Coagulant Dipping Time and Temperature Optimisation for Latex Glove Uneven Coating Investigation

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Abstract
Powdered glove is produced by natural latex with the aid of coagulant. The composition of the coagulant contains wetting agent, calcium nitrate as coagulant and anti-tack agent. Generally wetting agent also known as surfactant that cause foam and resulted uneven wall thickness in glove production. As a result, the objectives of this research that needs to be achieved are selecting the suitable wetting agent sample that could be used such as sample E and sample T as well as optimising the parameter such as temperature of coagulant, weight percentage of wetting agent and coagulant dipping time to reduce of uneven glove production. In order to achieve the objective, the methodology for this research involve foam height test, cloud point test, wetting agent charactherisation using Fourier Transform Infrared Spectroscopy (FTIR), surface tension test, full factorial design of the experiment, glove thickness test, tensile strength test, glove weight test and response surface methodology analysis. Throughout the wetting agent charactherisation, sample T is chosen instead of sample E due to similar bonding of the wetting agent. With the completion of methodology, the result is recorded and plot the graph as well as contour graph with colour bar for analysis purpose. The surface tension of coagulant and tensile strength of glove sample are able to meet the requirement with the variation of wetting agent amount. With the graph being analyse, concept verification can be completed. While contour graph that being analyse, optimisation parameter can be determine to achieve the desired objective. As a result, the optimise parameter are 0.0175 wt% of wetting agent and about 5 seconds dipping time at 63 °C. Throughout the optimum parameter that being determined, the average thickness is 0.09 ±0.004 mm with 11.33% error of thickness by comparing to 0.1mm thickness of ASTM standard. Hence, the objective of this research is achieved.

Keywords: Wetting agent, Uneven wall thickness, Coagulant, Foaming height, Surface tension

1. Introduction

In the present day, the glove has become an essential for daily activities such as housework and surgery operation. The purpose of these is basically to prevent infection and it is made up of natural latex. An example of glove that needs to be used in medical field such as surgical glove. This glove is mostly used for the doctor to treat patients. In order to produce this surgical glove, natural latex is required that can be obtained from Hevea Brasiliensis tree through bark tapping [1]. Besides, the thickness of the glove is essential in order to avoid pinhole of the glove. An uneven wall thickness or so called as 'fisheye' defect that can be refer in Figure 1. This is due to there is the presence of uneven adherence of latex on the mold. Former is basically referring to the mold that having the shape of a hand and it is used for glove production [2].

Figure 1: 'Fisheye' defect located in powdered glove.

In addition, 'fisheye' defect have a tendency to have a failure in tensile strength. For example, a glove that having variation in tensile strength would be easily torn off into pieces or difficulty when donning. With the 'fisheye' defect', the production of the powdered glove would have high rejection rate on the production. In order to reduce these issues, studies on the production of the powdered glove are necessary. However, there are various causes that could lead to 'fisheye' defect. The various causes are shown in Figure 2 below:

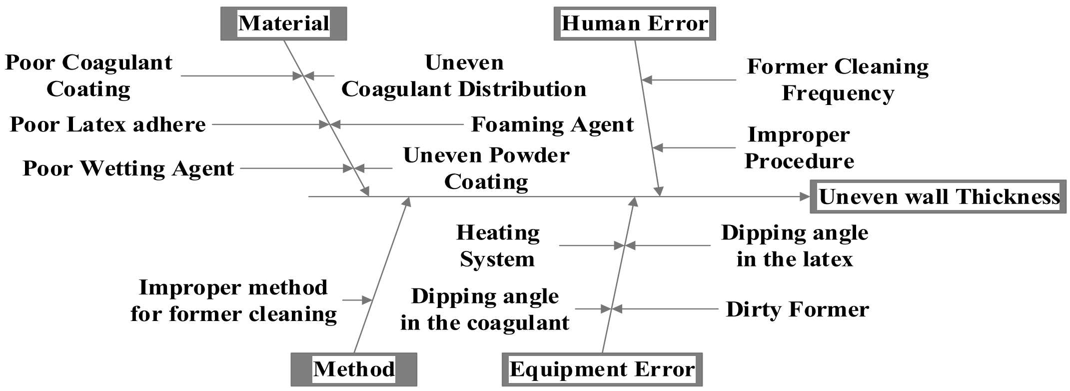

Figure 2: Ishikawa diagram for uneven thickness of glove [2-3].

By referring to Figure 2 above, 'fisheye' defect can be caused by human error, the material in the process line, equipment used and method. In term of the material in the process line, the coagulant is used for forming a coagulant layer so that latex able to adhere to the surface of the mold. An inefficient coagulant that used in the glove production would cause weak adherence of latex. For example, ammonia nitrate is one of the inefficient coagulants. Hence, calcium nitrate coagulant is mostly used in glove production where it has good adherence of latex [4]. The wetting agent is mostly used in the formulation of coagulant in the production of the powdered glove.

Wetting agent also known as foaming agent or surfactant. With the different amount of wetting agent can affect the thickness of the glove. This is because foam or bubble will be created when there is the presence of vigorous mixing of the solution with a wetting agent that adhere on the mold [5]. With this concept, repeatedly mold dipping on coagulant and stirrer that used to homogenise the coagulant can cause foam. However, the purpose of the wetting agent is to reduce the surface tension of the coagulant [5]. This is to allow coagulant is evenly coated the mold as the first layer.

In this research, foam is undesirable in the production of the powdered glove. As a result, it is necessary to understand how foam can be formed. In general, mold is required to dip into coagulant as the first layer. While coagulant consisted of a composition called as a wetting agent that functioned like a soap by which it can reduce the surface tension of the chemical solution [6]. Wetting agent will arise the issue of foam formation due to air entrapment whenever there is a presence of vigorous mixing. [5] In fact, the foam would trap about 80% of air whereby most of the production line would not desire as it would affect the productivity.[5] As a result, control on the rejection of the powdered glove is necessary as the purpose is to increase the quality of the glove and reduce the rejection rate. Meanwhile anti-tack agent is generally use to prevent the latex to adhere on the mold which result of glove to be strip off easily where it can be said as powdered agent [1].

Throughout this research paper, wetting agent named as sample E and sample would be used for experiment testing where both having general chemical functional alcohol ethoxylate. Objectives of this research that needs to be achieved are to select the suitable wetting agent sample that could be used such as sample E and sample T and optimise the parameter such as temperature of coagulant, weight percentage of wetting agent and coagulant dipping time to reduce of uneven glove production.

2. Methodology

In this research, objectives are desired to be achieved. In order to achieve the objective, quantitative research is implemented through using factorial design method to analyse glove sample. Besides, pre-screening test are needed to be done in order to screen out unnecessary experiment due to glove preparation sample consume a large amount of time. In order to optimise the different thickness in the production, analysis and optimise the parameter of the powdered glove production is determine through the tensile strength, thickness of glove. Hence, validation and verification of the result from the experiment will be performed in the section below.

2.1 Pre-screen Test – Foaming Height Test

The first screening test is initiate before the experiment is proceed. These first pre-screening test is to determine the root cause of the foaming during the agitation of the coagulant. As the coagulant need to be agitate over period of time. This is to ensure the homogeneity of the coagulant as well as avoid anti-tack agent to be sediment such as calcium carbonate [6]. Based on research, it state that wetting agent is used about 0.001 wt% to 85 wt% [7]. While based on other research, wetting agent also could be used with the range of 1 wt% to 10 wt% in production line [8]. Besides, wetting agent have been effective with a less amount where the purpose of the wetting agent is to reduce the surface tension of the coagulant [6]. Hence, small amount wetting agent from 0%, 0.005 wt%, 0.03 wt% and 0.05 wt% are require pre-screen test.

The procedure of the foaming height test is basically set the composition in weight percentage to be constant but varies the weight percentage of wetting agent. This is to verify the theory through research. After prepared the chemical sample, coagulant that added without wetting agent is placed inside the mechanical stability tester which operate at 14000 rpm. Recorded the reading of the foam height. Then repeat the same step for other weight percentage of wetting agent and test with mechanical stability tester.

2.2 Pre-screen Test – Cloud Point Test

After the first pre-screen test, it will be proceed to second pre-screen test which is cloud point test. Cloud point is basically refer to the point where wetting agent could no longer operate at its function when temperature is above particular temperature [9]. When this happen, the coagulant would turned cloudy [9]. However, sometime coagulant is added with anti-tack powder such as calcium carbonate where the coagulant would eventually turned into cloudy solution. Hence, the test would require to remove the anti-tack agent so that the coagulant is still in clear solution. The anti-tack agent is generally used for avoiding the glove to be stick on the mold when glove is being made [6]. The test would be varying 0 wt%, 0.005 wt%, 0.03 wt%, 0.05 wt% and 0.08 wt% of wetting agent with coagulant. The procedure of the test are basically coagulant without added with anti-tack agent and varies with 0 wt%, 0.005 wt%, 0.03 wt%, 0.05 wt% and 0.08 wt% of wetting agent. When the sample of coagulant without anti-tack agent and added with 0.005 wt% of wetting agent, heat the sample solution until the solution turned to be cloudy. Then repeat the experiment with 0 wt%, 0.03 wt%, 0.05 wt % and 0.08 wt% of wetting agent. With the result of the test, the coagulant temperature must be set below the cloud point where the common range is within 60°C to 70°C [10].

2.3 Pre-screen Test – Surfactant Characterisation

The next pre-screen test is refer to the surfactant charactherisation. In this research, there are two wetting agent sample which are sample E and sample T. Since both of this sample are alcohol ethoxylate that consist of general chemical structure of R-$(CH_2H_2O)_n$-H [10]. Where R is refer to alkyl group and also known as hydrophobic group [11]. While -$(CH_2H_2O)_n$- is refer to hydrophilic group and also known as ethylene oxide [11]. When more number of ethylene oxide group in one of the sample, it would have higher tendency to reduce more surface tension and creating more foam [11]. The procedure of this experiment is basically using Fourier Transform Infrared Spectroscopy (FTIR) equipment to charactherise the bonding of the chemical sample. The chemical sample are sample E and sample T. At first, wipe the diamond piece of Fourier Transform Infrared Spectroscopy with ethanol. Then of drop a liquid of water on the diamond piece on the plate and run as blank spectrum. After that, drop a of liquid of the sample E on the diamond piece that is on the top of the plate and collect the spectrum of sample E. Repeat the experiment for sample T. The sample E and sample T would be tested with Fourier Transform Infrared Spectroscopy and generate IR spectrum where bonding of the sample can be known.

2.4 Full Factorial Design

The major step of the experiment is design with full factorial design. The research are basically considering temperature of coagulant (X_1), weight percentage of wetting agent (X_2) and mold dipping time in the coagulant (X_3) that could affect the uneven thickness of the glove.

Besides, these factor consist of 3 level as well. This would provide the 3^3 full factorial design and lead to have 27 runs [12–14]. The experiment crafted with full factorial design will be conducted with triplicate.

2.5 Glove Sample Preparation

By refer to section 2.4, glove sample preparation is based on experiment design. The glove sample preparation is basically prepared manually instead of making used of production line. This is due to limitation of the equipment that could be used. The preparation of glove is called as lab dipping. Glove sample was prepared on lab scale basis, which consist of four dipping tank (volume for 7kg each). The first tank was filled with dilute acid; second tank of 0.005 wt% wetting agent; 3rd tank of pure latex, and 4th tank was filled with corn-starch. Firstly, dip the mold into the acid tank for 10 seconds and rinse with water. Then place the mold inside the oven and dry it for 3 minutes at about 140℃ [1,6]. At the same time, heat the coagulant until 58℃ and took out the mold after it have dried. After that, dip the mold into the coagulant for 5 seconds and dry it again for 3 minutes in the oven. After dried, dip the mold into the latex for 3 seconds and dried it for 10 minutes [6]. Then took out the mold and dip in cornstarch for 12 seconds. Finally, dried the mold again for 6 minutes. After 6 minutes, took out the mold and let it cool down so that glove can be stripped off. Repeat the experiment based on the full factorial design in section 2.4.

2.6 Glove Sample Characterisation

After the glove sample have been prepared, various test can be performed so that analysis of the sample can be done. The test that going to be done are tensile strength, thickness and glove weight. These parameter can be measure using Tensile Strength Tester, Tensile Test Sample Cutter and Thickness Gauge equipment.

2.6.1 Tensile Strength Tester and Sample Cutter

Tensile Strength Tester was used to determine the tensile strength of the glove. Based on ASTM D-3577 standard, the glove is generally required to have 18MPa that compounded from natural rubber latex [15-16]. This shows that tensile strength for the glove sample must be above 18MPa even though there is no thickness issue. This is because this research is studying on the thickness issue while maintaining the other trait such as tensile strength. In order to use the Tensile Strength Tester, sample have to be cut into plate shape based on the ASTM standard. The glove would be puncture with the Tensile Test Sample Cutter with glove cutter to form a plate shape glove which is shown below. Glove preparation throughout the experiment is cut using the glove cutter and tested with the tensile strength tester. Table 1 below shown the ASTM standard for the plate shape cutting. Hence, the plate shape cutting from the glove sample have to be follow the standard so that can be measured with Tensile Strength Tester.

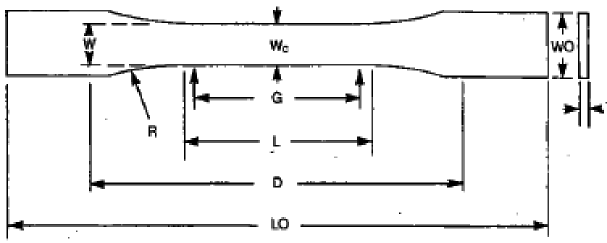

Figure 4: ASTM plate shape cutting [17].

Table 1: ASTM standard [17].

Dimension	Unit, mm
Width of narrow section (W)	6
Length of narrow section (L)	33
Width overall (WO)	19
Length overall (LO)	115
Gage length (G)	25
Distance between grips (D)	65
Radius of fillet (R)	14
Outer Radius (RO)	25

2.6.2 Thickness Gauge Test

In this research, the major scope of this studies is thickness of the glove. As a result, the sample of the glove that have been prepared would be measured with thickness gauge apparatus. Based on [15], the thickness of the glove is required to be around 0.1mm. Hence. The target of the thickness is 0.1mm.In this procedure, it is using the apparatus to measure the thickness of the glove at the location for the palm, between thumb with first finger, between first finger with second finger, between second finger with third finger and between third fingers with fourth finger.

2.7 Surface Tension Test

Based on section 2.4, the experiment is crafted through full factorial design. The coagulant of each combination with wetting agent is collected during the glove sample preparation. With this coagulant sample that being collected, it can be tested with surface tension meter DST-60 which are making use of wilhelmy plate method [18]. Based on [7], the ideal surface tension for coagulant is in the range of 1MPa to 40MPa. While any coagulant that having surface tension above 40MPa is undesirable [7].

2.8 Response Surface Methodology

After the test on section 2.6, response surface methodology can be applied to determine the optimum parameter in order to reduce uneven wall thickness issue. This methodology require full factorial design to execute. Based on section 2.4, there are 3 factor and 3 level. As a result, there would have 9 graph that would be representing the data of the glove sample. With the comparison of the graph, optimum parameter can be determine.

2.9 Verification Result

After the section 2.8 is completed, analysis for optimum parameter can be obtained. From this optimum parameter being collected, temperature of coagulant, time dipping of coagulant and amount of wetting agent would be tested for another manual dipping testing again. This is to verify the parameter on whether able to achieve the target of 0.1mm thickness of glove while maintaining the tensile strength. Then the error can be calculated based on difference of thickness comparing towards 0.1mm thickness. With this error, effectiveness of this method could be concluded.

3. Result and Discussion

Throughout the methodology that have been described, analysis on the result would be divided based three section. The four section are analysis on pre-screen test, tensile analysis, glove thickness analysis, glove weight analysis and response surface methodology analysis.

3.1 Analysis of First Pre – Screen test

As the result of the first pre-screen test is being done, the result is shown in Figure 5 below. Based on Figure 5, it shows that the increasing of the amount of wetting agent in coagulant would cause the foam height to be greater. While with no added wetting agent, there is no foam height is being formed. The purpose of this pre-screen test is to determine the root cause of the uneven thickness. This is due to uneven thickness is basically caused by various factor such as webbing foam on the between finger that appear during coagulant dipping. As a result, particular area that webbing foam occurs and rupture at the same time would lead calcium nitrate that disperse on the mold to fade. Hence, the glove thickness that produce would be affected.

Figure 5: Foaming Height versus Weight Percentage of Wetting Agent.

With this first test of the approach, the test is basically verify the concept of the wetting agent and would cause foam. In this research, other factor that explain in section 1 would be neglected except wetting agent. This is to allow the research study to be not complex. Hence, the root cause can be finalise as foam that created through wetting agent when there is agitation [5].

3.2 Analysis of Second Pre – Screen test

After the first pre-screen test is completed, cloud point test is the most crucial point to be study. This is because the cloud point is use to determine the functionality of the wetting agent that able to be used [9]. At the particular temperature, the temperature of the coagulant would cause the cloud point to be impaired. This resulted that the coagulant would not able to be operate above the temperature during the glove sample preparation process. As a result, the design temperature have to be lowered than the cloud point temperature of the sample E and sample T. Based on Table 2, sample E and sample T is basically having cloud point that is more than 80°C.

This shows that both wetting agent able to be function below the temperature of the cloud point. Hence, the design temperature is can be set in between 58℃ to 68℃ due to common range is within 60℃ to 70℃ for coagulant temperature [10].

Table 2: Cloud Point Test result.

Chemical	Weight Percentage of wetting agent, %	Cloud Point for Sample E, ℃	Cloud Point for Sample T, ℃
Coagulant	0	No Cloud Point	No Cloud Point
Coagulant	0.005	More than 80 ℃	More than 80 ℃
Coagulant	0.03	More than 80 ℃	More than 80 ℃
Coagulant	0.05	More than 80 ℃	More than 80 ℃
Coagulant	0.08	More than 80 ℃	More than 80 ℃

3.3 Analysis of Third Pre – Screen test

The final pre-screen test can be proceed when the other pre-screen is completed. This test is to determine the bonding of the wetting agent. Since both sample E and T are alcohol ethoxylate, there is possibility of the wetting agent to be having similar bonding. The screening is necessary due to section 2.4 is undergoing full factorial design where it would consume a large amount of time for glove sample preparation.

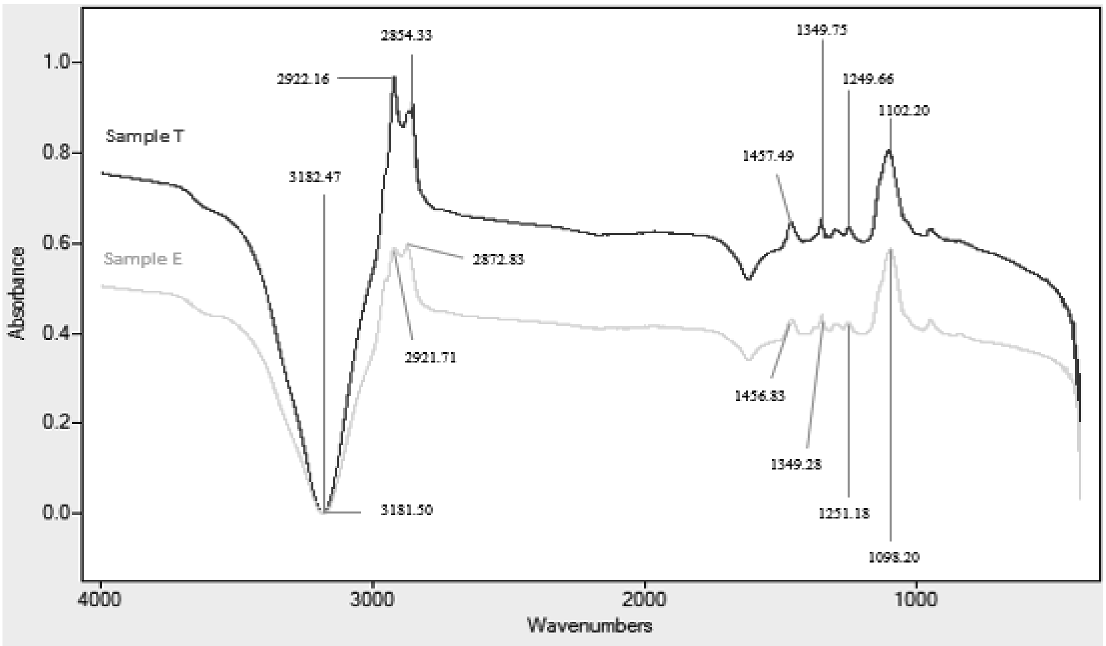

Figure 6: FTIR Spectrum of both sample

Based on Figure 6, it is refer to the spectrum of sample E and sample T. In the first zone section of sample T, there is U shape peak that located about 3182.47 cm^{-1} which in between 2650cm^{-1} to 3200cm^{-1} [19]. This U shape peak is broad and strong that would represent the OH- group [19]. On the zone 2, second peak is about 2872.79cm^{-1} and 2854.33cm^{-1} is refer to alkyl group or CH_3- which is in between 2960cm^{-1} to 2850 cm^{-1} [19]. On the fingerprint zone, peak at 1457.49cm^{-1}, 1349.75cm^{-1} and 1249.66cm^{-1} are methylene or –CH_2 [19].

While peak at 1102.20 cm^{-1} is refer to ether group or -C-O- [19]. While based on spectrum of sample E, in the first zone section, the U shape peak that located about 3181.50cm^{-1} that lies in between 2650cm^{-1} to 3200cm^{-1} [19]. This peak is broad and strong that represent the OH- group [19]. While on the zone 2, second peak is about 2921.71cm^{-1} and 2872.83 cm^{-1} is refer to alkyl group or CH_3- that lies in 2960cm^{-1} to 2850 cm^{-1} [19]. Lastly on the fingerprint zone, peak at 1456.83cm^{-1}, 1349.28cm^{-1} and 1251.18cm^{-1} are methylene or –CH_2 [19]. While peak at 1098.20 cm-1 is refer to ether group or -C-O- [19]. With both of the sample spectrum is shown in Figure 6, it shows that both of the sample of wetting agent is similar in term of bonding. This shows that sample T have more of hydrophilic and hydrophobic bonding compare to Sample E due to absorbance value is higher which mean the finger print zone of sample T have more ethylene oxide group [11]. Ethylene oxide group in alcohol ethoxylate is the role that promote foam and surface tension reduction properties [11]. As a result, sample T promote more foam and reduce more surface tension compare to sample E. Besides, sample T is easier available in market than sample E. Hence, sample E is removed.

3.4 Analysis of Surface Tension

Based on the coagulant with varies of wetting agent amount, Figure 7 below shows the decreases trends of the surface tension on coagulant with the increase of wetting agent. This test is to verifying the coagulant that need to be within the standard of the typical surface tension of the coagulant. The typical surface tension of coagulant is about 0.001 N/m to 0.040N/m [7]. Based on the Figure 7, the coagulant without the wetting agent is having greater surface tension which is 0.0486N/m. This means that the coagulant is not suitable for glove sample preparation. While with the small amount of the 0.005 wt% wetting agent added, the surface tension is about 0.04 N/m.

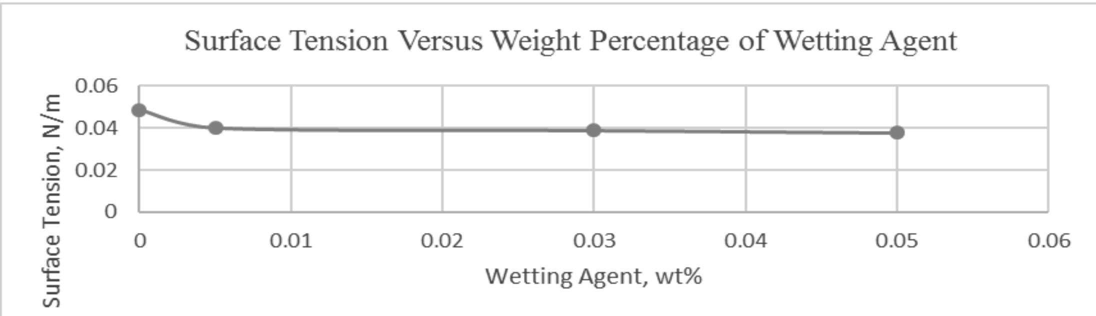

Figure 7: Surface Tension versus Weight Percentage of Wetting Agent.

3.5 Analysis of Glove Sample Characterisation

After the glove sample that have prepared, glove weight, glove thickness and its tensile strength are require to be studied so that optimisation on the parameter can be determined. With the result being collected, it can make use of Matlab software to plot the surface plot with colour bar as parameter to be studies. With the response surface methodology, optimisation of the production can be done.

3.5.1 Tensile Strength Analysis

After tested the glove with tensile strength, the glove standard need to achieve 18 MPa. The result is collected and plotted with surface plot with the factor of temperature of coagulant, dipping time of coagulant and tensile strength of the glove at different of amount of wetting agent. This plot is plotted using Matlab software.

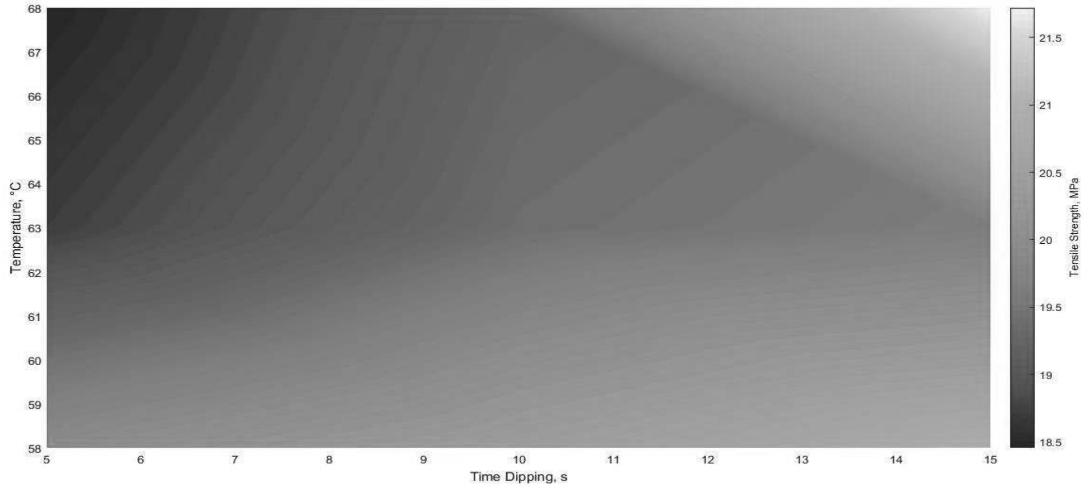

Figure 8: Contour of temperature and time against tensile strength of glove for 0.005 wt% of wetting agent

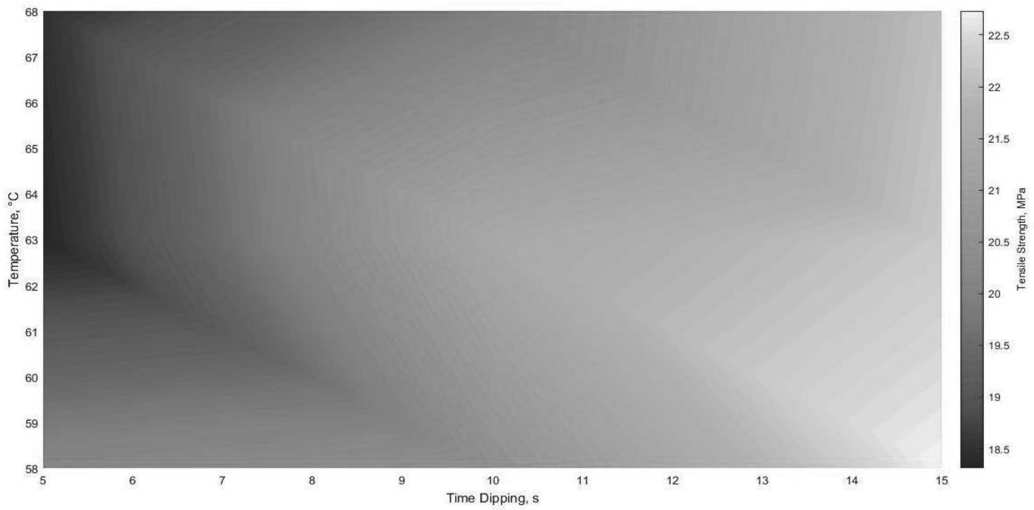

Figure 9: Contour of temperature and time against tensile strength of glove for 0.03 wt% of wetting agent

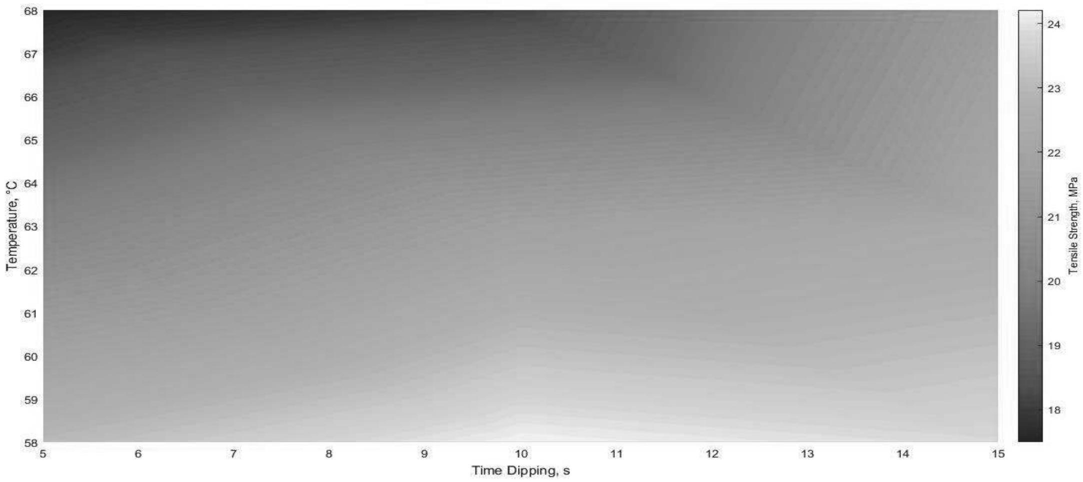

Figure 10: Contour of time and temperature against tensile strength of glove for 0.005 wt% of wetting agent

Based on Figure 8, the tensile strength against temperature and dipping time is basically meet the requirement of the standard at 18MPa which shown based on the colour bar. In this Figure 8, the glove sample prepared at 0.005 wt% of wetting agent. The glove that produce on at temperature range from 58℃ to 68℃ as well as the range of time dipping of 5 seconds to 15 seconds meet the standard requirement of the tensile strength. While at temperature of 63℃ and 15 seconds, tensile strength should have about 20MPa and above. Based on observation, whenever the temperature of the coagulant is low such as 58℃. The coagulant is hardly evaporate on the surface of the mold. This resulted the coagulant to be flowing on the mold instead of dried where the mold is having smooth surface. If the mold does not have smooth surface which allow forming of thin film without any restrain and would not dripped off [20]. This provide coagulant to adhere on the surface with a thicker film and provide higher tensile strength as well. By referring to Figure 8, coagulant is hardly evaporate at 58℃ and this allow the area on the mold that to have lesser amount of coagulant. Hence, the glove tensile strength should be lowered at lower temperature. This means that there is fluctuation in reading where it is actually require more glove sample so that the glove reading would be consistent.

While based on Figure 9, the glove sample is tested at 0.03 wt% of wetting agent. Based on the colour of the contour, it show that the tensile strength against temperature and dipping time is basically meet the requirement of the standard at 18MPa. Since the tensile strength does not varies much compare from 58℃ to 68℃, more glove sample are required to be studied so that to allow consistent reading. Based on the Figure 10, the tensile strength of the glove at 58℃ is greater than 68℃. This is basically not supposed to be happened theoretically and the result should be other way around. The reason of this difference of tensile strength is due to the dipping time for latex is not consistent that may due to allow the glove tends to be thicker. This resulted at 58℃ to have higher tensile strength. However, the reading of tensile strength against time dipping and temperature able to meet the standard of tensile strength.

3.5.2 Thickness Glove Analysis

On the other hand of glove thickness, it is the most crucial part as it determine the uneven wall thickness. Based on [14], the target standard of the powdered glove thickness is basically 0.1mm.

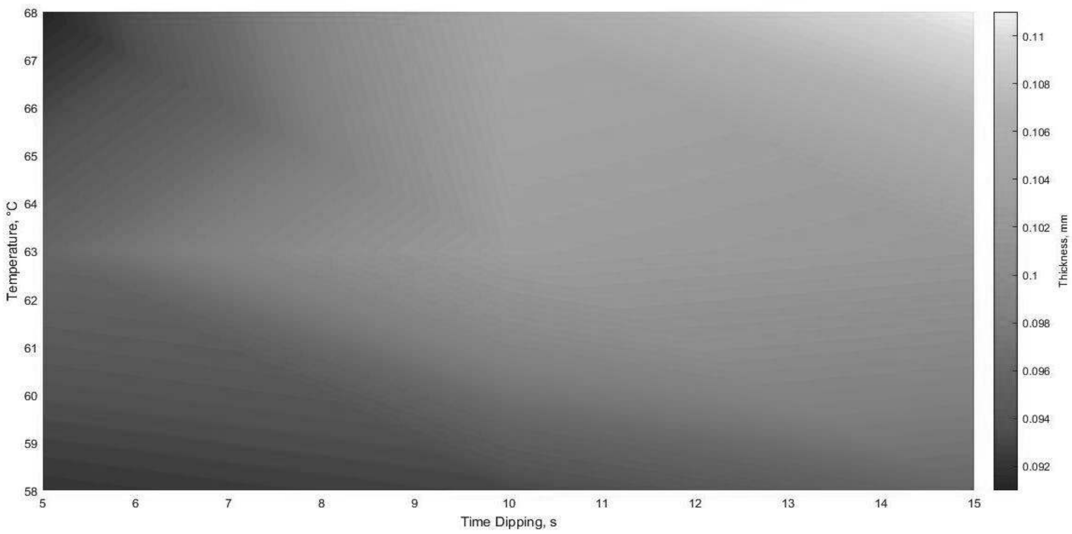

Figure 11: Contour of time and temperature against glove thickness for 0.005 wt% of wetting agent.

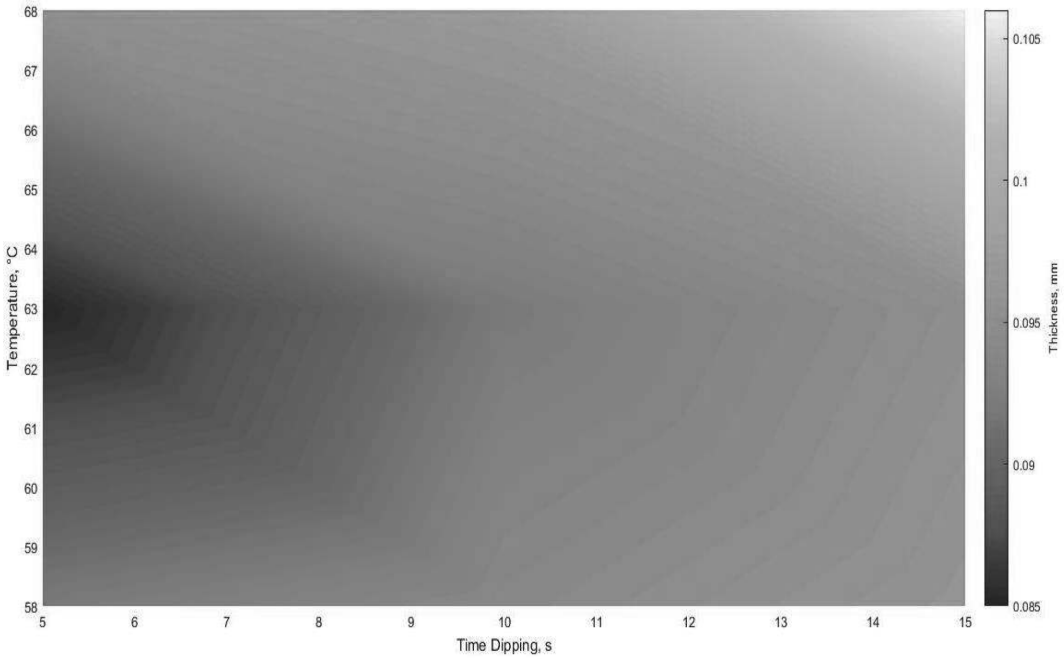

Figure 12: Contour of time and temperature against glove thickness for 0.03 wt% of wetting agent

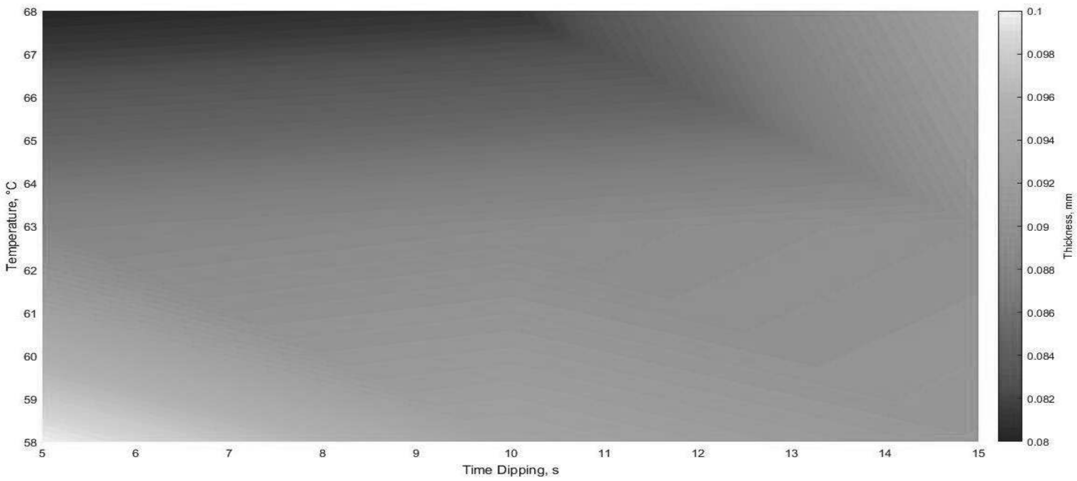

Figure 13: Contour of time and temperature against glove thickness for 0.05 wt% of wetting agent

Refer to the Figure 11, the colour bar shows the coagulant temperature at about 63℃ with 6 seconds dipping time. This enable to achieve the 0.1mm. Besides, at 68℃ with 8 seconds dipping time also able to achieved the 0.1mm. Moreover, this Figure 11 shows that the trend where thickness increases with the dipping time of the coagulant which is synchronise with the concept that mention previous section. Based on Figure 15, temperature at 66℃ until 68℃ with 12 to 15 seconds able to achieve thickness of 0.1mm. This result is not able to be applied in production line. This is because process line operate at high speed where 12 to 15 seconds is not able applicable. By comparing Figure 11 and Figure 12, Figure 12 should have better performance as 0.03 wt% wetting agent basically able to coat on the mold better than 0.005 wt%.

However, more amount of wetting agent would create more foam and bubble on the mold. Based on observation, the coagulant of wetting agent at 0.03 wt% and 0.05 wt% are having large amount of bubble compared to 0.005 wt% wetting agent. This can be shown in Figure 14. The reason that the coagulant need to be agitate constantly due to avoid the anti-tack agent to be sediment.

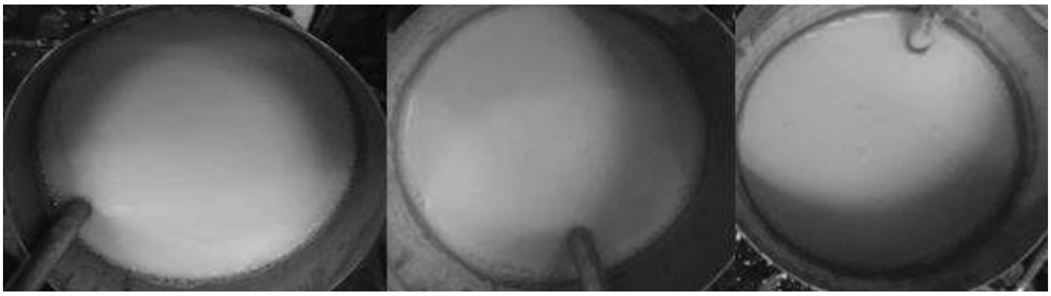

Figure 14: Wetting agent at 0.005 wt% (left), 0.03 wt% (middle) and 0.05 wt% on the (right)

The figure 17 below show the foam on the mold that affect the on the latex dipping. With this reason, the tensile strength of the glove is also affected by this foam that can compare Figure 9 and Figure 12. Also, higher temperature of the coagulant able to break the foam compared to the lower temperature as shown in Figure 11 and Figure 12. As a result, lower surface tension liquid would allow bubble foam of liquid would be larger [21-22]. Hence, increase in liquid drainage and lead bubble to rupture during withdrawing of mold after coagulant dipping. While at lower temperature, it would have higher viscosity that allow the bubble to retain is shape for a longer period. Besides, the bubble foam would having smaller bubble compare to higher temperature and liquid drainage tendency would be lower. As a result, the foam does not rupture. While this foam would only rupture during the drying process of coagulant in oven. This means that the rupture of foam in the certain area in oven will have less deposited of calcium nitrate. Hence, thickness of glove is affected.

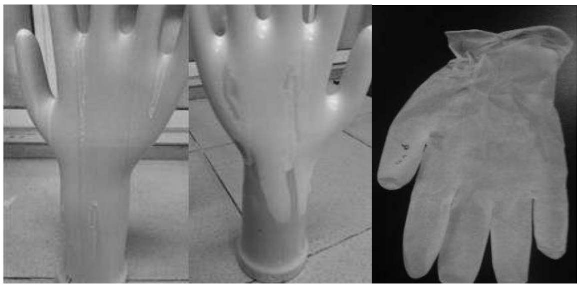

Figure 15: Foam on the mold (Left) and Latex uneven coating (Middle) and Sticky Glove at the cuff area (Right).

Based on Figure 13, the foam height at 0.05 wt% is greater than 0.005 wt% and 0.03 wt% where it could be refer to Figure 5. This shows 0.05 wt% have the foam issue that similar to wetting agent at 0.03 wt% that can be based on Figure 15. But 0.05 wt% wetting agent is having more serious issue where there is presence of webbing that happen between the thumb and first finger. Even though higher temperature is said to be able to break the foam forming. However, there is too much wetting agent in this range of temperature from 58°C to 68°C. As a result, the reading of the thickness fluctuate. This means that higher temperature is required to break more foam and more glove sample is require for consistent reading.

At 0.005 wt% wetting agent, the glove sample having issue of sticky where anti-tack agent is not disperse well enough. This is due to wetting agent is used to ensure a better coating effect on the mold. While wetting agent at 0.03 wt% and 0.05 wt%, the glove also the issue of sticky glove where located at the foam area during coagulant dipping.

3.6 Analysis of Response Surface Methodology Result

Since the result of the tensile strength on Figure 8, Figure 9 and Figure 10 show a positive result. Its narrow the optimisation of the glove thickness. Based on section 3.5.2, the best parameter of the glove sample are 63°C with 6 seconds dipping time and 68°C with 8 seconds dipping time. Both of this parameter able to achieve 0.1mm thickness with 0.005 wt%. But at 0.005 wt%, the glove tends to be sticky. Hence, more wetting agent is require so that anti-tack agent able to disperse evenly. Based on Figure 16 below, by choosing the parameter 63°C with 6 seconds dipping time would be wise as lower temperature would have lower operating cost for the coagulant. While lesser dipping time that is 6 seconds would have a better profit in glove production compare to 8 seconds. This is due to lesser time require to produce the glove sample. As a result, fixing the temperature at 63 °C and making variation of the wetting agent amount and dipping time would the final optimisation. The optimisation parameter on Figure 19 are 0.0175 wt% of wetting agent and about 5 seconds dipping time at 63 °C.

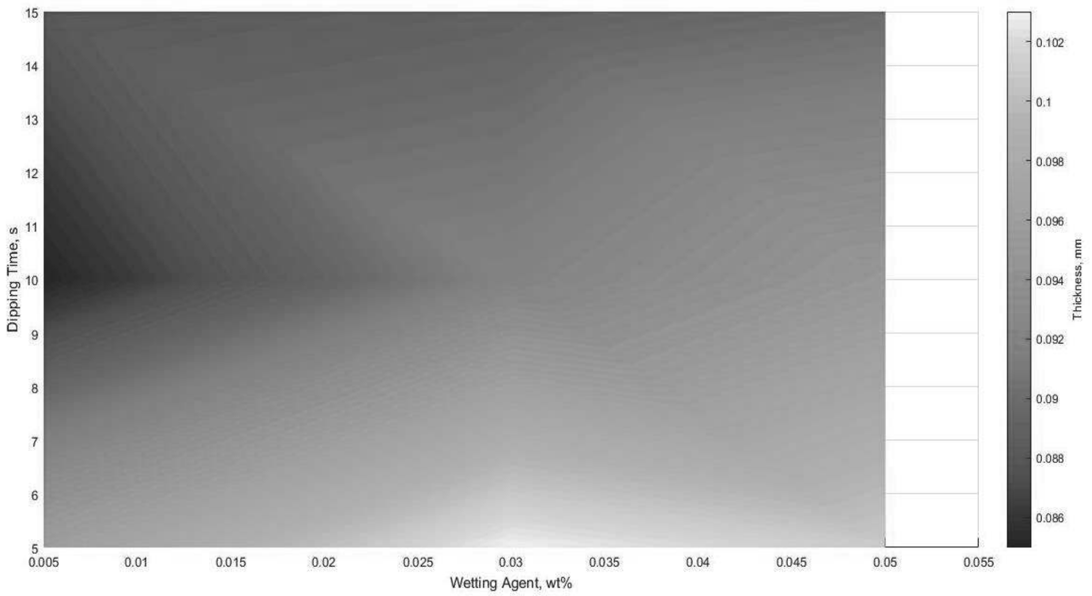

Figure 16: Predicted time and wetting agent amount against glove thickness for 63°C

3.7 Verification Result

As the optimum parameter is being collected, three sample of glove is obtained through the manual lab dipping. Table 3 below shows the average result of the thickness and tensile strength as well as error percentage of the result. By referring to Table 3, the glove that produce from the experiment is having average of $0.09 \pm\ 0.004\ mm$. This result is does not achieve the targeted value of 0.1mm for ASTM standard. Besides, there is having error about 11.33% lies in glove thickness result compared to targeted thickness. The reason of this error is mainly due to human error.

While the average tensile strength of glove produce at 19.480MPa is higher than ASTM standard of 18MPa. This means that the glove meet the requirement standard as the parameters suitable which synchronise with section 3.5.1 discussion. Furthermore, the glove that produce through the optimum parameter is having sticky effect on the surface of the glove. This is due to the wetting agent is not enough to disperse the anti-tack agent throughout the mold. In order to avoid this sticky issue, adding more anti-tack agent into coagulant would be able to negate this issue.

Table 3: Error percentage compared to targeted thickness.

Average Thickness, mm	Targeted Thickness, mm	Error Percentage, %	Average Tensile Strength, MPa
0.09	0.1	11.33	19.480

4. Conclusion

In conclusion, there is two potential optimum parameter that is considered before electing the wetting agent amount. The parameter are 5 seconds dipping time at 63 °C are compared with 8 seconds dipping time at 63 °C. Generally, lower temperature would have lower operating cost for the coagulant and lesser dipping time that is 5 seconds would have a better profit in glove production compare to 8 seconds. With lower operating cost on time dipping and temperature, this parameter is expected to able to produce mass amount of glove with low number of unweven wall thickness issue. This would indirectly increasing the profit due to more glove can be sold instead of dispose or sold in lowered price for unweven wall thickness glove. Besides, user who using the glove would have a better confidence in doing task instead. As a result, the optimise parameter throughout the whole experiment are 0.0175 wt% of wetting agent and about 5 seconds dipping time at 63 °C that being selected. Throughout the optimum parameter that being determined, the average thickness is 0.09 ±0.004 mm with 11.33% error of thickness by comparing to 0.1mm thickness of ASTM standard. While sample T is being used in this experiment instead of sample E due to sample T is easier to be obtained through market. Hence, the objective of this research is achieved.

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