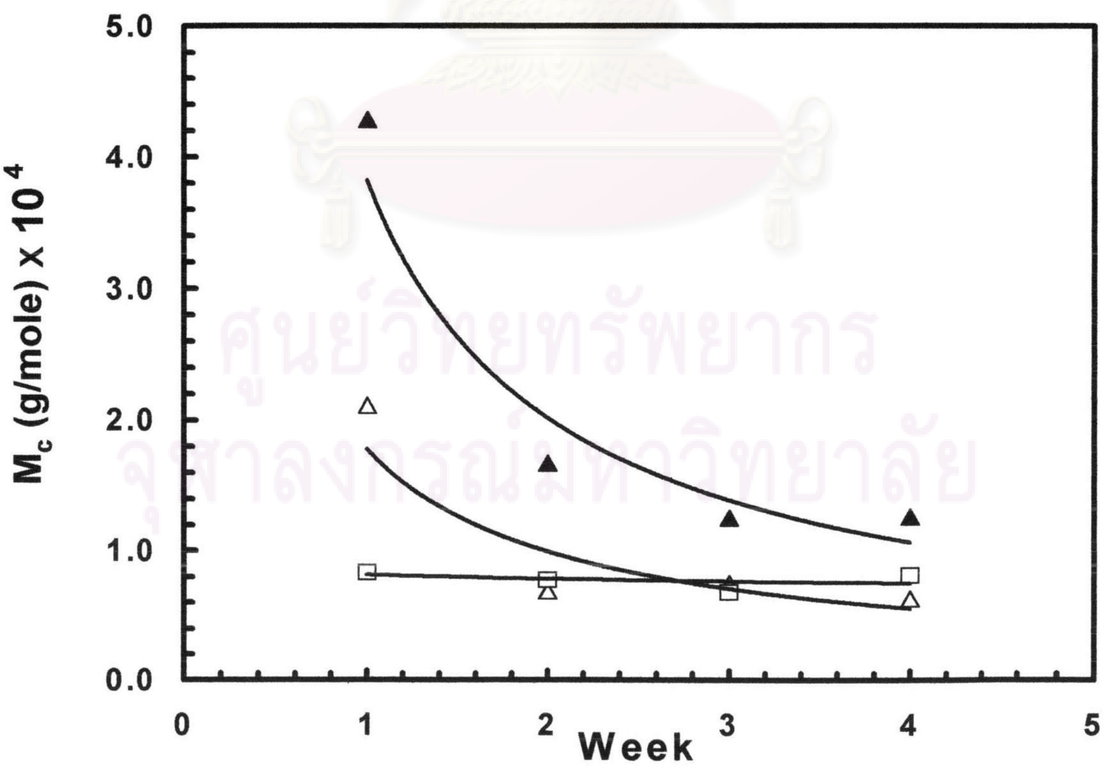


Figure 5.14 Effect of silicone resin types on molecular weight between crosslink at curing agent concentration of 1.5 phr as a function of time (△ RTV 585),(□ RTV 300), (▲ RTV 4503)

Figure 5.13 and 5.14, RTV 4503 show crosslink density and molecular weight between crosslink compare with those of silicone types. Figure 5.13 shows the change of crosslink density as a function of time of silicone resin types. It is noted that RTV 4503 presents the lowest crosslink density. Figure 5.14, the highest molecular weight between crosslink of RTV 4503 is consistent with the crosslink density. This may be molecular chain of RTV 4503 is longer than other so reactive group is fewer. It causes a lower of crosslink density.

From the previous results, they can confirm that RTV 4503 is not suitable for fabricating for breast-training model. Thus, for next experiment, RTV 585 and RTV 300 are only two silicone resin types that are determined.

5.2 THE SPECTROSCOPIC CHARACTERIZATION OF SILICONE RESIN

To imitate the real human breast, two layers of breast model with different elastomeric composition were proposed. The outer elastomeric layer acts as a human skin while the interior portion composes of gel-like silicone elastomer to imitate human dense connective glandular and adipose tissue. Besides, the model contains highly crosslinked irregular shaped silicone elastomer to function as breast tumors within the interior portion.

From previous results, they imply that RTV 585 is the most suitable for imitating skin layer because it is high tear strength and high modulus whereas RTV 300 is suitable for imitating interior portion because it has a great elastic property.

5.2.1 FT-IR Spectroscopy Silicone

5.2.1.1 Silicone resin

FT-IR spectra were taken for the molecular structure characterization of the silicone resin. FT-IR spectra of PDMS, RTV 585, RTV 300 and silicone oil are presented in Figure 5.15, 5.16 and 5.17 respectively.

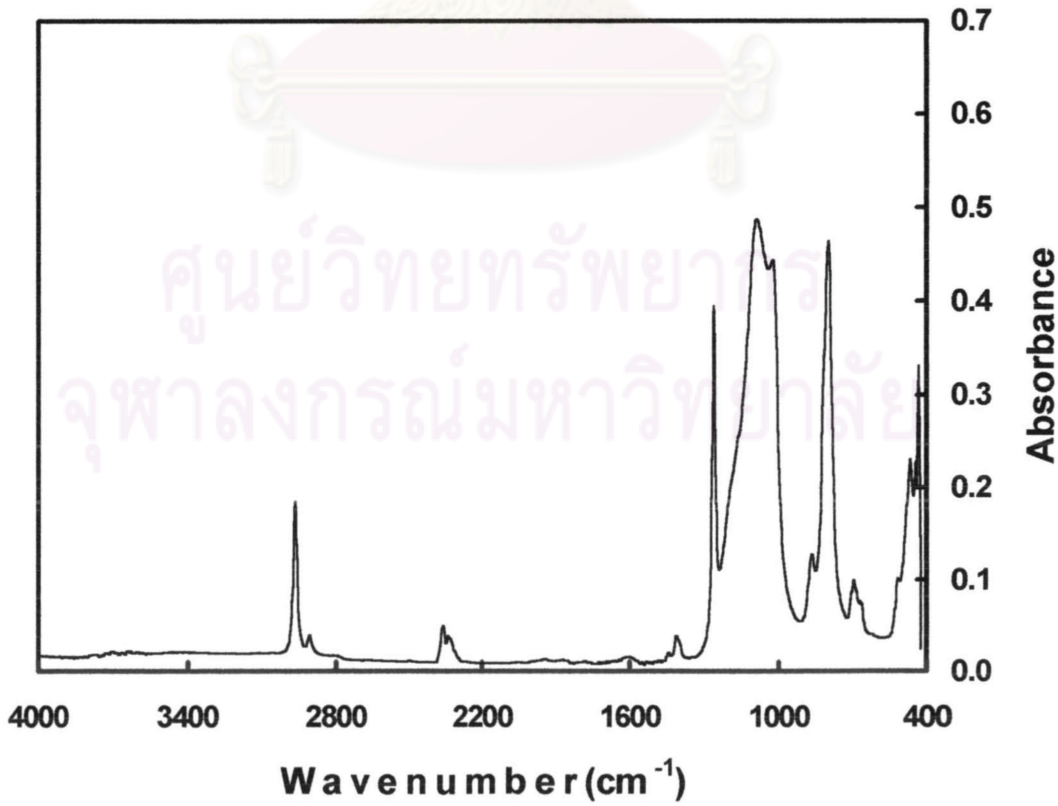


Figure 5.15 FT-IR spectrum of silicone resin RTV 585 (for skin layer)

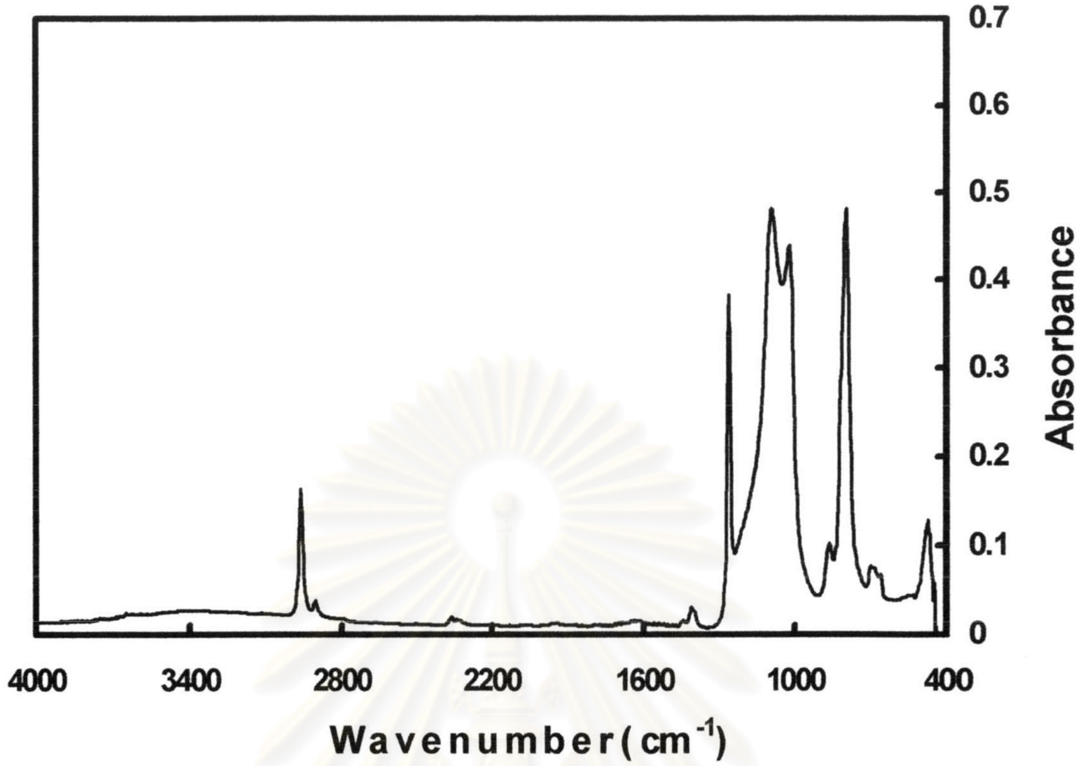


Figure 5.16 FT-IR spectrum of silicone resin RTV 300 (for interior portion)

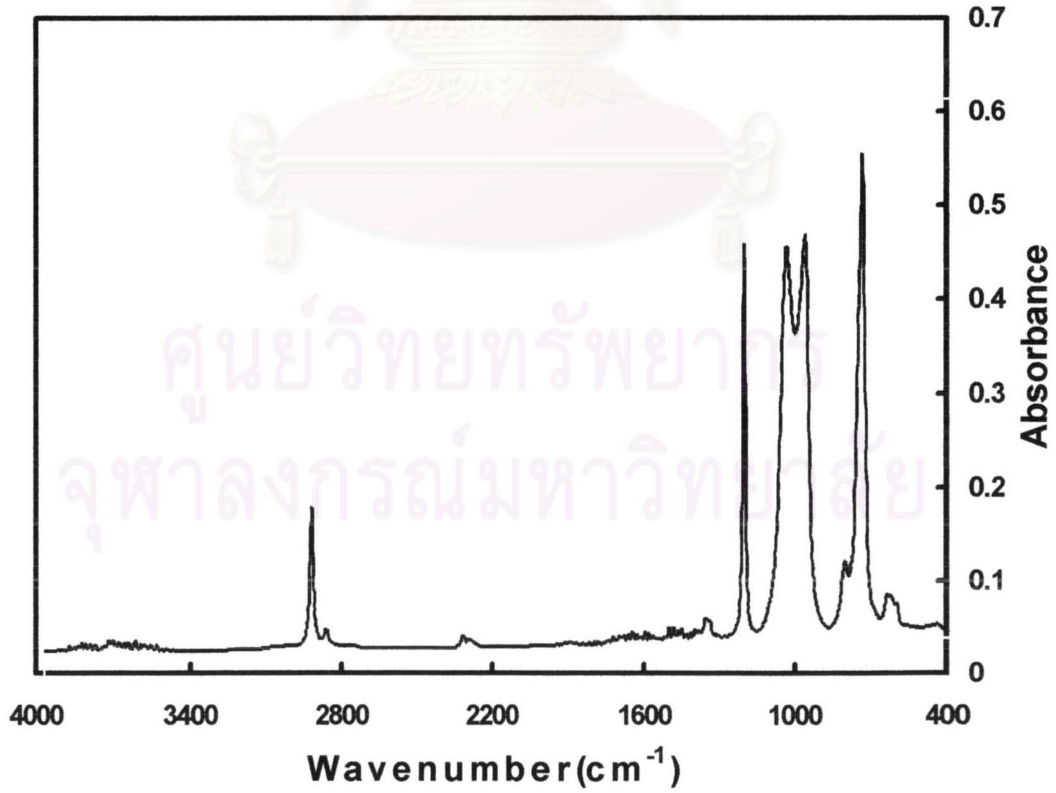


Figure 5.17 FT-IR spectrum of silicone oil (a modifier)

The strong peaks of PDMS are identified and determined by means of their IR spectra; the $Si\text{-}CH_3$ and $Si\text{-}(CH_3)_2$ groups absorb at 1259 and 800 cm^{-1}, respectively. The low frequency peak near 450 cm^{-1} is assigned to Si-O-Si out of plane bending. The bands at 800 cm^{-1} and 1000-1200 cm^{-1} are ascribed to Si-O-Si symmetric and antisymmetric stretching vibration. The bands detected at 2962 and 2904 cm^{-1} are assigned to antisymmetric and symmetric C-H stretching modes, respectively, of the $Si\text{-}CH_3$ groups on PDMS. The peaks at 2850-2990 cm^{-1} have been assigned to CH_3 and CH_2 [28].

Figure 5.15, 5.16 and 5.17 show similar absorbance spectra from 400 to 4000 cm^{-1}. This is due to the fact that RTV 585, RTV 300 and silicone oil are PDMS, but probably different in molecular weight.

5.2.1.2 Curing agent

In this work, the curing agent, that was used to form crosslinkages at room temperature, is unknown. Then, Figure 5.18 shows FT-IR spectrum of tetraethoxysilane that is the common curing agent for condensation curing system. For Figure 5.19 and Figure 5.20 is the FT-IR spectrum of curing agent of silicone resin (RTV 585) and FT-IR spectrum of curing agent of silicone resin (RTV 300), respectively. From comparison, Both present their spectrum the same, as spectrum of tetraethoxysilane so it can imply that the curing agent that are used in this work is tetraethoxysilane.

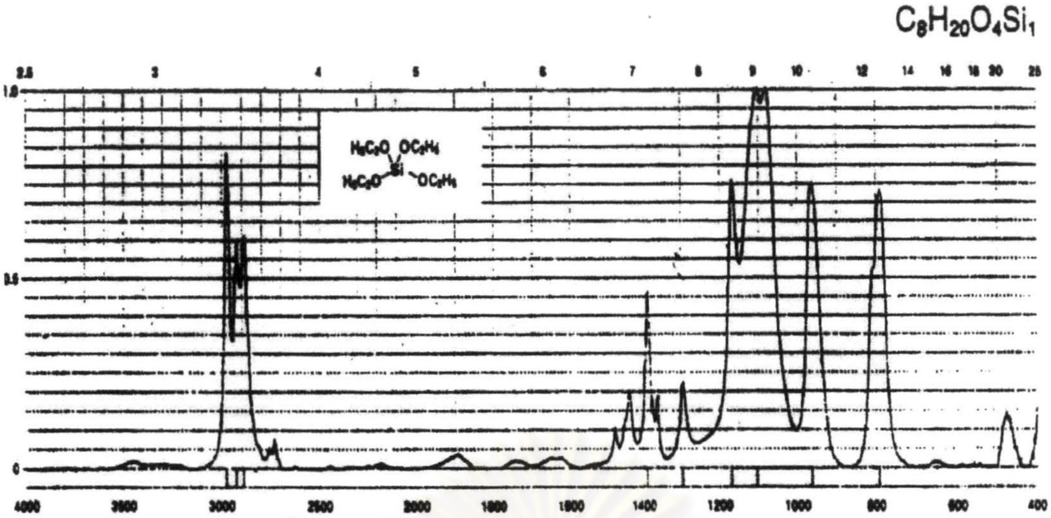


Figure 5.18 FT-IR spectrum of tetraethoxysilane [29]

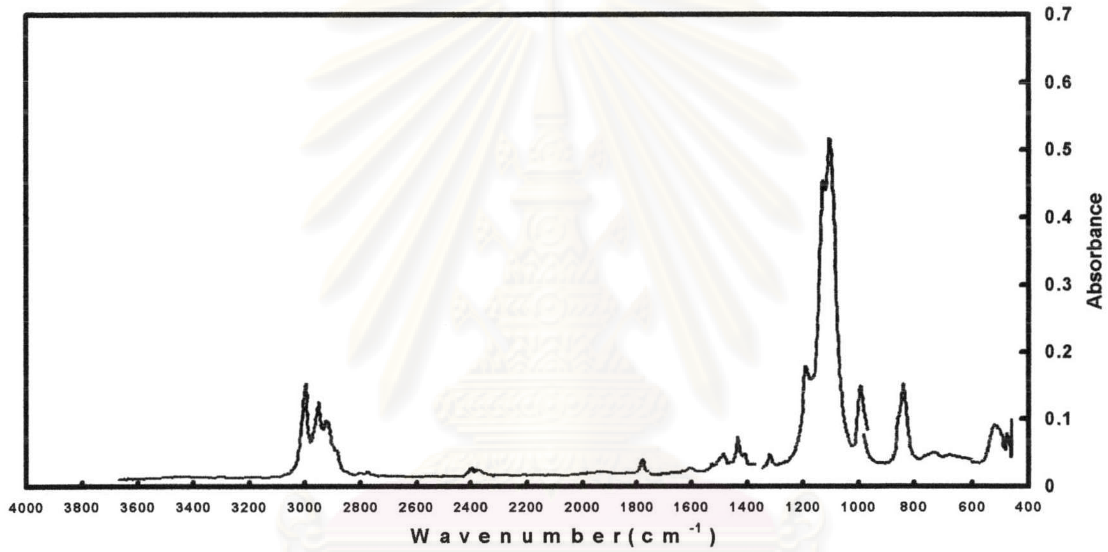


Figure 5.19 FT-IR spectrum of curing agent of silicone resin (RTV 585)

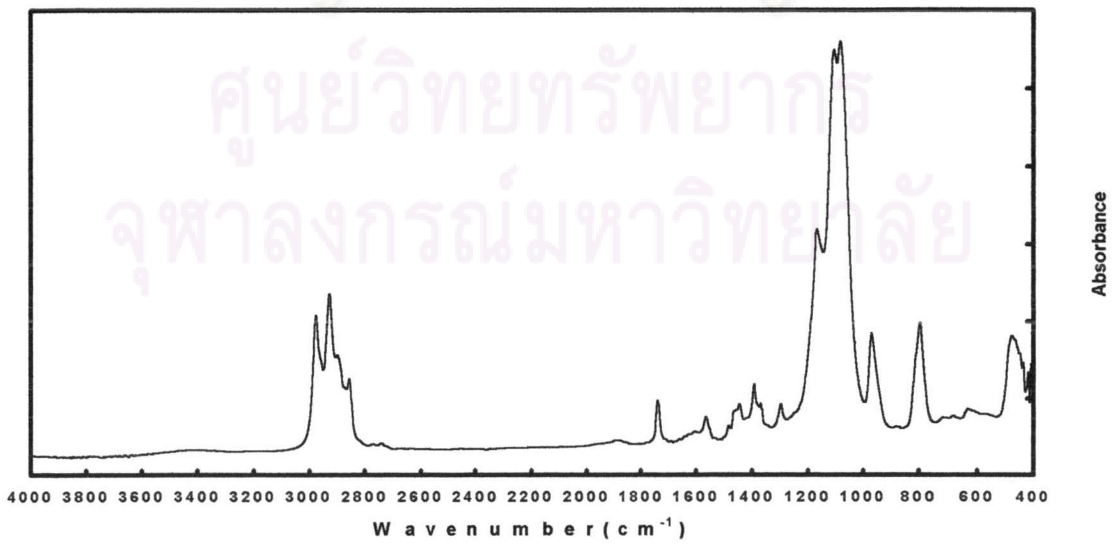


Figure 5.20 FT-IR spectrum of curing agent of silicone resin (RTV 300)

5.2.1.3 IR Spectra of silicone elastomer curing process

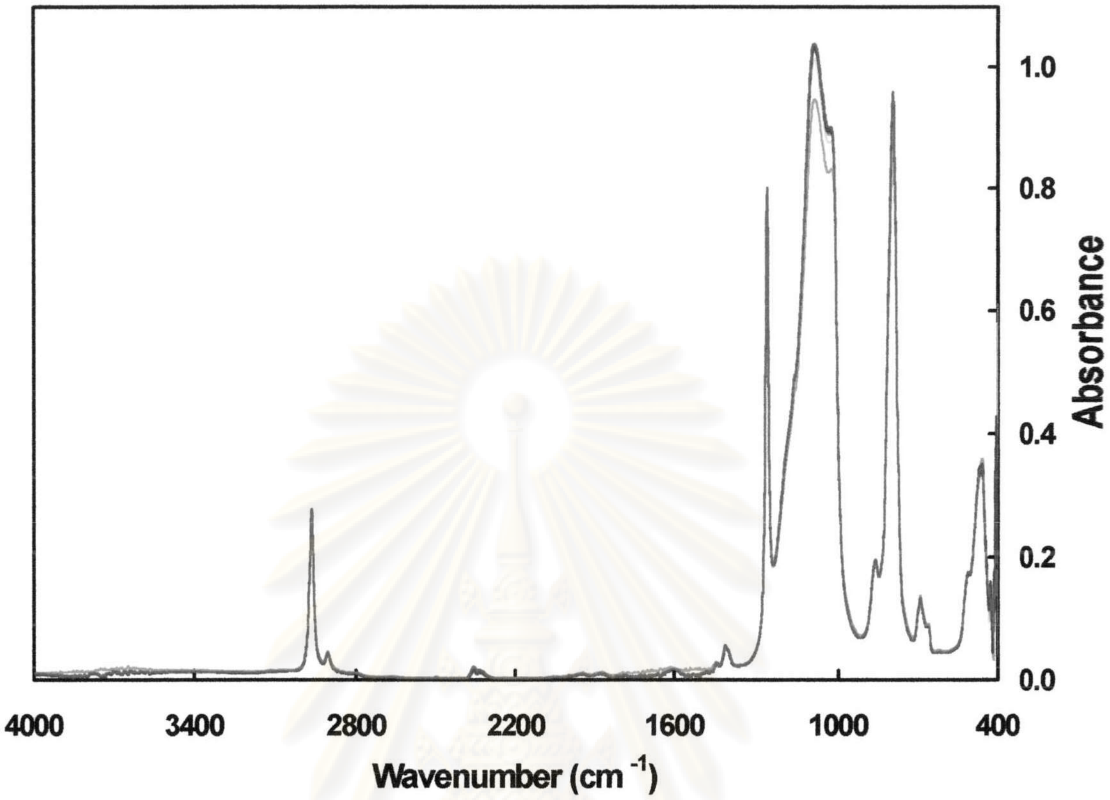


Figure 5.21 IR spectra of RTV 585 curing process at curing agent concentration 1.5 phr as a function of time (— 5 min), (— 10 min), (15 min), (— 20 min), (— 40 min), (— 60 min)

Figure 5.21 exhibits the crosslinking reaction of the spectrum of RTV 585 at 5, 10, 20, 15, 40 and 60 minutes, respectively. With increasing reaction time from 5 to 20 min, the band intensity at 1024-1085 cm^{-1} also increases rapidly as seen in the magnified pictures of Figure 5.20a-c.

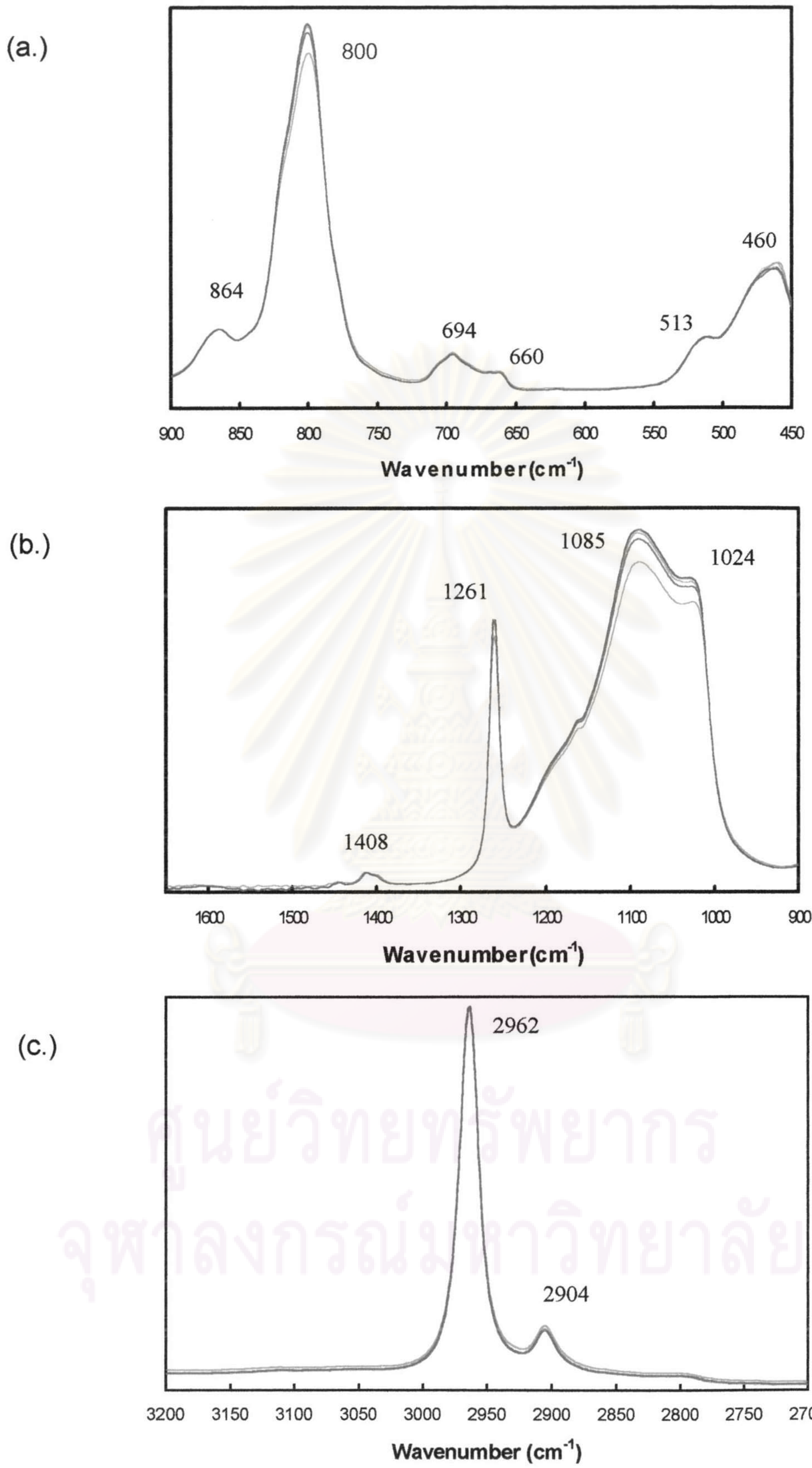


Figure 5.22 IR spectra for silicone elastomer RTV 585 (skin layer) at curing agent concentration of 1.5 phr as a function of time: (a) Spectral region 400-900 cm^{-1} (b) Spectral region 900-1600 cm^{-1} (c) Spectral region 2700-3200 cm^{-1}

From figure 5.22 a-c, each part of this figure represents a spectrum of the same condition of silicone elastomer in a different spectral region, each trace is the spectrum of the PDMS at various curing times. Figure 5.22 (a), illustrates the band at 800 cm^{-1} assigned to the symmetric stretching modes of the Si- $(CH_3)_2$ [30]. The band intensity of the Si- $(CH_3)_2$ increase from 5 to 20 min results from formation of the Si-$(CH_3)_2$ of the polymerization reaction.

Figure 5.22 (b), represents the spectral region from 900-1600 cm^{-1} for the same reaction. As curing times increase from 5 to 60 min, the band intensities of the Si-O stretching modes at 1024 cm^{-1} and Si-O-Si stretching modes at 1085 cm-1 also increase. It indicates the increase of the Si-O stretching band from 5 to 20 min as a result of the formulation of the Si-O-CH_2 entities. On the other hand, beyond 20 min, the of Si-O and Si- $(CH_3)_2$ stretching band intensities are stable. Figure 5.22 (c), indicates the decrease of the band intensity at 2904 cm^{-1}. When reaction time increases up to 20 min, the intensity of this band decreases. This band is attributed to the C-H deformation modes of the Si-CH_3 groups in PDMS.

Quantitative FT-IR analysis shows that the crosslink process of the silicone resin RTV 585 at the curing agent concentration of 1.5 phr increases for the discharge times up to 20 min. This reaction follows stepwise polymerization so small molecular functional groups rapidly loss in the first of reaction. Although polymer may be not formed completely.

5.3 PROPERTIES OF SILICONE RESIN FOR FABRICATING A SKIN LAYER OF A BREAST TRAINING MODEL

5.3.1 Crosslink Density and Molecular Weight between Crosslink

From our previous results, we can clearly see that RTV 585 is the best candidate with most properties suitable for imitating a human skin layer and it has mechanical properties at a particular level similar to real human skin. Figure 5.23 and 5.24 show a crosslink density and molecular weight between crosslink of silicone resin, RTV 585, as a function of time at different curing agent concentrations.

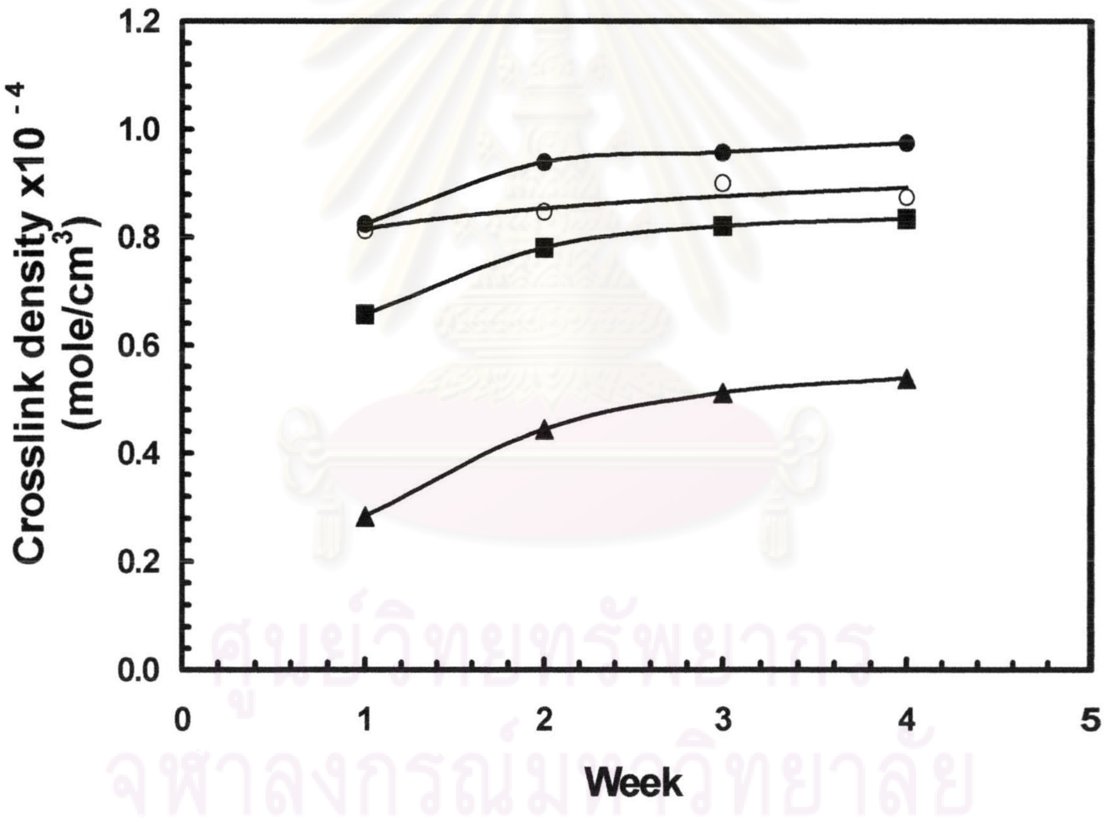


Figure 5.23 Crosslink density of RTV 585 as a function of curing agent concentrations (—▲— curing agent 1.0 phr), (—■— curing agent 1.5 phr), (—○— curing agent 2.0 phr), (—●— curing agent 2.5 phr)

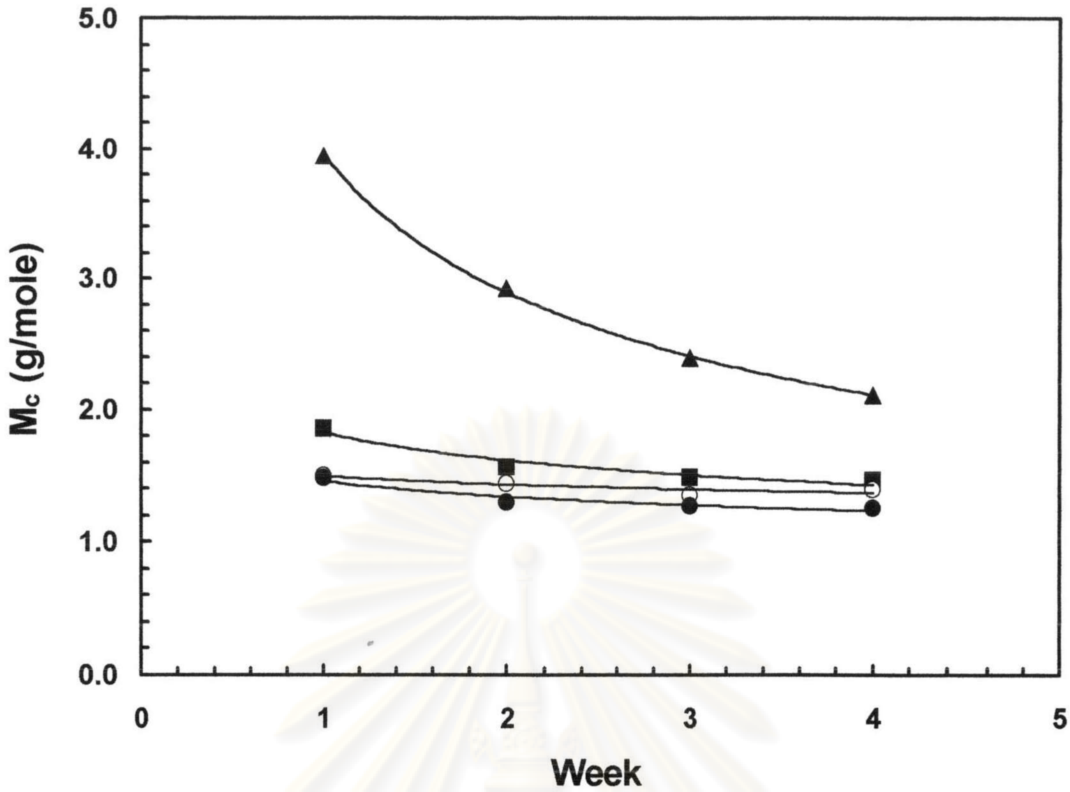


Figure 5.24 Molecular weight between crosslink of silicone resin RTV 585 as a function of curing agent concentration (—▲— curing agent 1.0 phr), (—■— curing agent 1.5 phr),(—○— curing agent 2.0 phr),

Figure 5.23 suggests an increase in crosslink density with increasing curing agent concentration whereas Figure 5.24 shows a decrease in molecular weight between crosslink with increasing the amount of curing agent. Moreover, crosslink density and molecular weight between crosslink were developing as the curing proceeded and became stable after 2 weeks. The specimen using curing agent concentration of 1.5 phr was found to be the most suitable composition for fabricating a breast model's skin layer with approximately 0.8×10^{-4} mole/cm^3 in its crosslink density.

5.3.2 Effect of Temperature on the Mechanical Properties of the Silicone Elastomer

From this experimental result, it was found that the mechanical properties of silicone elastomer increased rapidly with time at the beginning of the experiment and became stable within two weeks. Figure 5.25 shows the stress-strain behavior of silicone resin RTV 585 at curing agent concentration of 1.5 phr when treated at elevated temperature for 1 hour. The samples used were fully cured and were stored under ambient condition for three weeks.

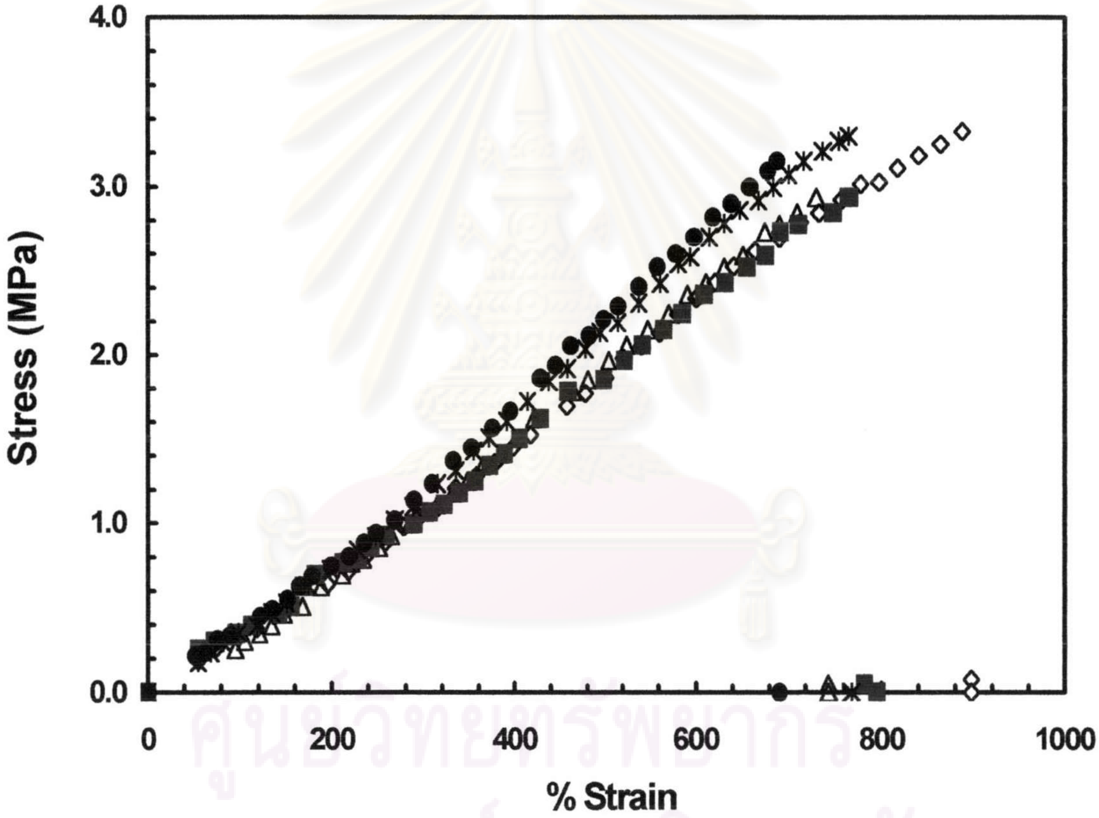


Figure 5.25 Stress-strain relations of silicone resin RTV 585 at curing agent concentration of 1.5 phr as a function of temperature (◇ room temperature), (△ 50°C), (■ 75 °C), (● 125 °C), (✱ 150 °C)

From Figure 5.25, it is evident that the heat treatment showed negligible effect on mechanical properties of the fully cured silicone elastomers. This experiment was performed in order to confirm that there are no other factors i.e. physical or chemical aging, affecting the modulus of the elastomer under evaluation. Thus, it can be concluded that measured modulus of silicone elastomer can directly be related to crosslink density of the polymer network.

5.3.3 Mechanical Properties of Human Skin

Skin Layers [31,32,33]

The skin is composed of several layers. The lowest layer is called the dermis. This layer is composed of connective tissue, blood vessels, nerve endings, hair follicles, and sweat and oil glands. The outermost or top layer of skin is called the epidermis. This is the layer of skin which we see. This layer rests on top of the dermis. The thickness of the epidermis varies with age, sex, and the location on the body of the skin. For example, the epidermis on the underside of the forearm is about 5 cell-layers thick. The mechanical measurements of human skin is given as [34]:

Skin Model	Value (MPa)
$0 < \varepsilon_{skin} < 0.54$	**3.43**
$0.54 < \varepsilon_{skin} < 0.68$	28.89
$0.68 < \varepsilon_{skin} < 1$	157.13

Notes: Ductal carcinoma (Skin thinckness = 1.0 mm.)

Several cell types are present in the epidermis. The epidermis consists of many layers: The stratum corneum or outer layer is made of flattened epithelial cells in multiple layers. These layers are called keratinized layers because of the build-up of the protein keratin in those cells. Keratin is a strong protein that is specific to the skin. This layer of skin is, for the most part, composed of cells that are almost pure protein.

The modulus of our breast model's skin layer is approximately 3.3 MPa and is close to that of the real human skin at small strain (as shown in the above table). Since most breast-training models are used at relatively low percent elongation, this property can be accepted for this application.

5.3.4 Gelation Using Rheological Measurement

Rheological behavior of substance is controlled directly by molecular structure, crystallinity, cross-linking, and polydispersity. The storage modulus is a measure of a sample's ability to store energy, and is called the elastic modulus. Elasticity is controlled by molecular structure, most notably molecular weight, molecular weight distribution, as well as cross-linking or branching.

The objective of this study is to use rheology as a tool to determine the sol-gel transition, the so-called gel point, of silicone resin. The effect of curing agent concentration on the gel time of silicone elastomer was examined and displayed in Figure 5.26

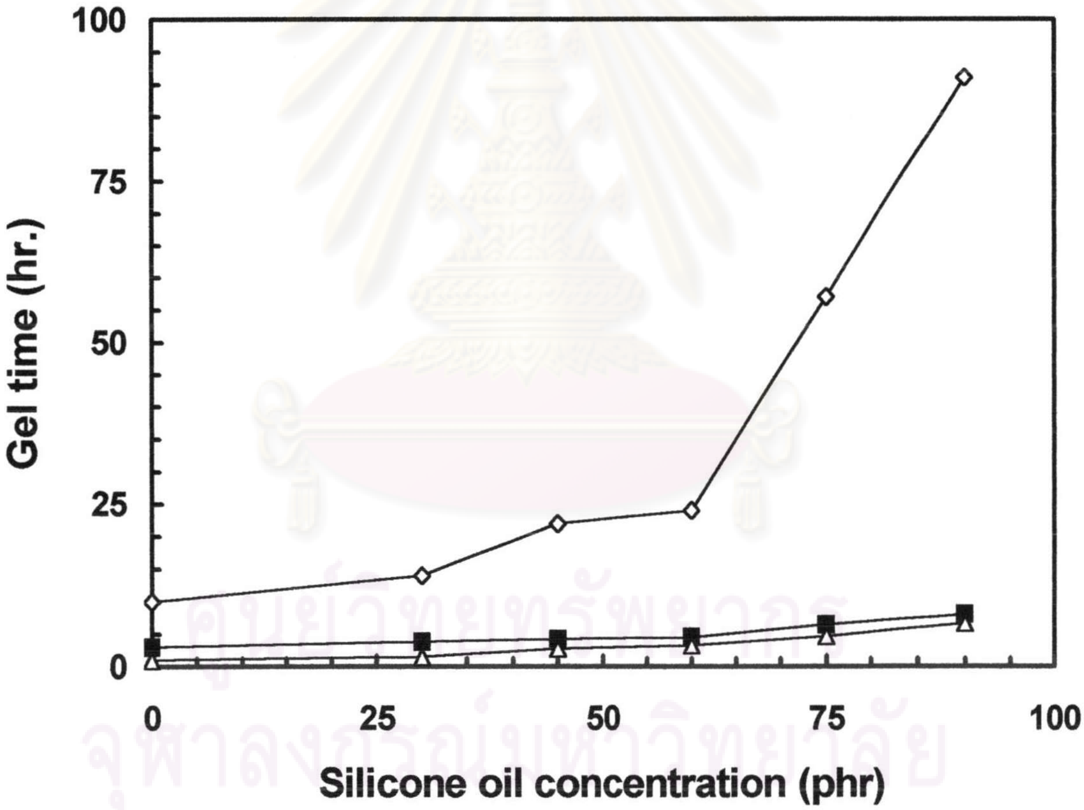


Figure 5.26 Effect of silicone oil concentration on gel time of silicone resin RTV 585 at various curing agent concentrations (—◇— curing agent 1.0 phr), (—■— curing agent 1.5 phr), (—△— curing agent 2.0 phr) : ASTM D2471

Figure 5.26 presents effect of silicone oil concentration on gel time of RTV 585 (skin layer) at various curing agent concentrations. The result showed that the resin's gel time increased as the silicone oil (modifier) increased. This can be explained as due to the fact that the silicone oil, which is a non-reactive component, suspends in the silicone resin showing the dilution effect to the resin mixture resulting in retardation of network crosslinking. Generally, it can be seen that the change in gel time depends on the concentration of the curing agent. In this study, it was observed that the gel time of curing agent at 1.5 phr. was similar to the gel time with 2.0 phr of curing agent. On the other hand, it took much longer time when the amount of curing agent was 1.0 phr. To obtain a reasonable curing time, the suggested amount of curing agent was; therefore, 1.5 phr. The gelation characteristics of our artificial skin layer (RTV 585) is shown in Figure 5.27

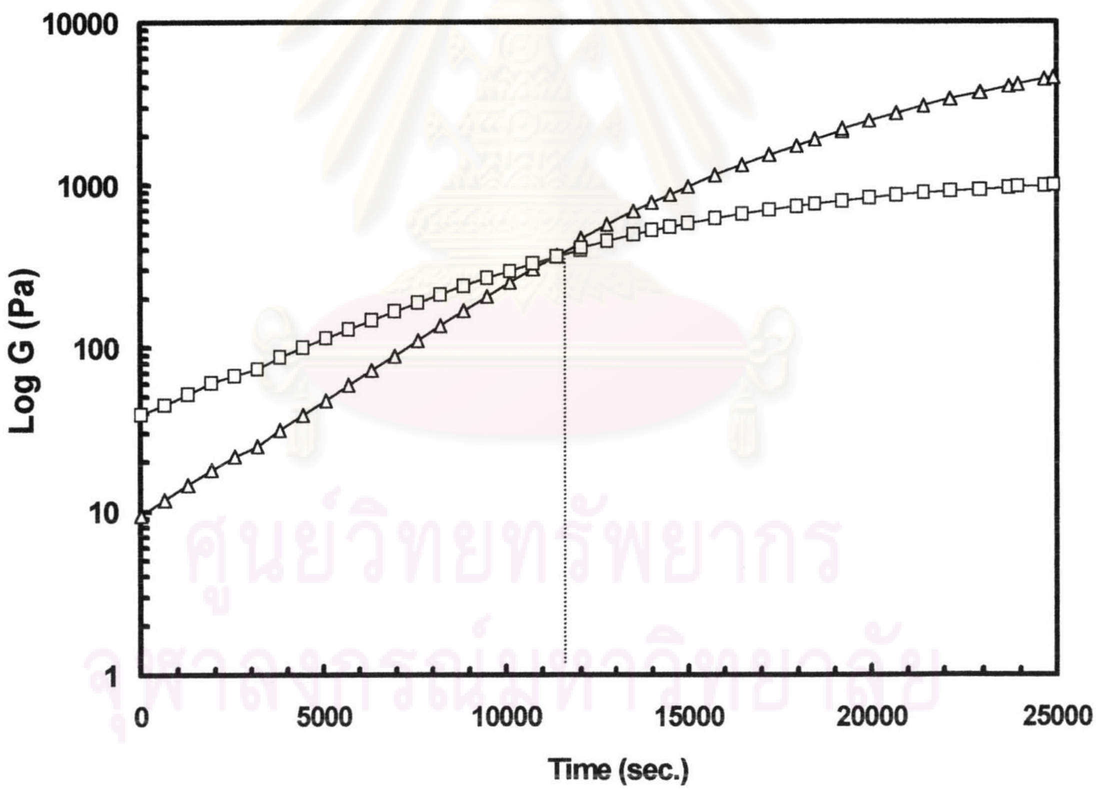


Figure 5.27 Dynamic moduli as a function of time for skin layer (RTV 585) at curing agent concentration of 1.5 phr (–△– storage modulus), (–□– loss modulus)

From Figure 5.27, the storage modulus (G′) and the loss modulus (G″) at a fixed frequency (1 Hz.) as a function of curing time are shown. In this study, the G′-G″ crossover was used as a gel point. At this point, G′ surpasses G″ though both moduli keep increase steadily. However, the increase of G″ becomes relatively slow comparing to G’, indicating the formation of an elastic network structure. Beyond the gel point, elastic effects dominate, since the network is capable of storing energy. This is why G′ increases at a more rapid rate than G″ at longer time. Eventually, G′ levels steadily as the sample becomes completely cross-linked by covalent bonds. The gel time of our elastomer from this plot is 11,200 seconds,

The effect of curing agent concentration on the rheological properties of the silicone resin RTV 585 and RTV 300 is illustrated in Figure 5.28.

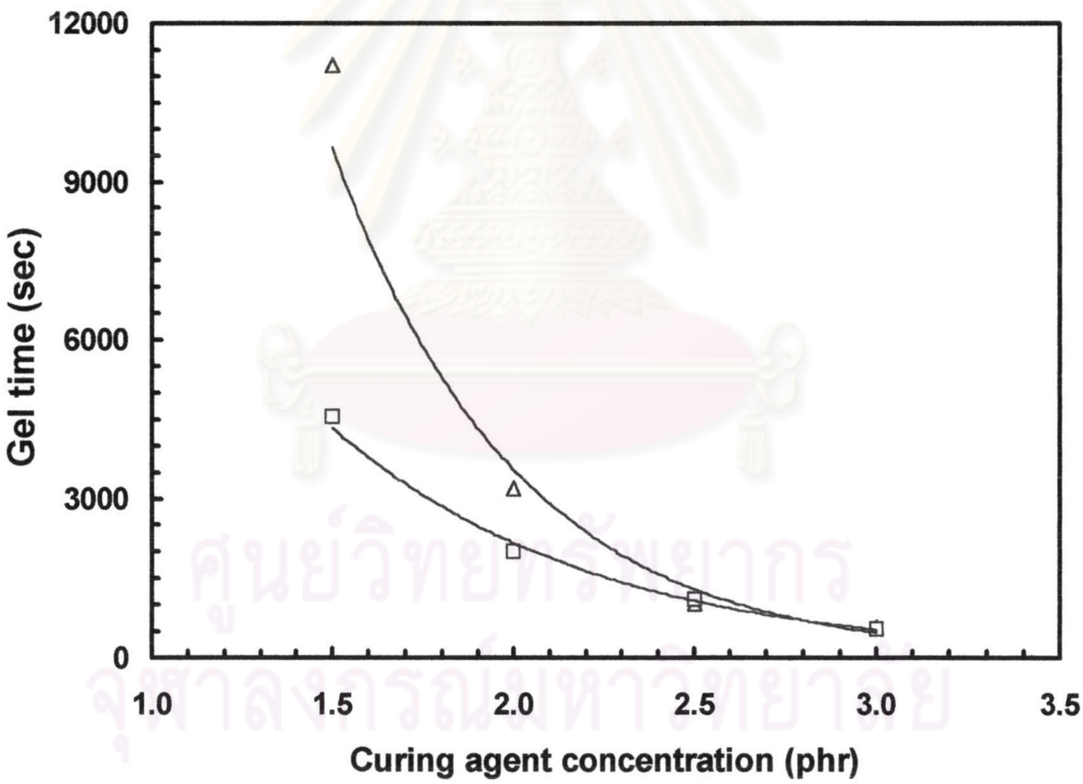


Figure 5.28 Effect of curing agent concentration on gel time for different silicone resin (△ RTV 585), (□ RTV 300)

Figure 5.28 shows the effect of curing agent concentration on gel time of two types of silicone resins used to fabricate the breast model. From the results, the gel time decreased with increasing curing agent concentration due to the increasing rate of the crosslinking reaction. Moreover, the rate of the crosslinking of RTV 300 was found to be faster than RTV 585. RTV 300 is; therefore, suitable for fabricating the interior portion of breast model because it can compensate the retardation reaction from the addition of silicone oil in this part.

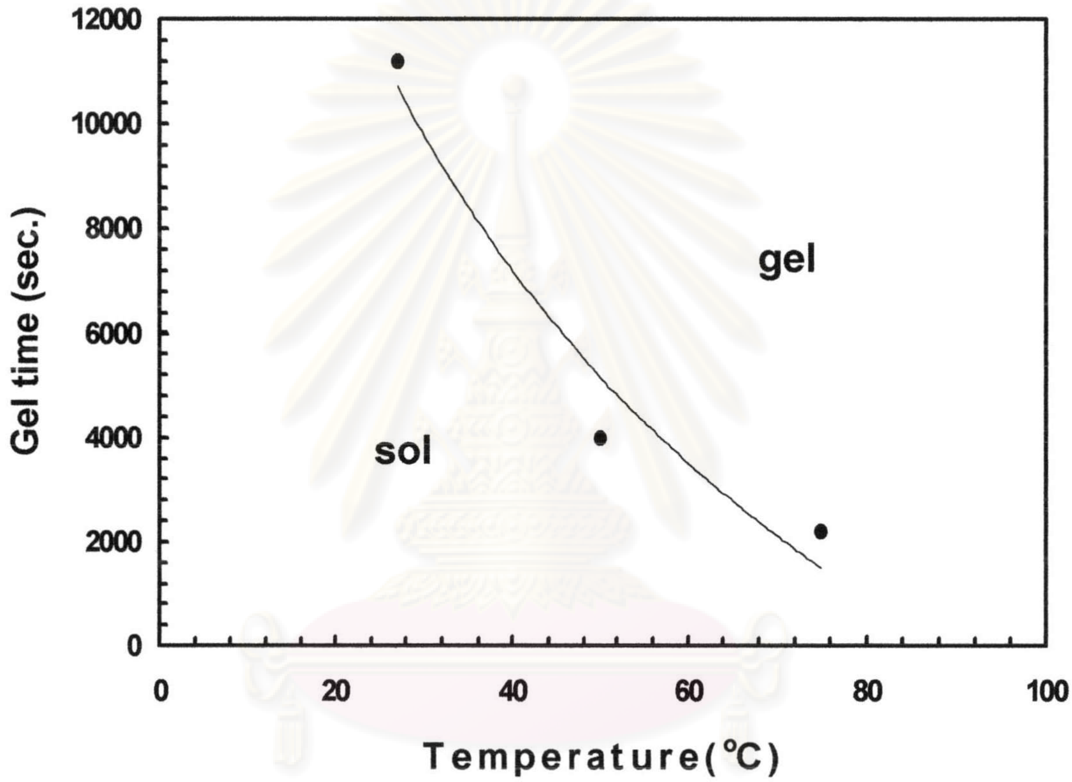


Figure 5.29 Effect of temperature on gelation of silicone resin RTV 585 (for skin layer) at curing agent concentration of 1.5 phr

Figure 5.29 shows an effect of temperature on gelation of silicone resin RTV 585 at curing agent concentration of 1.5 phr. The gel time decreases when curing temperature increases. This means temperature can significantly accelerate the curing process of this silicone elastomer. The behavior is found in typical RTV systems and is useful in some applications to minimize the processing time [35].

5.3.5 Prediction the Gelation Process

From the previous results, it is observed that temperature can accelerate the gelation of silicone elastomer. An Arrhenius model is frequently used to predict the gelation process of crosslinked network [36]. The relation between gel time, t_{gel}, the temperature is given by the following equation 5.3:

$$t_{gel} = Ae^{-\frac{\Delta E}{RT}}$$

$$\ln(t_{gel}) = \ln A + \left(-\frac{\Delta E}{RT}\right) \qquad \text{..(5.3)}$$

where A is a frequency factor (constant), ΔE is an activation energy with a unit in kJ/mol, R is a gas constant and T is temperature in Kelvin

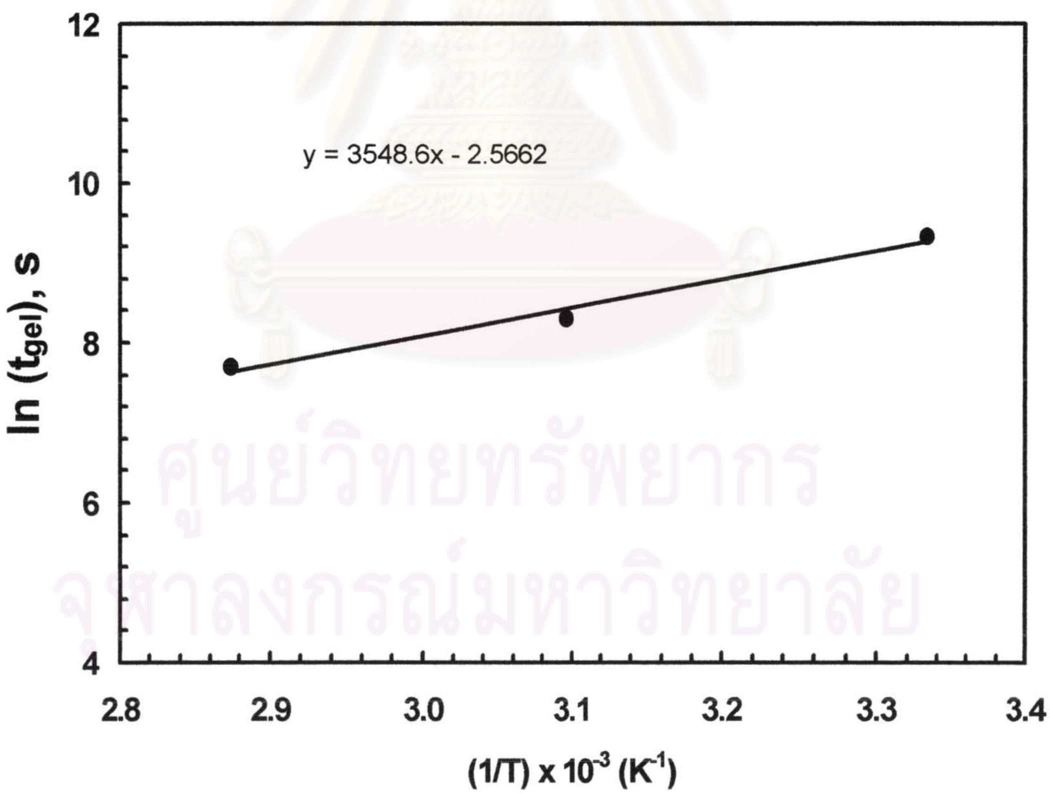


Figure 5.30 Arrhenius plot of gelation behavior of silicone resin RTV 585 at the curing agent concentration of 1.5 phr. (for skin layer)

Arrhenius plot of this gelation process in Figure 5.30 shows slope or activation energy and constant value in the gelation process of curing silicone elastomer. It shows the plot yields a constant A = 7.768 x 10^{-2} s and activation energy, ΔE = 29.5 kJ/mol The values are in good agreement with those of typical RTV resin reported elsewhere [37]. Therefore the gel equation for predicting the gelation process of our silicone elastomer at the desirable temperature can be given by the following equation 5.4:

$$t_{gel} = 0.07768e^{\left(\frac{-29.5}{RT}\right)} \qquad \text{.................................(5.4)}$$

From the results of effect of temperature on gelation, they found that temperature can accelerate the gelation of this process. Furthermore, mechanical properties of silicone elastomer when treated with temperature at 75 °C were studied. Figure 5.31 shows stress-strain behavior of silicone resin RTV 585 at curing agent concentration of 1.5 phr at various cure times for curing temperature 75 °C.

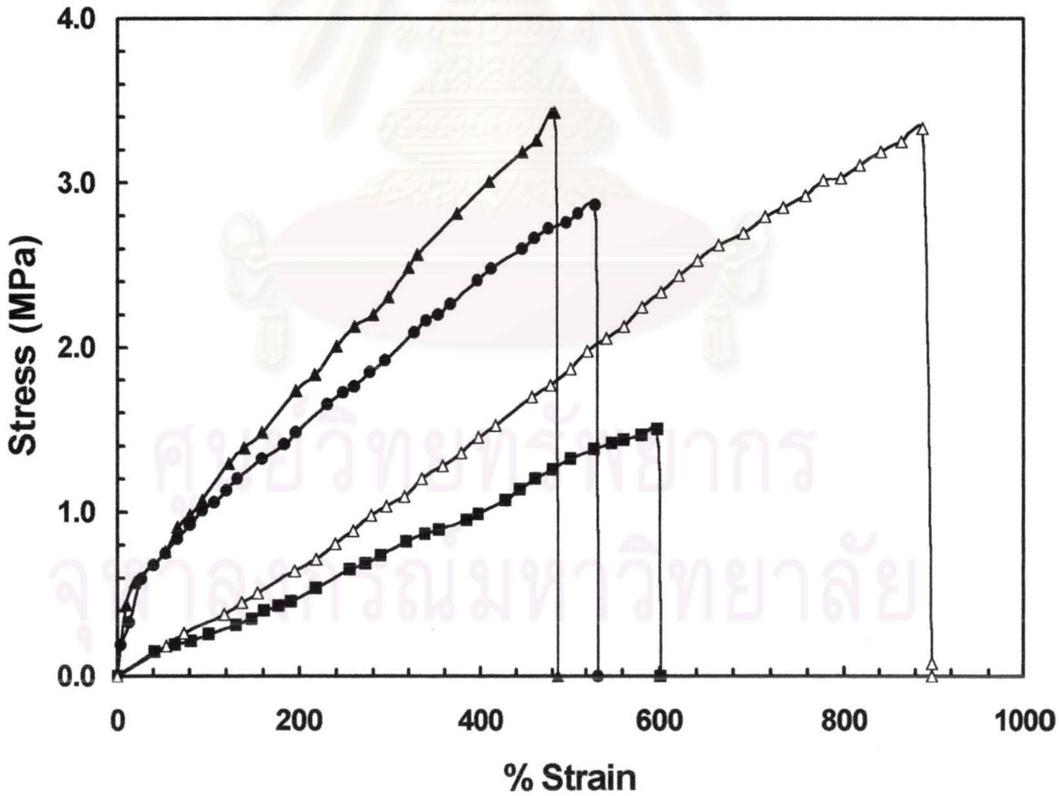


Figure 5.31 Stress-strain behavior of silicone resin RTV 585 (for skin layer) at curing agent concentration of 1.5 phr at various cure time for curing temperature 75 °C (-■- 8 hours), (-●- 12 hours), (-▲- 14 hours), (-△- 3 weeks at room temperature)

From Figure 5.29, it shows that a fast process for PDMS networks is developed which is potentially important from the standpoint of commercial application. Figure 5.31 presents the stress-strain behavior of silicone resin RTV 585 at curing temperature 75 °C as a function of cure time. It is observed that the tensile strength increase with cure time and after approximate 14 hours, the stress becomes slightly increase. From this result observes that the percentage of elongation of heat-treated silicone elastomer trend to decrease when compare with curing at room temperature. Thus, it can conclude that it should not use heat-treated silicone elastomer because the elongation is one of the most important factor for fabricating skin layer of breast model.

5.4 PROPERTY ANALYSIS OF SILICONE RESIN FOR FABRICATING INTERIOR PORTION OF BREAST TRAINING MODEL

Gel time of the breast model's interior portion (plasticized RTV 300) is illustrated in Figure 5.32.

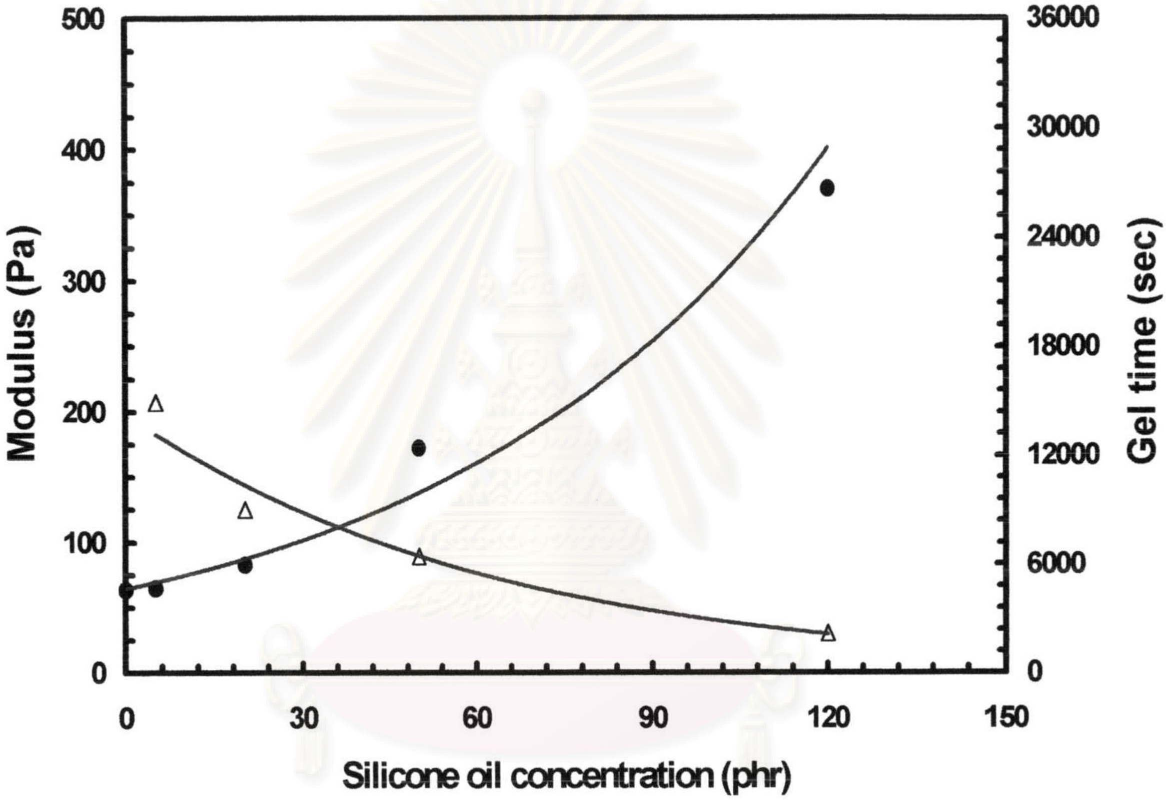


Figure 5.32 Effect of silicone oil concentration on modulus and gel time of inner layer at curing agent concentration of 1.5 phr (△ modulus), (● gel time)

Figure 5.32 reveals that the rate of gelation of RTV300 increased with the increment of silicone oil concentration. On the other hand, the modulus can be significantly decreased with increasing silicone oil concentration. This implies that the silicone elastomer's properties can be altered from hard to much softer material when the appropriate amount of silicone oil concentration is added.

Figure 5.33 and Figure 5.34 show the effect of curing agent concentration and silicone oil concentration on gel formation of interior layer (RTV 300).

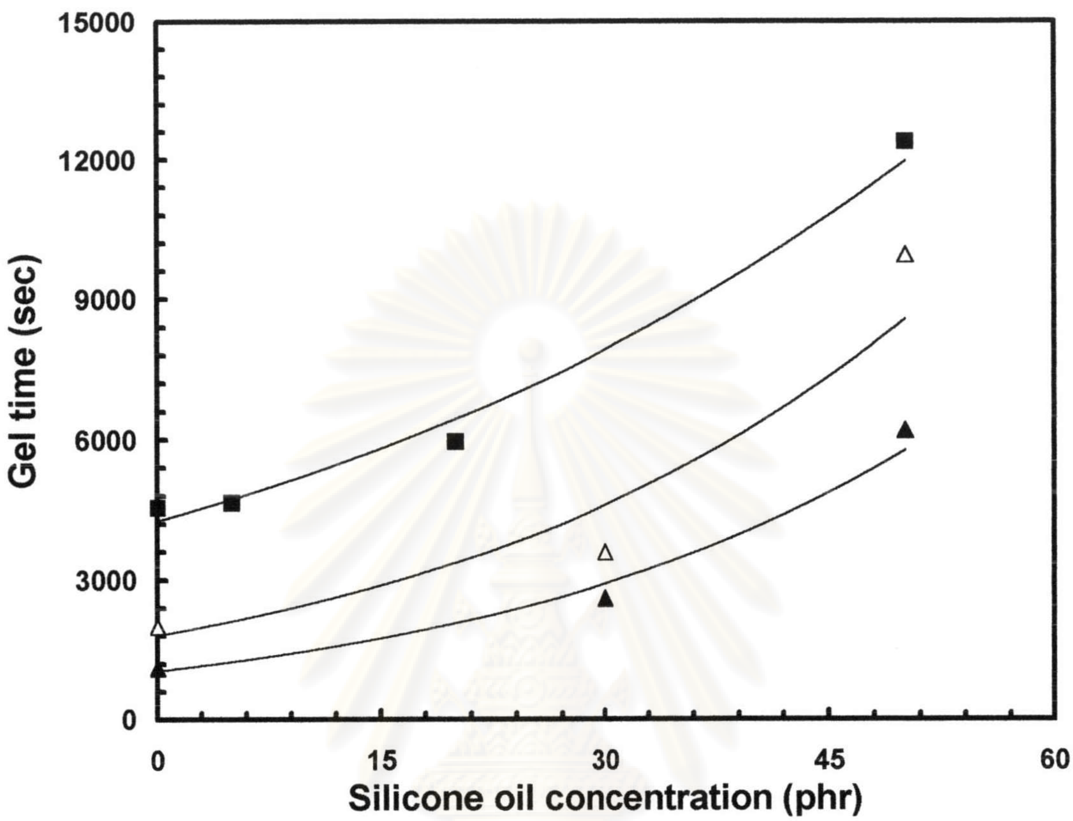


Figure 5.33 Effect of curing agent concentration on gel time of inner layer at various silicone oil concentration (■ curing agent 1.5 phr), (△ curing agent 2.0 phr), (▲ curing agent 2.5 phr)

From Figure 5.33, it is clearly seen that gel time tend to increase when greater concentration of the curing agents were added. The relation is non-linear as the effect of silicone oil quantity on prolonging the elastomer's gel time seems to be more pronounced at higher oil content. The effect of silicone oil concentration on gel time of inner portion of breast model at various curing agent concentrations is shown in Figure 5.34.

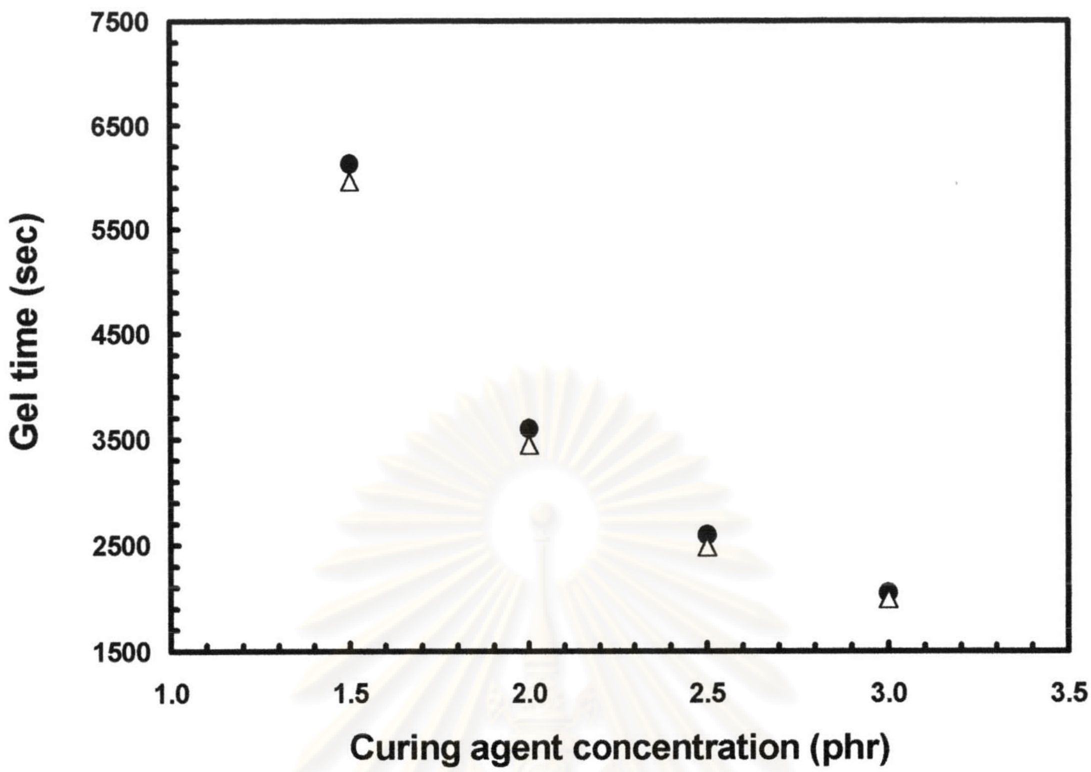


Figure 5.34 Effect of silicone oil concentration on gel time of inner layer at various curing agent concentration (△ oil 20 phr), (● oil 30 phr)

Figure 5.34 indicates an increase in silicone oil content slightly influences the gel time when compare with the change in the curing agent concentration as seen in Figure 5.33. The finding is useful for adjusting the properties of silicone resins to yield soft-humanlike feel which can be obtained either by lowering the curing agent concentration, but significantly affect its gel time, or by addition of silicone oil with lesser effect on the specimen's gel time.

The interior portion of this breast model is a gel-like material. Consequently, we can not test the mechanical properties in the same way as that of the skin layer specimen. The method that was used in this work for the property evaluation of the interior portion of model is the statistical analysis by breast cancer experts. The results of this analysis are shown in Table 5.2

Table 5.2 Breast model samples for statistical analysis by breast expert examiners

*Sample No.	Silicone oil concentration (phr)	Curing agent concentration (phr)
1.	**130**	**1.5**
2.	**130**	**1.4**
3.	**130**	**1.3**
4.	120	1.5
5.	120	1.4
6.	120	1.3
7.	100	1.5
8.	100	1.4
9.	100	1.3

* same composition as of the skin layer

Members of the breast model's examiners:

Faculty of Nursing

1) Assoc. Prof. Dr. Puangthip Chaiphibalsarisdi

2) Assist. Prof. Dr. Suchada Ratchukul

3) Dr. Chompunut Sopajaree

Faculty of Medicine

4) Assist. Prof. Dr. Unnop Jaisamrarn

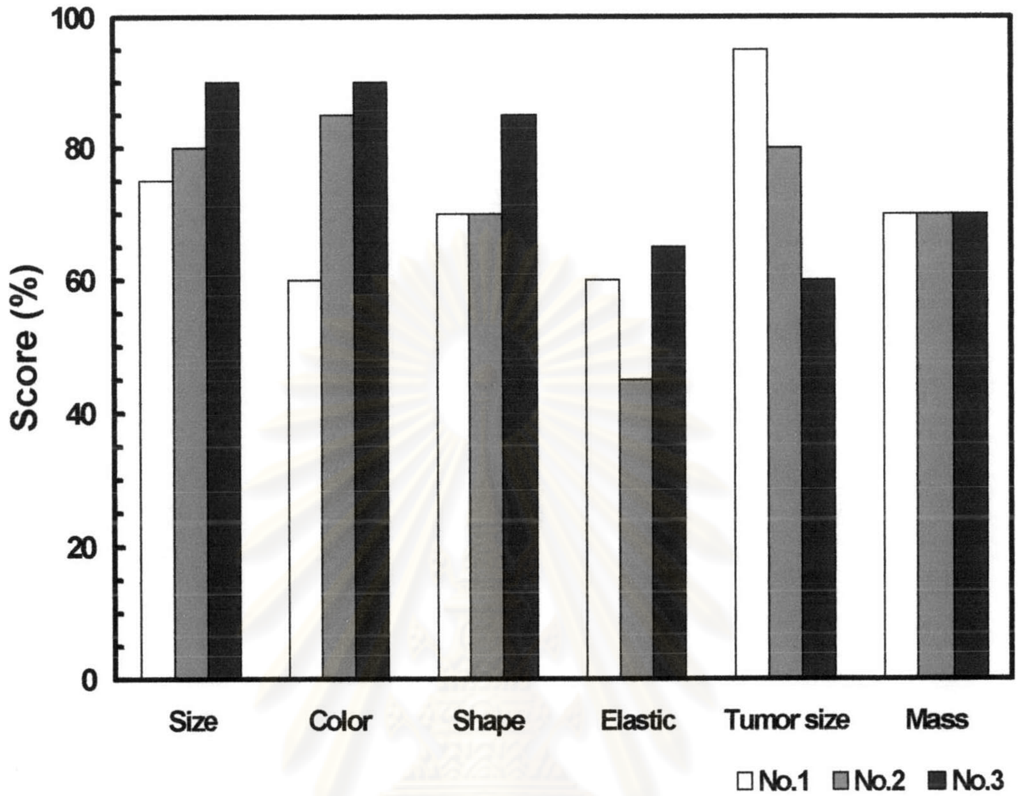
CU Hospital

5) Mrs. Orawan Sudthipongkiat (Nurse)

Note: all experts are affiliated with CU.

Table 5.2 shows the breast model samples for statistical analysis by breast expert examiners. Firstly, all nine specimens were preliminarily investigated by the experts number 2 and 3 to select the samples that closely imitate the human breast. Three models out of those nine specimens were recommended by the examiners for further evaluation. They are sample No. 1, 2 and 3.

Poll results of breast model



Sample No.	Silicon resin (parts)	Silicone oil (parts)	Curing agent (parts)
1.	100	130	1.5
2.	100	130	1.4
3.	100	130	1.3

From the poll results of the five breast examiners, the most suitable composition of interior portion is the composition of model sample No. 3. From the polls show the percentage of size, color and shape of model No. 3 are higher than 80 %. Thus, it implied the best elastic property, which was compared with others.