EXPERIMENTAL STUDY OF PARAFFIN WAX POTENTIAL AS A PHYSICAL MODELLING MATERIAL FOR LOCAL ENVIRONMENT

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ABSTRACT

An experimental study on paraffin wax was done to investigate its potential as modelling material and observing the effect of local environment thermal parameter. Testing and analysis done using cromatographer, differential calorimeter scanner, instron strength analyzer, durometer and laboratory experimental equipment have given us the opportunity to clarify certain elements in understanding the wax characteristics. Wax, through this experiment, have been proven viable as a modelling material. The surface finish is found to be better than Industrial Design (ID) clay and stable for the local environment as long as it is not exposed to direct heat source such as sunlight.

1.0 INTRODUCTION

Modelling is a part of normal design process. Modelling can be made for visualisation, 3-dimensional appreciation, design evaluation, aesthetic valuation and testing.

Modelling material such as ID clay and wood are frequently used by model maker. Petroleum by plastic product like polyurethane foam is found to be very useful, as the materials can be found in rigid and semi-rigid form as required.

Most of the modelling materials are not recyclable, some are hazardous as it may cause skin irritation and health deterioration, some contain environmental unfriendly material and even difficult to dispose and the cost is expensive.

Paraffin wax turn up for an alternative, this is mainly due to the following factor [1] :

a. Paraffin wax are inexpensive.
b. Available in practically unlimited quantities.
c. The grades do not vary.

But the question is the compatibility and the performance of this material in our Malaysian weather. Series of testing have been made to overview the material characteristic and thermal reaction problem.

2.0 EXPERIMENTAL THEORY

Paraffin wax is a hydrocarbon. In all macrocrystalline paraffin waxes with melting point between 53° C and 61° C, the majority of n-alkane molecules are in the C_{18} to C_{30} range. Generally, the paraffin wax majority components are n-alkanes, branched alkanes, mono-cyclo-alkanes, polycycloalkanes, monocycloaromatics, and aromatic cycloalkanes groups [2].

2.1 Surface Profile Analysis

The surface profile is one of the important parts to look into, so we could distinguish the surface roughness. Using Nikon microscope some figures from both material surfaces finish were taken for the observation purposes.

2.2 Shore Hardness Testing

A Shore Hardness Durometer was used to determine both wax and ID clay indentation hardness. The hardness comparison was made between wax and ID clay. The hardness range of the materials will give some general ideas of how the workability condition of the wax.

Generally, ID clay is much softer and stretchable. On the other hand, wax is more rigid and brittle. This general evaluation is not sufficient to give a definite comparison. The shore hardness testing method was designed to give some readings for references and analysis.

Hardness readings were taken on five differences sample from the same wax and five differences sample from the ID clay. This method is practiced to minimize error due to uneven distribution of oil content that is naturally present in the wax, and mixture of sulphur, ash, and wax exists in the ID clay. The average values were calculated to represent the hardness value for the wax and the ID clay.

2.3 Strength Analysis

The analysis on the strength of paraffin wax could give us the idea about the wax and the chance to make some comparative studies between wax and ID clay. The outcome of this test will provide us the data about working condition of both materials.

Three points bending flexural test was done to overview the strength of both materials strength as structural member, even though, the use of both materials is mainly as filler mechanism. This fact will explore new extended application and evaluation of both materials as strut, beam, pillar, and cantilever.

2.4 Composition Analysis Using Infra Red

Using *Fourier Transfer-Infra Red* (FTIR) system 2000 we could get a range of infra red transmitance spectra. Certain carbon compounds has its owns vibration frequency pattern. When infra red ray is transmitted through the wax sample, some wavelength will be absorbed and we will get a pattern of wavelength spectra. From

this spectra we could identify certain group in the wax sample that was used in this research experiment.

The tested sample was required in a form of uniform thin layer below 1 mm thickness and rounded dimension about 15 mm in diameter. The sample was then position in a hollow thin annulus, which act as a holder. The holder will be positioned in the analyzer to begin the analysis work.

2.5 Chromatography Analysis

Chromatography is another method to identify the components contain in a certain material. Despite IR analysis, which is qualitative, chromatography provides us a quantitative result. Solvent (Benzene) was used to dissolve the wax. The analyzer use Ultra 1 Methyl Silicone column type and the capillary dimension is 25 m x 320 μm x 0.17 μm. This technique enable us to separate the alkanes up to C80 carbon number and provide result in carbon number distribution [3].

2.6 Differential Scanning Calorimeter (DSC)

This machine has been used widely in thermal analysis of wax, petrolatum, oil, gas, and polymeric material. In this testing experimental wax, samples were prepared using clean cork borer and slice with razor blade into discs of desired thickness.

Samples weight range normally from 5 mg to 12 mg. The waxes were scanned at the rate 10° C/min during normal heating runs. The first melting scans were not reported since they are often non-reproducible. This is probably due to a repositioning of the sample in the sealed pans.

Two types of sample were subjected for testing. First sample is a new paraffin wax, which is comes directly from supplier. The sample weight is 5.60 mg. The second sample is a recycled wax, which has been used for several times in the operation of model making experiment. The recycled wax sample weight is 5.75 mg.

Setting parameter of the testing machine healing and cooling rate at 10° C And the cooling agent used are Sodium Chloride, Methanol and Liquid Nitrogen.

2.7 Cooling Curve Experiment.

In this experiment, a close observation was made on the variation of the wax volumetric change during cooling time. The purpose of this experiment is to determine the temperature range in concern of the material volumetric stability. The volumetric stability is important since it has a significant effect on the dimension of the mass.

3.0 EXPERIMENTAL SETUP

The analysis on the strength of paraffin wax could gave us the idea about the wax and the chance to make some comparative studies between wax and ID clay. The Material hardness of both materials will be tested using Shore Hardness Durometer. The outcome of this test will provide us the data about working condition of both materials. Three points bending flexural test was done to overview both materials strength as structural member, even though, the use of both materials are mainly as filler mechanism. This fact will explore new extended application of both materials as strut, beam, pillar, and cantilever.

Temperature has a very distinctive effect on wax characteristic. Thermal analysis were done to studies and understanding the wax thermal properties. The local weather provides heat variation from 27° C to 35° C. For this temperature is in the range of the wax solid-solid transition period, it is expect that, the wax will undergo some deformation. The behavior of the wax deform under the influence of the local environmental is essential to predict the performance of the wax as modelling material in the local environment.

Table 1 shows the objective of the individual experimental and testing setup and the equipment and facilities used.

Table 1 Experimental Setup

Experiment	Method	Equipment	Objective
Density Determination	Water Displacement	100ml Measuring Cylinder, Digital Weighing Machine	Material Density
Density And Volume Shrinkage	Water Displacement	1000ml Cone Beaker, 100ml Measuring Cylinder, Digital Weighing Machine	Material Density And Volume Shrinkage
Infra Red	Frequency Pattern (Spectral) Identification	Fourier Transfer Infra Red (FTIR System 2000)	Material Composition By Quality
Cooling Curve	Water Displacement	1000ml Cone Beaker, 100ml Measuring Cylinder, Digital Weighing Machine, Glass tube, Beuret and Insulator.	Volumetric Change Relative to Temperature Drop.
Gas Chromatography	Vapourise Compound Analysis	Column Type Ultra 1 Methyl Silicone HP19091A-012	Material Composition By Percentage Quantity
Shore Hardness	Surface Indentation	Shore Hardness Testing Machine	Material Hardness
Strength Test	Three Points Bend	Instron Testing Machine	Material Stresses

4.0 EXPERIMENTAL RESULT

The experimental results were taken and analyzed. Some of the experiment readings were compared to the previous testing result and chart to assist the identification of the material composition.

4.1 Density Determination

A simple test experiment using the method of water displacement was done to confirm the density of the wax and ID clay. A sample of wax weight 4.27 gram and ID clay weight 6.36 gram were dipped into a measuring cylinder fill with 50 ml of water. The displacement reading, obtained from the measuring cylinder was taken as the sample volume. The density of the individual sample was calculated using mass over volume equation. Table 2 shows the density of the ID clay and the paraffin wax.

Table 2 Samples Weight, Volume And Density

Sample	Weight g	Volume ml	Volume cm^3	Density g/cm^3
Wax	4.27	4.50	4.50	0.9488
ID clay	6.36	4.52	4.52	1.4070

4.2 Determination of Paraffin Wax Density and Volume Shrinkage

Another experiments done to observed the volumetric behavior of the wax at liquid and solid state. Using the same water displacement method, liquefy wax was fill into 1000 ml cone biker at the level of 600 ml and weighed. The wax was let to cool and solidify under room temperature. All readings and measurements were recorded and shown in the Table 3.

Table 3 Experimental Readings and Measurements

	Temperature ^{o}C	Volume ml	Weight g	Density g/cm^3
Biker	27	-	340.00	-
Liquid wax	85	600.00	481.38	0.8023
Water	27	86..20	86.21	1.0001
Solid wax	27	513.79	481.50	0.9372

From the Table 3, an analysis was made on the volumetric change of the wax from temperature 85 ^{o}C to 27 ^{o}C. The Volumetric analysis shows a negative value that representing shrinkage (refer to the calculation below)

$$\% \text{ Change in volume} = 100x(513.79-600)/600$$
$$= -14.37\ \%$$

The weight at the liquid state, compare to the weight at the solid state also shows a small difference. The phenomena occur because there was a big different in temperature. Practically proven that hot air is lighter than the cold air, and the hot air balloon float. The change in volume also influence the density (refer to the calculation below)

$$\% \text{ Change in density} = 100x(0.8023-0.9372)/0.9372$$
$$= -14.39\ \%$$

4.3 Thermal Property – DSC Analysis and Cooling Curve Experiment

The results from the DSC (Fig. 1) shows that the are slight changes in melting point and solid-solid transitions temperature. Table 4 shows the contrast of the changes. Melting point of used wax is slightly higher than the new one by 1.66^{o} C. On the

other hand, the solid-solid transition temperature of used wax is slightly lower with the difference of 1.94^{O}C.

Table 4 New And Used Wax Temperature Changes

Paraffin wax	Solid-solid transitions ^{o}C	Melting point ^{o}C
New	34.47	44.46
Used	32.53	46.12

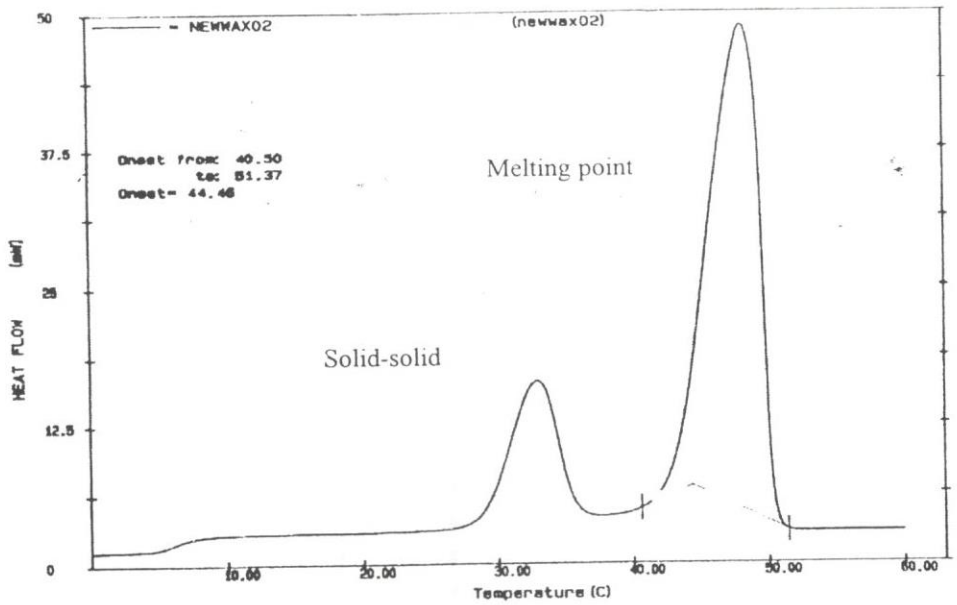

Fig. 1: DSC - New Wax Melting And Solid-Solid Transitions Point

As shown in Fig. 2, the cooling curve experiment indicate that at local temperature variation of 27°C to 35°C the wax has a minimal shrinkage effect of less then 1%. Above the 35° C line, the wax volume shrinkage was large and very stable at room temperature.

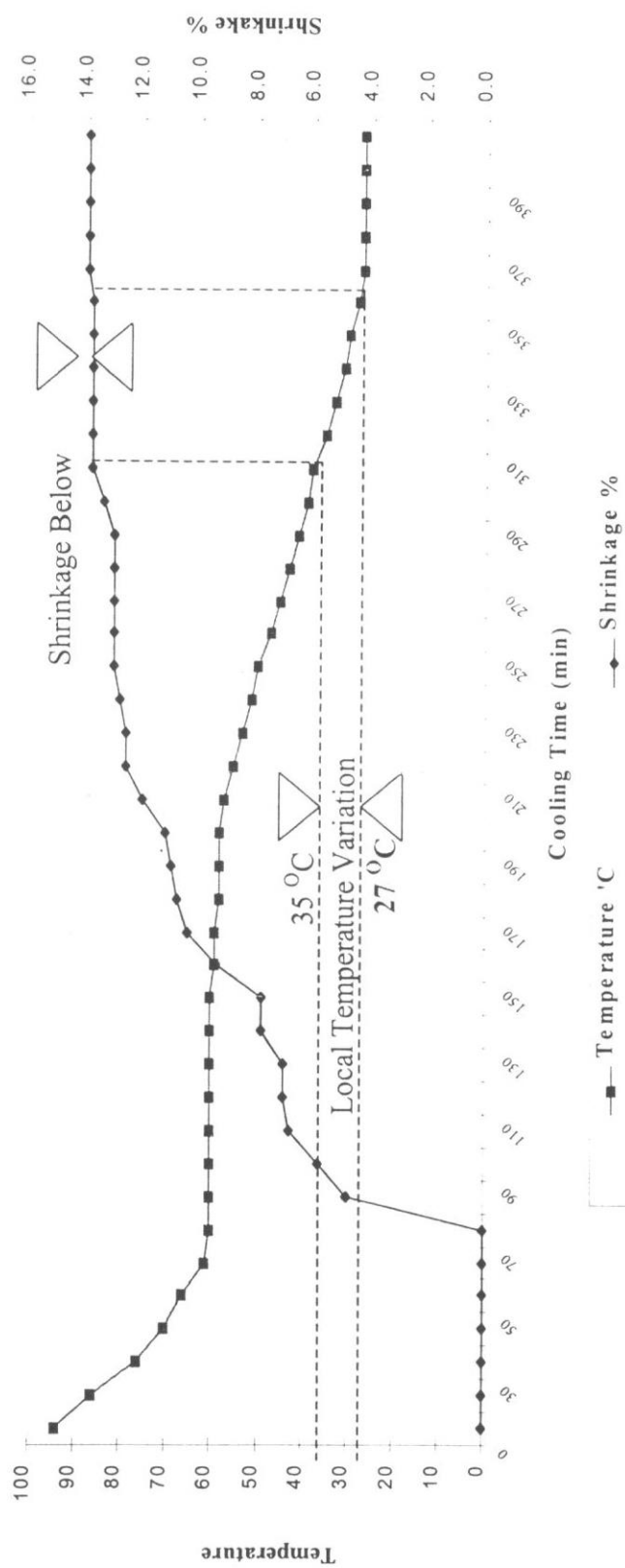

Fig. 2 Cooling Curve

4.4 Material Composition

Figure 3 shows the IR spectra of a new wax sample and recycled wax sample. The peaks of the IR spectra represent certain range of carbon compound groups, which were used to determine the wax composition. The new wax compositions are shown in Table 5.

Table 5 New Wax Compositions

Spectral Peak	Compound	Description
3607	Aromatics	Cycloalkenes
3367	Aromatics	CH_3 $CH_3CH_2CHCH_2OH$
3017	Alkenes $R_2C=CHR$	=C-H stretch
3001	Alkanes	C-H stretch
2972	Alkanes	C-H stretch
2956	Alkanes	C-H stretch
2939	Alkanes	C-H stretch
2924	Alkanes	C-H stretch
2888	Alkanes	C-H stretch
2823	Aldehydes	C-H stretch
2735	Aldehydes	C-H stretch
2636	Aldehydes	C-F stretch
2526	Methylphosphine	CH_3PH_2
2414	Dimethylsulfonate	$(CH_3)_2SO_2$
2336	Alkyl metallic halide	FCH_2 CH_2SiF_3
2151	Cycloalkene	C-F stretch
1898	Alkyl metallic halide	FCH_2 CH_2SiF_3
1810	Alkenes $RCH=CH_2$	Overtone
1472	Alkanes	CH_2 and CH_3 bend
1459	Alkanes	CH_2 and CH_3 bend
1370	Alkanes	CH_2 and CH_3 bend
1304	Alkyl halide R-F	C-F stretch
1127	Alkyl halide R-F	C-F stretch
1081	Alkyl halide R-F	C-F stretch
961	Organometalic-amide	NaCNO
889	Alkenes $R_2C=CH_2$	C-H out of plane bend
725	Alkanes	CH_2 and CH_3 bend
390	Alkyl halide R-I	C-I
374	Alkyl halide R-I	C-I

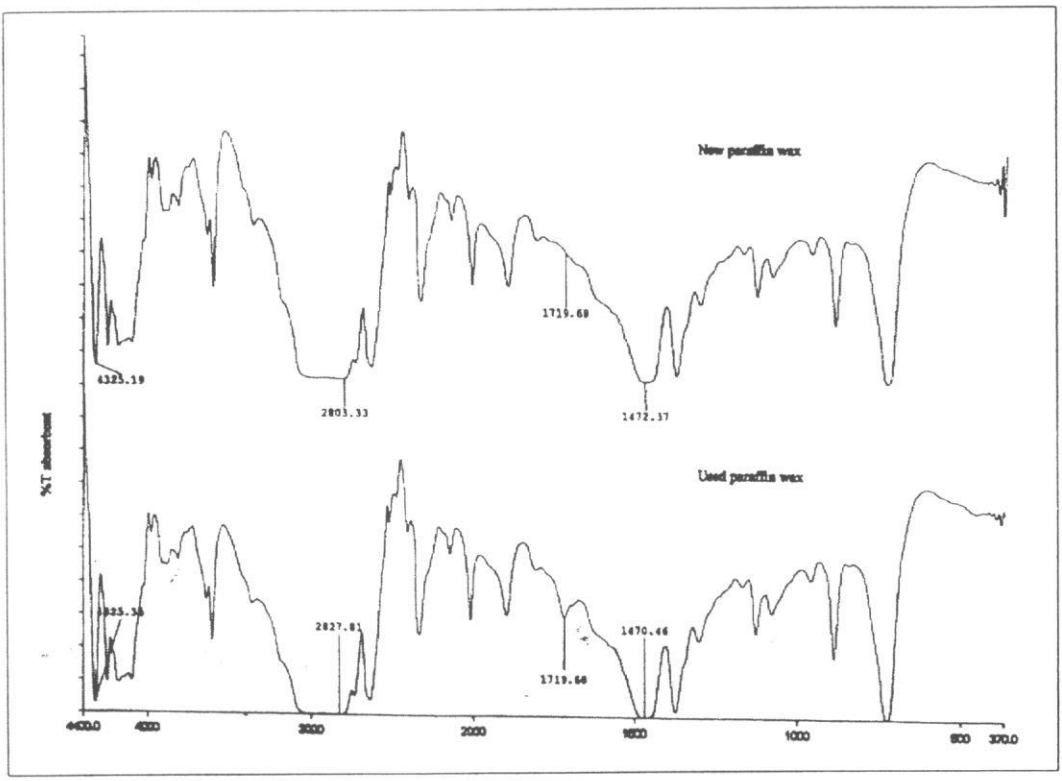

Fig. 3 Infra Red Spectral Analysis Of New And Recycled Wax

4.5 Gas Chromatography

The fragments of the wax sample were firstly dissolved with benzene (solvent for paraffin wax). The mixture concentration was 2.809% wax and 97.191% benzene. The mixture was manually injected into the heating chamber that slowly heated up with the rate of 1.5° C/min.

Figure 4 and Table 7 show the quantity and type of alkane contain in the sample paraffin wax used the form of bar chart. (SC-straight chain, BC-branched chain, OC-cycloalkanes).

Table 6 Other Paraffin Waxes Chromatographic Analysis

Type Of Alkanes	**% Content In Paraffin Wax**
Straight chain	65-95
Branched chain	3-20
Cycloalkanes	3-15
Carbon number range	18-40

By comparing the experimented GC result to the confirm paraffin Waxes Chromatographic Analysis (Tables 6 and 7), the contents of the sample wax lies in the paraffin waxes domain. Therefore we could conclude that, the sample wax is a paraffin wax which major components are straight chain, branched chain, and cycloalkanes. This result will be used to correct the result generate by IR spectra which result is mainly qualitative (IR analysis result do not show any quantitative value besides the material contents) [3].

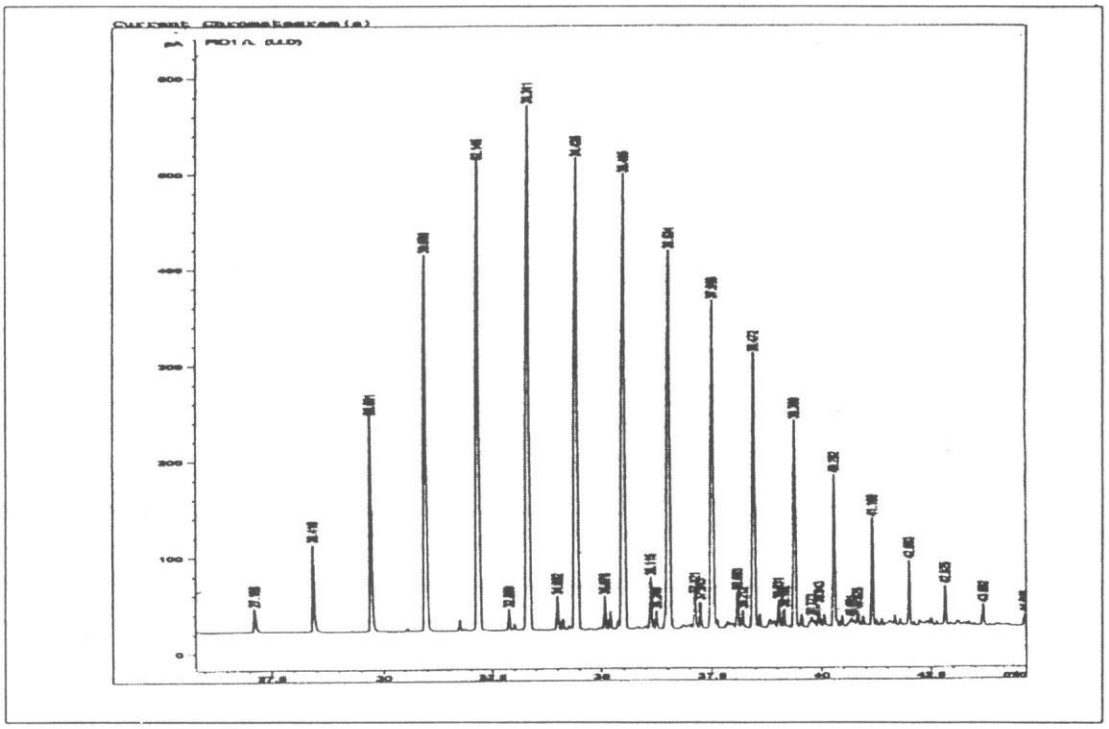

Fig. 4 Gas Chromatography Analysis Of Wax Components

Table 7 Sample Wax Chromatography Analysis

Peak	Component	Time	Sample Area	Wax Content %		
1	Benzene(solvent)	1.542	SC	BC	OC	
2	Straight chain alkanes	27.108	0.41			
3	Straight chain alkanes	28.419	1.40			
4	Straight chain alkanes	29.691	3.62			
5	Straight chain alkanes	30.938	7.99			
6	Straight chain alkanes	32.145	11.14			
7	Branched Alkanes	32.889		0.27		
8	Straight chain alkanes	33.311	13.29			
9	Branched Alkanes	34.002		0.46		
10	Straight chain alkanes	34.425	12.18			
11	Branched Alkanes	35.078		0.48		
12	Straight chain alkanes	35.495	11.53			
13	Branched Alkanes	36.115		0.74		
14	Others alkanes	36.240			0.26	
15	Straight chain alkanes	36.524	9.05			
16	Branched Alkanes	37.121		0.53		
17	Others alkanes	37.243			0.38	
18	Straight chain alkanes	37.518	7.40			
19	Branched Alkanes	38.093		0.59		
20	Others alkanes	38.212			0.31	
21	Straight chain alkanes	38.472	5.41			
22	Branched Alkanes	39.031		0.44		
23	Others alkanes	39.152			0.33	
24	Straight chain alkanes	39.399	3.92			
25	Others alkanes	39.773			0.28	
26	Branched Alkanes	39.943		0.40		
27	Straight chain alkanes	40.292	2.56			
28	Others alkanes	40.681			0.28	
29	Branched Alkanes	40.825		0.30		
30	Straight chain alkanes	41.160	1.55			
31	Straight chain alkanes	42.003	1.06			
32	Straight chain alkanes	42.825	0.70			
33	Straight chain alkanes	43.692	0.42			
34	Straight chain alkanes	44.656	0.31			
	Content %		93.95	4.21	1.84	100.00

4.6 Material Strength and Hardness

From strength test , wax filled tube was found to have more bigger potential to withstand bending pressure as shown in Fig. 5. The action in filling the tube also increase the tube strength compare to the non filled tube.

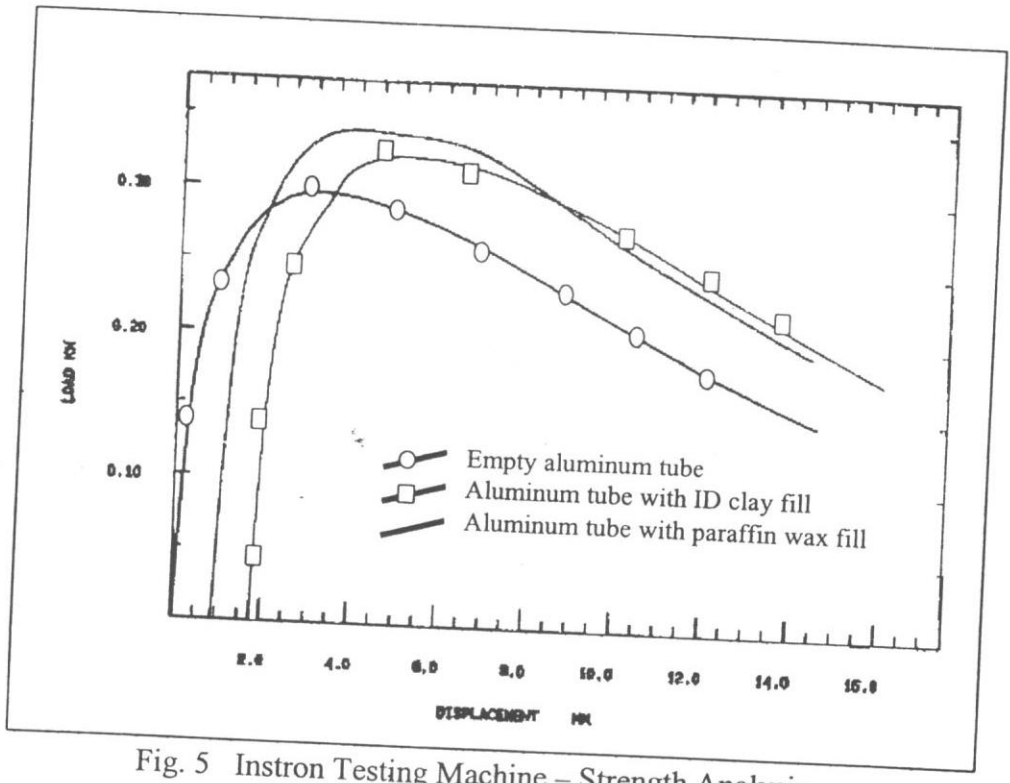

Fig. 5 Instron Testing Machine – Strength Analysis

The average hardness value for the wax sample is 85.8 from the Shore A readings and the average hardness value of ID clay sample is 23.1 also from the Shore A readings. Wax is 3.7 time harder than the ID clay as shown in Table 8.

Table 8 Shore Hardness Readings

Wax	Readings	ID clay	Readings
1	A/30:85.0	1	A/30:23.0
2	A/30:87.5	2	A/30:22.5
3	A/30:86.0	3	A/30:22.5
4	A/30:86.5	4	A/30:23.5
5	A/30:84.0	5	A/30:24.0
Average	**A/30:85.8**	**Average**	**A/30:23.1**

4.7 Surface profile

Referring to Figures 6 and 7, Wax surface profile looks like metallic surface profile. The surface profile seems to be flat all around as we focusing to the higher magnification level. At only 1000 times, magnification, some areas are out of focus. Through the microscopic view at 1000 times magnification the wax surface profile found to be like endless and shallow wavy pattern.

Referring to Figures 6 and 7, ID clay surface profile looks like a sand papers surface, at higher level of magnification some area were found to be out of focus. These phenomena show that there are a lot of peak and valley. When focusing were made on the peak the valley will be out of focussing range and that made the valley became blur. These became vice-versa as we were focusing the valley.

Using the microscope too, observation also made on the edge cutting profile. Figure 8 shows both samples wax and ID clay under magnification of 100 times

The effect heat on wax is very critical. Therefore, some picture under series of magnification has been take to observe the direct sunlight effect. A sample of wax was expose to direct sunlight for one hour and the surface temperature was 41°C. Figure 9 shows us the wax surface profile due to heat deformations.

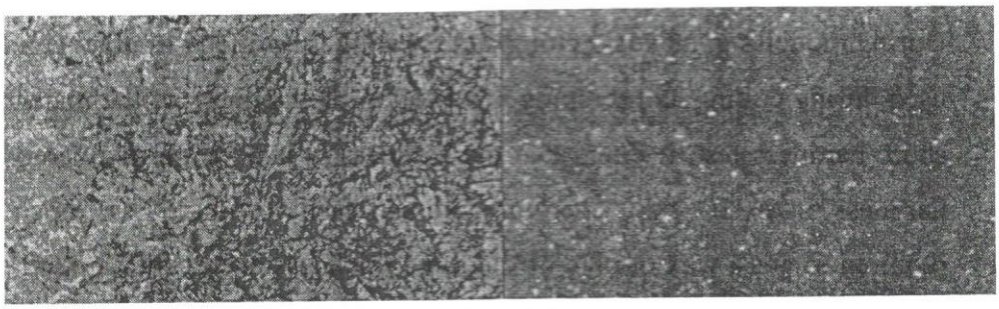

Fig. 6 Wax And ID Clay Surface Under 10X Magnification

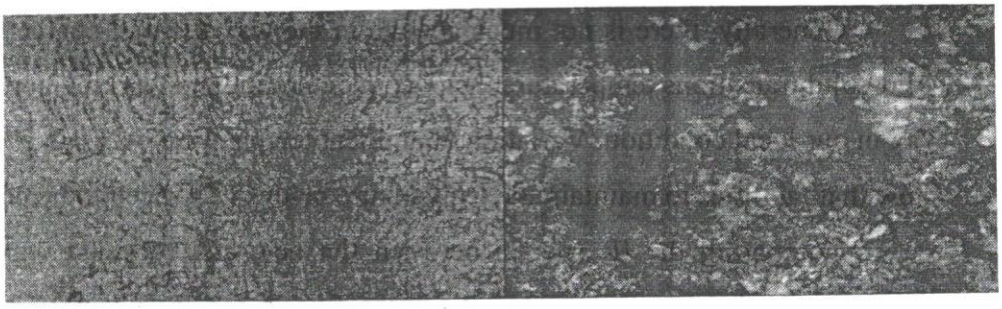

Fig. 7 Wax And ID Clay Surface Under 100X Magnification

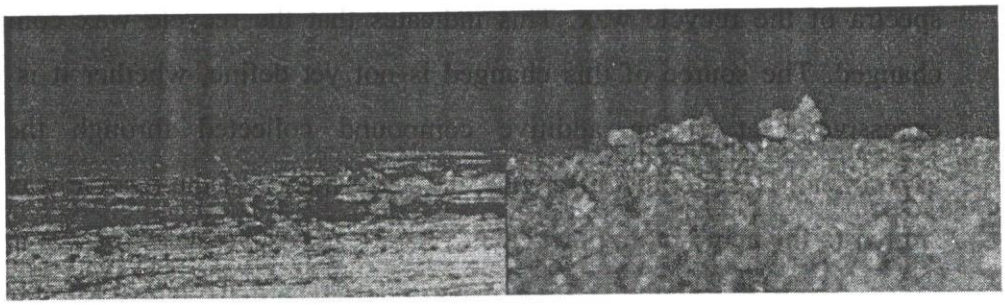

Fig. 8 Wax And ID Clay Edge Cutting Profile 100X Magnification

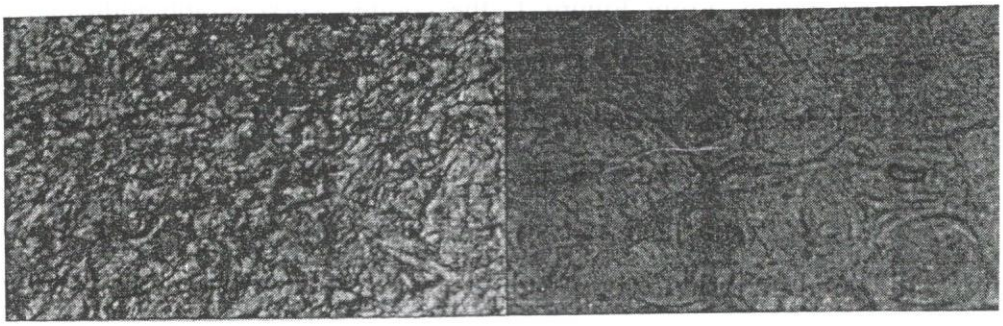

Fig. 9 Wax Surface Heat Deformation Under 10X and 100X Magnification

5.0 DISCUSSIONS

During modelling, manual cutting and scraping is normally in practice. Cutting force used during cutting and scraping is related to the hardness of the material. From the shore hardness test, it found that the hardness of wax is approximately 4 times the hardness of the ID clay. Therefore, we can easily estimate how much the force is required to cut a wax or clay of the same thickness and at the same rate. In case of wax manual shaping, the model maker will have to adjust the working rate to suit the job specification and dimension.

Generally, there is not much change in the wax thermal characteristics. The solid-solid transitions temperature, help us in determine the working condition of the wax in our local condition. Variation of ambient temperature between 27° C to 35° C show that facilities to maintain the temperature below 32°C need to be considered.

Comparing the IR spectra between the new and recycled wax, the peaks presence in both spectra were almost similar. Except for one peak at 1719 represent Ketone of six membered types was not present in the new wax but occurred in the spectra of the recycle wax. This indicates that the recycle wax composition has changed. The source of this changed is not yet define, whether it is an effect of excessive heat or an additive compound collected through the Modelling experiment. Despite this difference, the performance of the recycle wax found to be similar to the new wax in practical.

From the cooling curve experiment, recorded change of volumes at the respective temperature levels can be represents by a graph, corresponding to the cooling period. From Figure 1, the cooling curve graph indicates that between temperature 38° C and 27° C the volumetric change seems to be stabilized. The level of shrinkage at this period is 13.7 % to 14 %. Based on the local temperature range of 27° C and 35° C, the stable period is within the limit.

DSC testing and analysis result shows that, the wax should be used below the solid-solid transition temperature. Since above the transition temperature the wax is in the state of viscous.

In the observations surface profile, wax is much better than the surface of the ID clay. In the real practice, ID clay always requires Dinoc film for quality measures for surface finish and material protection. With wax in practice, the Dinoc film is unnecessary item. The ID clay surface under magnification seems to be very porous with a lot of holes and uneven height. Wax in comparison shows a very solid and rigid surface, with minor pinholes and pitting trace problem.

Through this observation, the surface seems to be dramatically change under the microscopic magnification. Under naked eyes observation, the surface seems to get a new mat finish surface texture which is initially gloss finish. The condition of the surface is similar to a surface after undergo sandblast process. One more fact that learned from this observation is that there is no spot bubble or pinhole and pitting trace problem. May be from the method of exposing to heat we could find a way to improve the surface quality. Further studies should be suggests to finds out the method of controlling the heat exposure for quality measures.

6.0 CONCLUSION

Through this experiment, wax has been proven viable as material in modelling. Its technical properties give us some clear ideas of how to use wax in the local environment. Hot and wet climate in Malaysia gives the ambient temperature range between 27° C to 35° C. This range is lower than the wax softening range between 33° C to 40° C (Estimation figure from sections 5 and 4.3). During the experiment, the studio environment is not air-conditioned.

The wax specific gravity (density) is less than clay as describes in Table 2. The usage of equal volume, given us half of the total weight. This property, allow us to construct the based structure which required less strength to support the material. Furthermore, less weight assisted us in handling and transferring the model.

The wax is harder than clay. The average value wax sample readings (table 7) is A/30:85.8 and the average readings of ID clay sample is A/30:23.1. The wax is 3.7 time harder than the ID clay (Section 4.6). The workability on shaping process required more energy at the same rate of about 4 times. Even though to work with

wax there is more hardship but the surface hardness have given us the assurance that the wax can withstand applied 4 times applied force. Stability of the surface here is the right words to describe the wax capability.

Surface finish is one more characterization that came into consideration when making model. Wax surface finish can be workout to the quality of gloss finish. Both materials have been observes under microscope. The clay surfaces and edges found to be rougher than wax. In normal application with additional cost, to overcome this unevenness, Dinoc film were introduces for improving the quality of the surface finish and protecting the clay from contaminated by coating and painting materials. The understanding of the material properties have given us some assistance in manipulating the material towards the modelling application.

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