Recycling of PVC:
Dissolution Precipitation Method

by

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

JANUARY 2014

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Chemical Engineering Programme

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Approved by,

13/01/2014.

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2014

CERTIFICATE OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(MUHAMAD LUKMAN BIN SAINAL)

ABSTRACT

The increasing amount of PVC waste nowadays has gained increasing importance in the public discussion especially in the ways how it is being disposed. This is due to hazard associated with the chlorine contain in the PVC waste which will cause harm to the environment, people as well as to the equipment involve in handling it. Several ways of disposing PVC waste such as landfilling, incineration, mechanical recycling and chemical recycling techniques are practiced nowadays. Among the techniques, chemical recycling is the most environmental friendly method with the least degree of pollution. However due to the lack of research and high cost of current chemical recycling techniques available, only a small amount of chemical recycling plant can be found worldwide. This paper presents a new economic environmentally sustainable technique for chemical recycling of PVC waste by the means of dissolution and precipitation method.

ACKNOWLEDGEMENT

Alhamdulillah, thanks to the Almighty, Allah s.w.t., this project is finally completed and all results were successfully obtained. All process flows were run smoothly according to the work timeline.

With the exposure to the reality of researching, it is very much understood that researching process is not as easy as it looks. Researching through this study has provided me tools and skills to experienced life as a researcher. Even though there are problems encountered along the way in completing this project, with the help of my supervisor, Dr. Iqbal Ahmed, such problems were managed to be handled wisely. With his assistance and guidance, much information and understanding of this project were successfully obtained and developed through simulation works and literature research. My utmost gratitude goes to him for spending lots of time monitoring all FYP students worked under his supervision.

Not to forget the coordinator, Dr Asna Md Zain for her arrangement and assistance for making all of this possible.

My sincere thank you also goes for all personnel who have directly or indirectly contributed to the completion of this project.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1. INTRODUCTION

1.1 Background of Study

Polyvinyl chloride or PVC is a universal polymer which is widely used in various sectors; building and construction, automotive, packaging, electric and electronic and etc. It has the capability to compound with various type of additives (Braun, 2002), and transform into variety of short-life and long-life products.

In World Vinyl Forum 2007, Steve Brian, the Global Business Director of Chemical Market Association Inc., CMAI reports PVC is ranked as the second highest most demanded polymer in worldwide demand. The demand keeps increasing every year as the application of PVC expanding.

As a result, a large numbers of PVC wastes are produced and most of it is disposed in landfills with other municipal solid wastes. PVC waste contributes quite significant value to the amount of solid wastes. This phenomenon leads to various environmental issues such as land and air pollution. Furthermore, landfilling of PVC waste can cause potential environmental hazards associated with the poisonous chlorine content in the polymer. Besides, landfilling of municipal solid wastes will lead to decreasing of existing landfilling areas. For example in United States, about 80% of waste is dumped into landfills (Braun, 2002). If this rate is continuously occurring, the future will be threatened by diminishing of landfill capacity.

Incineration is another method used to overcome the rapid growth of solid waste. The concept of incineration is to recover the energy from solid waste by means of combustion. However, the presence of PVC cause pollution problems due to high chlorine content mainly hydrochloric acid, chlorine gas, dioxins and when thermal treatment is involved (Borgianni et. al., 2002).

A more convenient and sustainable way to handle such PVC waste is by recycling. It can be done either by chemical or mechanical recycling. Up to now, a lot of scientist and industrialists has come out with variety of chemical and mechanical recycling techniques. They suggested that PVC can be successfully recycled into a variety of products such as bottles, various pipes, pipe fittings and other profiles with good appearance and properties (Sadat & Bakhshandeh, 2011). However, only small amount of PVC waste is recycled in the world.

The review regarding chemical and mechanical recycling technique of PVC will be explained in detail in chapter 2. These two methods are chosen for reviewing because they are the most used recycling technique for PVC plastic waste.

Table 1 shows the comparison of different approaches for disposing of PVC wastes. In this table, four methods for disposing PVC waste are chosen; landfilling, incineration, chemical recycling is and mechanical recycling. The comparison is based on the impact of the recycling techniques to the environment, the cost involved, properties of the products, number of plant around the world and accepting of those techniques in the recent era.

Table 1: The Comparison of Different Approaches of Disposing of PVC Waste (Sadat & Bakhshandeh, 2011)

Method of Disposing	Landfilling	Incineration	Mechanical recycling	Chemical recycling
Sensitivity to impurities	Non-sensitive	Usually non-sensitive	Highly sensitive	Relatively sensitive
Degree of pollution generation	Very high	Very high	low	Usually low
Cost	Low-cost	Usually low-cost Energy	Middle-cost	Usually high-cost
Recycled product(s)	No material recycled	Energy	PVC	Diverse raw materials
Properties of the recycled material	-	Usually energetically not efficient	Dependent on feed material and processing variables of recycling	Dependent on feed material and processing variables of recycling
Number of plants in operation around the world	Large	Large	Fair	Small
Accepting by countries (during the recent decade, especially for developed countries)	Non-acceptable	Non-acceptable	Highly acceptable	Low acceptable

This study is aimed to develop a new economic, sustainable and environmental technique of PVC chemical recycling by the means of dissolution precipitation methods at low temperature. The study will proceed with characterization of the recycled PVC. Experimental methodology, result and discussion will be explained in detail later in section 4 and 5 respectively.

1.2 Problem Statement

Chemical recycling method is one of the methods used to for disposing PVC waste. Among the techniques are hydrogenation, pyrolysis, and gasification. Most of the techniques involve high temperature or the use of catalyst. For example, pyrolysis is conducted at temperature which ranging 500-900°C. As a result, high cost is needed to operate such plant. This explains why only few chemical recycling processing plant are developed in the recent years compare to other type of recycling plant such as mechanical recycling plant.

Therefore this study is conducted to investigate a new chemical recycling technique which is energy efficient and sustainable by the means of dissolution and precipitation techniques.

This method is aimed to recover the PVC from PVC pipe at temperature as low as 40°C by using solvent. The correct ratio of solvent to polymer waste, the reusable amount of the solvent, characterization of the recycled PVC shall be performed to test the effectiveness of this proposed method.

1.3 Objectives and Scope of Study

In this experiment, PVC pipe will be used to be recycled by the proposed method; dissolution and precipitation. The objectives of this study are:

1. To determine the ratio polymer to solvent in order to dissolve PVC pipe completely in the selected solvents at constant temperature of 40°C within one hour.
2. To determine the amount of the selected precipitant used to precipitate the recycled PVC.
3. To recover and determine to what extent the solvent can be reused.
4. To perform characterization to the recycled PVC and the solvent.

CHAPTER 2
LITERATURE RIVIEW

2. LITERATURE RIVIEW

2.1 Properties of PVC

Table 2 shows the characteristics of PVC. The characteristics of PVC are explained qualitatively based on tensile strength, chemical resistance, workability, cost, consistency and flammability properties.

Table 2: Characteristic of PVC
(Material Properties- Plastic Properties, 2013)

Criteria	Explanation
Strength	PVC combines tensile strength and stiffness for the toughest applications
Chemical Resistance	PVC is resistance to most acids and alkali solutions
Workability	PVC can be machined, cut, welded and glued for fabrication versatility
Low Cost	PVC is an economical cost for fabricating equipment, tanks, pumps, and etc.
Consistency	PVC is extruded through most of the available gauges for dimensional consistency
Flammability	PVC is self-extinguishing

Table 3 shows the properties of PVC at 23°C. This table explains the properties of PVC quantitatively based on physical, mechanical, thermal, electrical and chemical properties. Standards used for testing are also provided for references.

Table 3: Properties of PVC
(Material Properties- Plastic Properties, 2013)

Property	ASTM Test Method	Units	PVC
Physical			
Density	D 792	g/cc	1.42
Water Absorption	D 570	%	0.06
Cell Class	1784		12454-B
Rockwell Hardness	D 785	R Scale	115
Shore Durometer	D 2240	D	89
Mechanical			
Tensile Modulus	D 638	psi	411,000
Yield Strength	D 638	psi	7,500
Flexural Modulus	D 790	psi	481,000
Yield Strength	D 790	psi	12,800
Izod Impact	D 256	ft-lb/in	1.0
Thermal			
Vicate Softening Point	D 1525	°F	181
Heat Deflection Temperature	D 648	°F	179
Linear Coefficient of Expansion		in/in/°F	3.2×10^{-5}
Flammability	D 635	—	Self-Extinguishing
Flammability	UL 94	—	V-0
Flame Spread	E 84	—	15
Electrical			
Volume Resistivity	D 257	ohm/cm	5.4×10^{15}
Dielectric Constant	D 150	60 Hz	3.19
Dissipation Factor	D 150	60 Hz	0.0096
Loss Index	D 150	60 Hz	0.030
Dielectric Strength	D 149	V/mil	544
Chemical			
Chemical Resistance	D 1784	—	Class B

2.2 Mechanical Recycling of PVC

Mechanical recycling is a popular technique used for recycling in plastic industry. Mechanical recycling is a preferable method whenever enough quantities of homogenous and source separated waste stream are available Figure 1 illustrates the typical mechanical recycling process.

In the first stage, the plastic waste will be separated either manually by hand or with the assists of machine. Then it will be cut into small pellets in a high speed machine (e.g.: grinner).Once small pellets is obtained, they will be cleaned by detergent or water spray. Lastly, they will be fed to converter and melt down ready to be change to new plastic products.

Figure 1: Illustration of mechanical recycling process

At global level, it has been estimated that the mechanical recycling of post-consumer and pre-consumer PVC wastes will be 1.4 million tons in 2010 (Yarahmadi et. al, 2003). However, the price the value of recycled PVC will be varies. The most important factors that determine the final cost of the recycled material are the available volumes of the recyclable wastes, the quality and the cost of sorting and regeneration.

Table 4 summarizes common problems involving mechanical recycling of PVC summarize by Sadat & Bakhshandeh, (2011). Usually the problems areised will be due to the inhomogenity of PVC plastic waste, high sensitivity of PVC materials to environment and the presence of additives in PVC products.

Table 4: Problems involving mechanical recycling of plastic wastes

No	Problems involving mechanical recycling of plastic wastes containing PVC
1	Inhomogeneity of PVC plastic waste • Inhomogeneity of PVC plastic waste gives rise to a material which is very difficult to process and/or has inferior mechanical and physical properties.
2	High sensitivity of PVC materials to environment • Will results continuous changes in its morphological structures and properties due to shear stress during processing of PVC
3	The presence of additives • Additive which present in the PVC waste might change or accelerate dehydrochlorination process.

To overcome the problem which regard to mechanical recycling, it is advisable to combine PVC with other thermoplastic. With the right combination, it is proven in many literatures these techniques can improve the characteristic of recycle PVC.

2.3 Chemical Recycling of PVC

Besides the material recycling of PVC there is several attempts to prepare low molecular products from PVC by chemical or thermal treatment (Braun, 2002). The chemical or feedstock recycling is based on the idea of breaking up polymer waste to the basic chemicals by means of heat, chemical agents and catalysts

Table 5 shows the comparison of various chemical recycling techniques; thermal cracking and pyrolysis. Thermal cracking is among the prominent chemical recycling technique of PVC. The concept of thermal cracking is the process whereby complex organic molecules are broken down into simpler molecules such as light hydrocarbons, by the breaking of carbon-carbon bonds. In the other hand, pyrolysis is a process involving the decomposition of organic material where high temperature is applied.

Table 5: Comparison of various chemical recycling techniques

Techniques	Review
Thermal cracking	The main intermediate product is polyene (which later on continue to degrade and become other products which is highly determined by process parameter; type of atmosphere, temperature and residence time).Following is the example of thermal cracking products: I. Polyene (the main intermediate product) II. Hydrochloric acid (in inert atmosphere) III. CO, CO_2 and H_2 (In steam atmosphere at high temperature)
Pyrolysis	Products: I. Hydrocarbon(oil) II. Soot III. HCL IV. Chlorinated hydrocarbon Disadvantages of this techniques: I. Corrosion of equipment

2.4 Characterization of PVC

According to Matuschek et. al., (2000), in recycling of PVC, the raw material for the process needs to be checked for PVC content and for additional polymers and on the other hand, the recycled PVC needs to be characterized. This is baecause in most PVC product, it consist of combination of PVC and and other additives such as plasticizers, modifiers, fillers, lubricants and stabilizer (Yarahmadi et. al., 2003). These additives have significant impact especially on the mechanical properties of the PVC.

EGA method among a good method for characterization of raw material for recyling product. They can give information about the PVC content as well as the inorganic filler materials and softeners which are important values for the recycling process (Matuschek et. al, 2000). TG-FTIR and TG-MS also can be used to determine the compostion of compound present in the PVC. In the other hand Scanning Electron Microscopy (SEM) analysis was used to perform morphological characterization (Gizli et. al., 2012).

Yarahmadi et. al., (2011) performing an experiment in investigateing the effects of repeated extrusion on the properties and durability of rigid PVC scrap. The material(PVC) was characterised after each extrusion using measurements of colour, degree of gelation, stress–strain at break and UV-Vis-NIR spectroscopy (Yarahmadi et. al,, 2001).

CHAPTER 3
METHODOLOGY

3. METHODHOLOGY

3.1 Research Methodology

Figure 2 explain the methodology used for this study. It will start with preparation of sample and end with characterization of sample. The steps involved are explained in detail in the chapter.

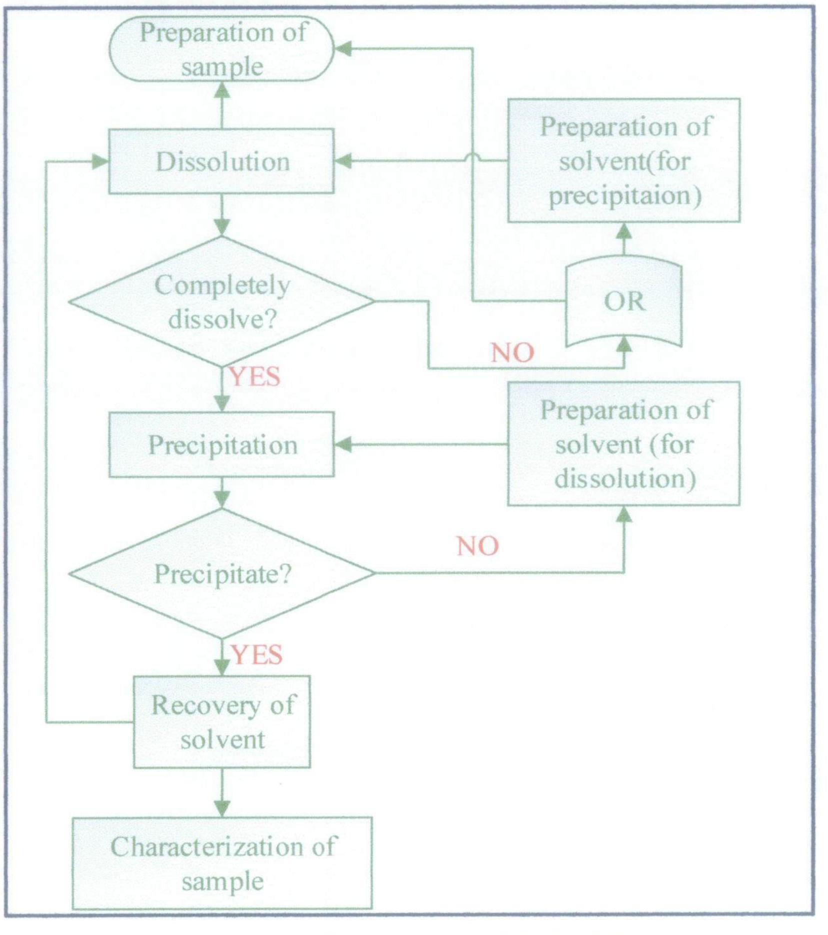


Figure 2: Summary of Experimental Methodology

Sample preparation

Figure 3 illustrates the steps involve in sample preparation. PVC pipe is collected from construction area and wash to remove any impurities (concrete, glue and etc.) which stick to its wall. The pipe is then cut into several segments before proceeding to granulation and shred to size of 5mm. The PVC pipe is further wash by distilled and deionized water before being dry at temperature of 30°C.

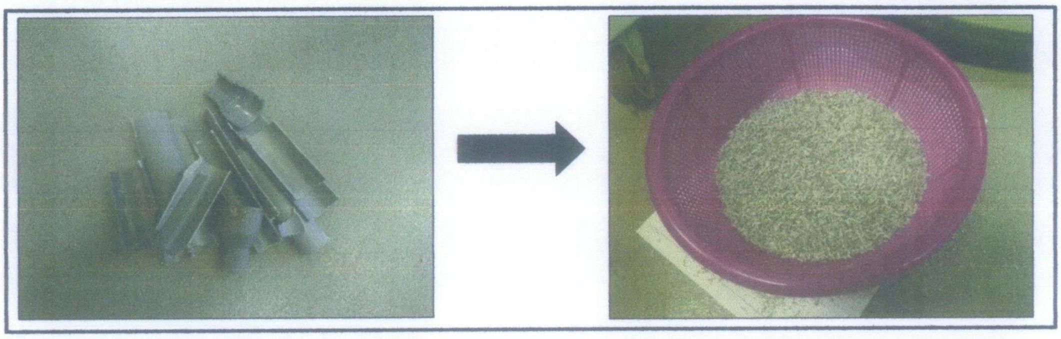


Figure 3: Sample preparation

Dissolution

For purpose of dissolution, two solvents are used to dissolve PVC which are N-Methyl-2-pyrrolidone, NMP and dimethylacetamide, DMAC. Table 6 shows the ratio of solvent to polymer. Solvent may refer to NMP or DMAC while polymer is referred to the used PVC. The ratio is calculated based on mass percent.

Table 6: Solvent to polymer ratio

Solvent	Solvent to polymer ratio by mass percent
NMP	70% to 30%
	80% to 20%
	85% to 15%
DMAC	70% to 30%
	80% to 20%
	85% to 15%

Figure 4 shows the set up for dissolution process. By using hot plate, the solution is heated to 40°C and is stirred by magnetic stirrer in a close system for an hour. If PVC not completely dissolves even after 90 to 15 percent of solvent to polymer ratio, the ratio of polymer should be further decreases.

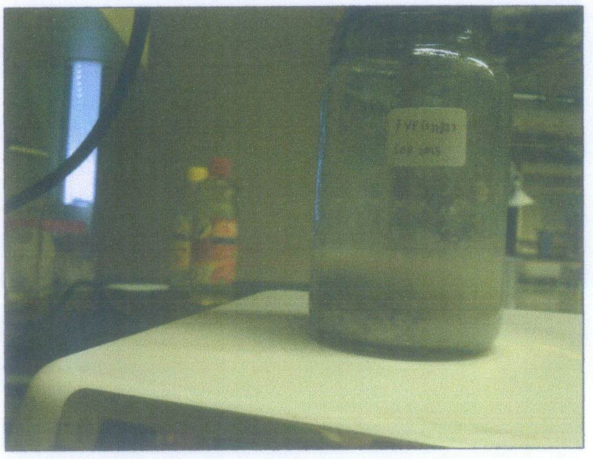


Figure 4: Dissolution Process

Precipitation:

Once the dissolve homogenous PVC containing solution is obtained, it is left to cool at room temperature. Figure 5 illustrate the set up used for precipitation process. Three solvents are introduced as precipitant which are acetone, water and methanol. The amount of precipitant needed for precipitation to occur is recorded.

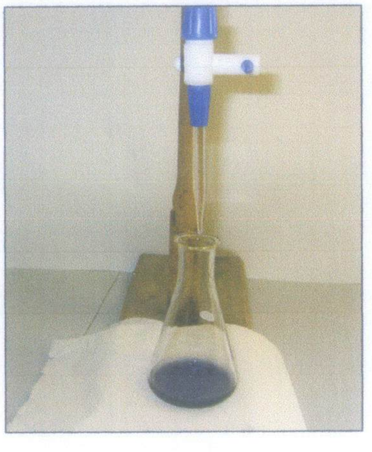


Figure 5: Precipitation Process

Recovery of solvent:

The precipitate form will be separated for characterization and the recovered solvent will be reused again. Figure 6 shows the separation of precipitate from the solution. By us by using filter paper at size 100 micron, the solid precipitate is separated from the solution.

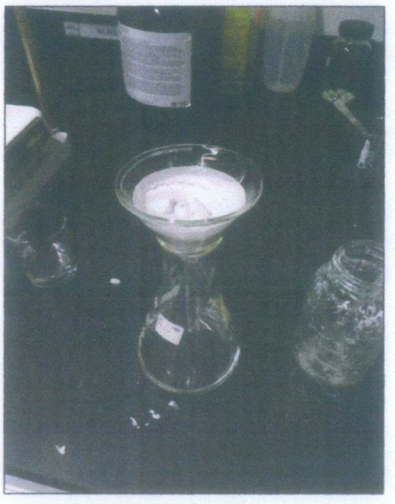


Figure 6: Separation of Precipitate and Solvent

Once the recycled PVC is separated, the recovered solvent is heated to remove any remaining precipitant. Then, the solvent is reused. A part of it will be used for characterization.

The precipitate is dried at temperature of 40°C in the oven.

Characterization:

Once the precipitate is dried, it is characterized and test for it mechanical strength. Tensile strength test and FTIR are used to determine the tensile strength and composition of the recycled PVC.

3.2 Gantt chart

Table 7 shows the management Gantt chart for this study in semester 2. The detail of work is explained together with the time frame for each work to be accomplished.

Table 7: Gantt chart

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Project Work Continues	■	■	■	■	■	■	■	Mid-Semester Break								
2	Submission of Progress Report									●	11th Nov 2013						
3	Project Work Continues									■	■	■	■	■			
4	Pre-EDX												●	2th Dec 2013			
5	Submission of Draft Report										9th Dec			●			
6	Submission of Dissertation (soft bound)											16th Dec 2013			●		
7	Submission of Technical Paper												16th Dec 2013		●		
8	Oral Presentation												23th – 27th Dec 2013			●	
9	Submission of Project Dissertation (Hard Bound)												2nd Jan 2014				●

● Suggested milestone
■ Process

3.3 Project Activities and Key Milestones

Table 8 shows the key milestone and project activity for the study. The table is developed based on timeframe planned in Gantt chart as explained is section 3.2.

Table 8: Key milestone and project activities

Key Milestone	Project Activities
Week 2-12	-Performing the experimental procedure for the study -Updating progress report and technical report -Preparation for oral presentation -Meeting with SV
Week 8	-Submission of progress report -Meeting with SV
Week 12	-Submission of project dissertation (softcopy) -Meeting with SV
Week 13	-Submission of technical paper -Meeting with SV
Week 14	-Oral presentation
Week 15	- Submission of project dissertation (hardcopy)

3.4 Tools

These are the chemicals that will be used in this project:

I. NMP
II. DMAC
III. Acetone
IV. Methanol

These are the list of glassware/apparatus that will be used in this project:

I. Beaker
II. Two neck round bottle
III. Filter paper
IV. Conical flask
V. Sample bottle
VI. Pipette
VII. Measuring cylinder
VIII. Filter tunnel

These are the equipment or tools that will be used in this project:

I. Tensile strength test machine
II. FTIR
III. Hot plate with magnetic stirrer

There might be other materials or equipment will be added along the completion of this project.

CHAPTER 4
RESULTS AND DISCUSSIONS

4. RESULTS AND DISCUSSIONS

4.1 Data Gathering and Analysis

Dissolution (trial 1):

Table 9 shows the results obtained from dissolution trial 1. Both solvent NMP and DMAC are used to dissolve used PVC with initial solvent to polymer ratio at 70 to 30 by mass percent. The observations are recorded as follows:

Table 9: Dissolution process observation (trial 1)

Solvent	Solvent to polymer ratio by mass percent	Observations
NMP	70% to 30%	- PVC is not completely dissolve - Very viscous solution is obtained
	80% to 20%	- PVC is not completely dissolve - Moderate viscous solution is obtained
	85% to 15%	- PVC is not completely dissolve - Slightly viscous solution is obtained
DMAC	70% to 30%	- PVC is not completely dissolve - Very viscous solution is obtained
	80% to 20%	- PVC is not completely dissolve - Moderate viscous solution is obtained
	85% to 15%	- PVC is not completely dissolve - Moderate viscous solution is obtained

From the observation, for every suggested solvent to polymer ratio, all of them are not dissolving completely at temperature of 40°C within one hour.

It is observe some of the PVC pellets are stuck at the wall of the glass as shown in the figure 7. The arrow in the figure pointed to the PVC pallets which get stuck to the glass wall although a continuous stirring is given.

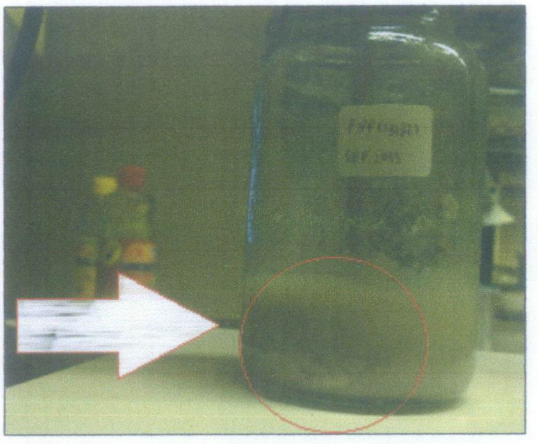


Figure 7: PVC Pellet Get Stuck to the Glass's wall

As a result, the area of PVC pipe which stick to the wall is not exposed to the solution causing the process of dissolution very slow. This phenomenon occurs due to the stirring system problem which is to slow. A more vigorous stirring system is suggested to solve this problem.

Dissolution (trial 2):

The major problem identified from the failure of dissolving used PVC pipe is the slow stirring system as discussed in dissolution trial 1. For dissolution trial 2, some changes are made for the stirring system. Instead of the solution automatically being stirred by the magnetic stirrer, a manually stirring with glass rode for every 10 minutes interval within one hour is introduced.

Table 10 shows the result for dissolution trial 2. The same solvent to polymer ratio is used as in trial 1. Both NMP and DMAC completely dissolve the used PVC with solvent to polymer ratio at 85 to 15 percent by mass percent. It is proven the changes made to the stirring system is not only successfully eliminated the sticky problem of used PVC pellet to the wall, but completely dissolved the used PVC pipe.

Table 10: Dissolution process observation (trial 2)

Solvent	Solvent to polymer ratio by mass percent	Observations
NMP	70% to 30%	- PVC is not completely dissolve - Very viscous solution is obtained
	80% to 20%	- PVC is not completely dissolve - Moderate viscous solution is obtained
	85% to 15%	- PVC is completely dissolve - Slightly viscous solution is obtained
DMAC	70% to 30%	- PVC is not completely dissolve - Very viscous solution is obtained
	80% to 20%	- PVC is not completely dissolve - Moderate viscous solution is obtained
	85% to 15%	- PVC is completely dissolve - Moderate viscous solution is obtained

Precipitation:

Both NMP/PVC and DMAC/PVC at ratio of 85 % and 15 % are used for the next stage of experiment which is precipitation Table 11 shows the summary of precipitation process. The amount of precipitant used and observation are recorded.

Table 11: Summary of Precipitation Process

Solution	Precipitant	Amount of precipitant used (ml)	Observation
NMP/PVC	Acetone	500	No precipitate form
	Water	10	A bulk solid form
	Methanol	35	Precipitation occur and small solid powder is obtained
DMAC/PVC	Acetone	500	No precipitate form
	Water	12	A bulk solid form
	Methanol	38	Precipitation occur and small solid powder is obtained

From the observation, acetone is not able to precipitate both NMP/PVC and DMAC/PVC solution. This shows acetone is not a precipitant agent for this solution. Meanwhile, water was able to precipitate the PVC. However the process is incomplete since bulk solid is obtain. In the other hand, methanol is the most efficient precipitant since it can precipitate both solutions completely.

Recovery of solvent:

Figure 8 shows the recovery of solvent process. Once the precipitate is separated from the solvent, the solvent is recovered by the means of heating to remove excess precipitant. As a result, the pure solvent is recovered and can be reused.

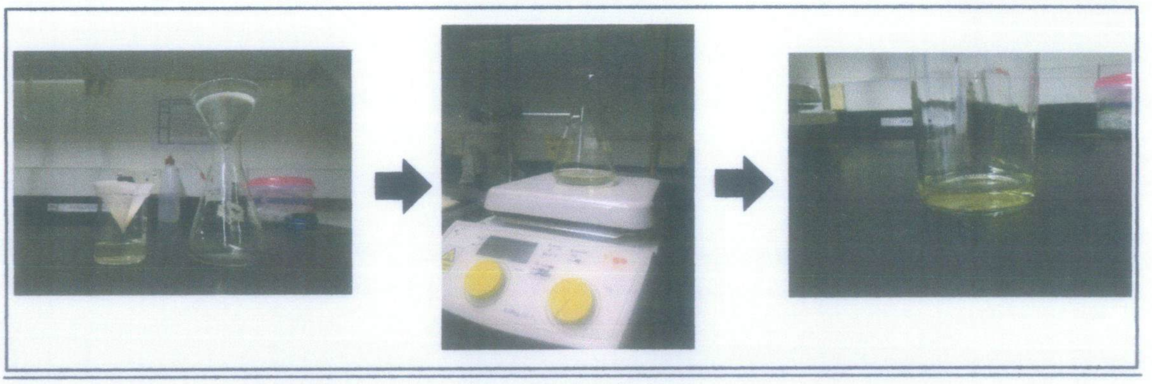


Figure 8: Recovery of solvent process

The recovery of solvent from water is time consuming since water boiling point is quite high, 100°C. In the other hand the recovery of solvent from methanol is much easier and faster since the boiling point of methanol is much lower which is 64.5°C. In term of economical perspective, the used of methanol is more economic since low energy is used to remove the precipitant from the solvent. Besides only low temperature for separation of solvent/precipitant, time can be saved too.

The recovered solvent is reused.

Characterization recycled PVC

FTIR:

Four peaks originating from soft PVC as stated by literature are compared with the samples. According to SHIMADZU Corp. in Infrared Spectra of Polyvinyl Chloride, for soft PVC, the peaks in the vicinities of 1425 cm^{-1}, 959 cm^{-1} and 610 cm^{-1} are peaks originating from the PVC but when other additives such as calcium carbonate and silicate salt are also included as additives, the peaks near 1425 cm^{-1} and 959 cm^{-1} are overlapped and are therefore difficult to confirm. Therefore, in many infrared spectra of soft PVC, verification of PVC is accomplished using the C – Cl stretching vibration near 610 cm^{-1}. A band near 1720 cm^{-1} is often observed in the infrared spectra of commercial samples of PVC.

Figure 9 shows the result obtains from FTIR for used PVC pipe. For used PVC pipe, two peaks are seen exist which are 1425cm^{-1} and 610 cm^{-1}. This discovery confirms the sample used is PVC. However they are two peaks which are missing according to the FTIR test which are 1720 cm^{-1} and 959 cm^{-1}. This is due to the various additives presents in the used PVC pipe cause the peaks to overlap. Therefore it is difficult to confirm.

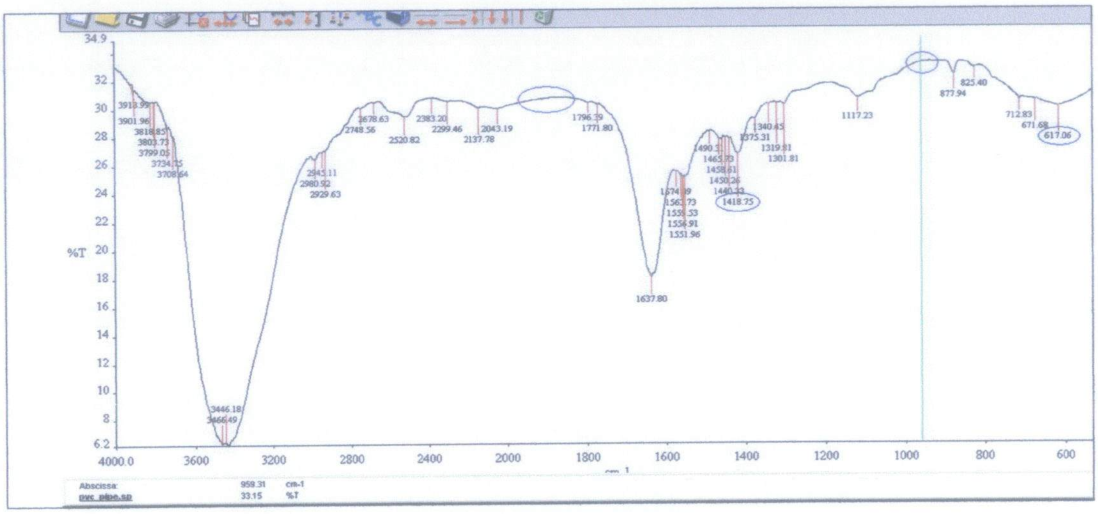


Figure 9: FTIR Results - Used PVC pipe

Figures 10 and 11 shows the result obtains from FTIR for precipitate from used PVC recycled in NMP + water and used PVC recycled in NMP + methanol. It is observed for both results, there are only one peak for soft PVC exist which is a peak nearer to 1425cm^{-1}. For precipitate from used PVC recycled in NMP + water, the identified peak is 1427.6 cm^{-1} where used PVC recycled in NMP + methanol is 1423 cm^{-1}.The other three important peaks are seen vanished including the most important one which is peak at 610 cm^{-1} (C-Cl bond). This shows the C-Cl element is disappeared during the recycling process.

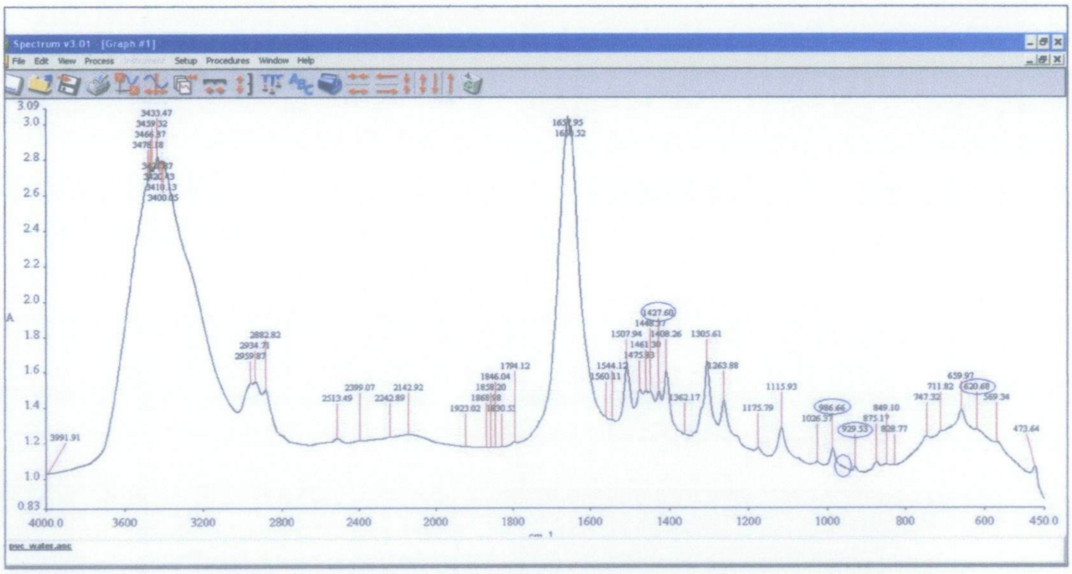


Figure 10: FTIR Results - PVC/NMP precipitated by water

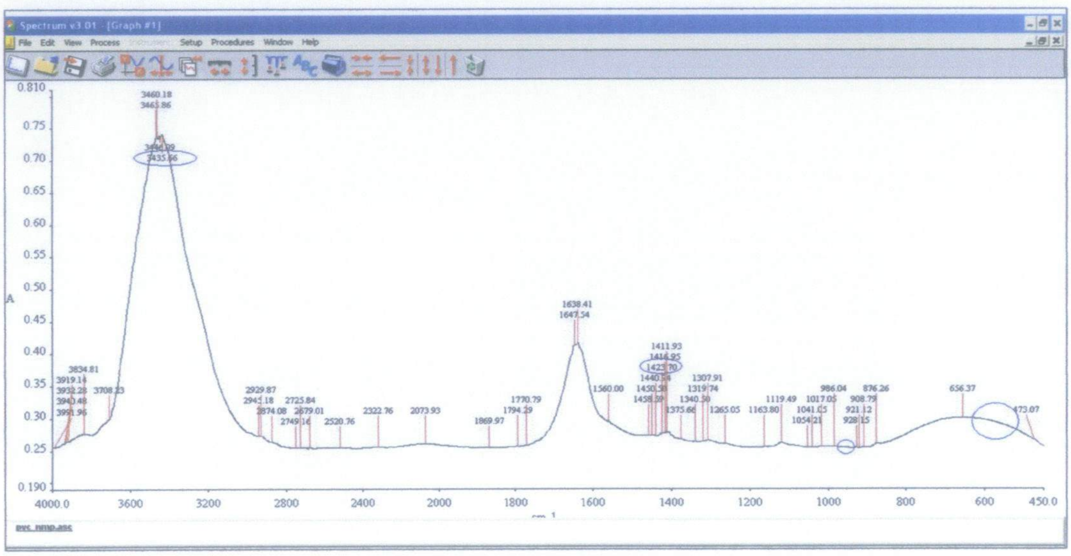


Figure 11: FTIR Results - PVC/NMP precipitated by methanol

Figure 12 shows the last sample which is used PVC recycled in DMAC + methanol. From the observation, two initial peaks from used PVC nearer to 1425cm^{-1} and 610 cm^{-1} which is peaks 964.75 cm^{-1} and 1716.83 cm^{-1} is successfully preserved. Beyond that, another two peaks originating from soft PVC which are 1720 cm^{-1} and 959 cm^{-1} are successfully recovered. This discoveries show, the dissolution by DMAC was not only preserved the initial important peak of PVC, but also manage to recover another two peaks originating from soft PVC.

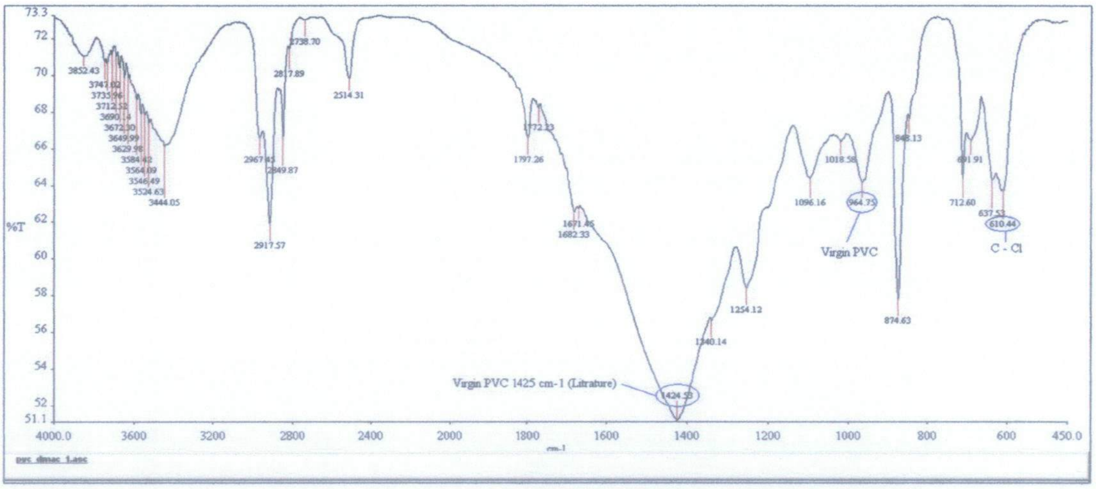


Figure 12: FTIR - Results - PVC/DMAC precipitated by methanol

Table 12 summarizes the FTIR result for the entire samples:

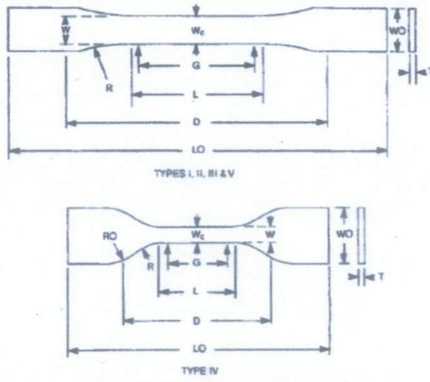
1. Used PVC pipe
2. Precipitate from used PVC recycled in NMP + water
3. Precipitate from used PVC recycled in NMP + methanol
4. Precipitate from used PVC recycled in DMAC+ methanol

Table 12: FTIR results

Wavelength number originating from soft PVC (cm-1)		1720	1425	959	610
Wavelength number from FTIR (cm-1)	Used PVC pipe	N/A	1418.75	N/A	617.06
	PVC/NMP + H2O	N/A	1427.6	N/A	N/A
	PVC/NMP + Me OH	N/A	1423.7	N/A	N/A
	PVC/DMAC + Me OH	1716.83	1424.53	964.75	610.44

Mechanical tensile strength test:

Mechanical tensile strength test is performed by preparing three specimens of recycled PVC (PVC/DMAC precipitated by methanol) according to ASTM D638 standard as shown in figure 13. In the figure, the dimension of specimens is stated according to specimen type. In this study, specimen type I is selected for testing purpose.



Specimen Dimensions for Thickness, T, mm (in.)[A]

Dimensions (see drawings)	7 (0.28) or under		Over 7 to 14 (0.28 to 0.55), incl	4 (0.16) or under		Tolerances
	Type I	Type II	Type III	Type IV[B]	Type V[C,D]	
W—Width of narrow section[E,F]	13 (0.50)	6 (0.25)	19 (0.75)	6 (0.25)	3.18 (0.125)	±0.5 (±0.02)[B,C]
L—Length of narrow section	57 (2.25)	57 (2.25)	57 (2.25)	33 (1.30)	9.53 (0.375)	±0.5 (±0.02)[C]
WO—Width overall, min[G]	19 (0.75)	19 (0.75)	29 (1.13)	19 (0.75)	...	+ 6.4 (+ 0.25)
WO—Width overall, min[G]	...	...	...	...	9.53 (0.375)	+ 3.18 (+ 0.125)
LO—Length overall, min[H]	165 (6.5)	183 (7.2)	246 (9.7)	115 (4.5)	63.5 (2.5)	no max (no max)
G—Gage length[I]	50 (2.00)	50 (2.00)	50 (2.00)	...	7.62 (0.300)	±0.25 (±0.010)[C]
G—Gage length[I]	...	...	...	25 (1.00)	...	±0.13 (±0.005)
D—Distance between grips	115 (4.5)	135 (5.3)	115 (4.5)	65 (2.5)[J]	25.4 (1.0)	±5 (±0.2)
R—Radius of fillet	76 (3.00)	76 (3.00)	76 (3.00)	14 (0.56)	12.7 (0.5)	±1 (±0.04)[C]
RO—Outer radius (Type IV)	...	...	...	25 (1.00)	...	±1 (±0.04)

Figure 13: Specimen dimensions

The specimens are prepared by using compression molded machine. Figure 14 illustrates the specimen preparation steps. Recycled PVC is molded at temperature of 190°C for 15 minute. Then the specimen obtained is cooled down under compression to temperature of 40°C.

Molding process	cooling process	Final specimen

Figure 14: Specimen preparation process

The specimens is then tested for it tensile properties. Figure 12 shows the specimen is placed inside the tensile strength test machine during the test conducted. Speed rate at 50 mm/min is applied to the specimens during the mechanical tensile strength test.

Figure 15: Tensile strength test machine

The full report of mechanical strength test can be obtained from Appendix 1. Table 13 shows summary of result obtains from mechanical tensile strength test. From the results obtained, it is observed the lowest tensile strength is specimen A, 10.846 N/mm^2, followed by specimen C, 15.326 N/mm^2 and specimen B, 19.748 N/mm^2.

Table 13: Mechanical strength test summary

Specimen	Area (mm^2)	Max. load (N)	Yield strength (N/m)	Elongation at break (%)	Tensile strength (N/mm^2)
A	47.394	514.051	1321156.667	2	10.846
B	48.343	954.674	6196362.001	2	19.748
C	46.975	719.944	2489955.662	2	15.326

As stated by Kogyo Chosakai Publishing Co. Ltd. (1990) the tensile strength of soft PVC ranging from 6.9-25 N/mm^2. Therefore it is confirmed the recycled PVC is soft PVC.

4.2 Experimentation

The experimentation methodology is explained in section 3.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5. CONCLUSION AND RECOMMENDATION

Conclusion:

In conclusion both NMP and DMAC were able to completely dissolve PVC at 85% to 15 % of solvent to polymer ratio. However dissolution by using NMP is caused the C-Cl bond disappear during the process. It is proven from FTIR results.

Precipitation by using methanol is seen as the most effective compare to water since small powder of recycled PVC is obtained. Acetone in the other hand was unable to precipitate the solution. Dissolution and precipitation by using DMAC and methanol is proven as the best option since they manage to recycle the PVC as similar to soft PVC proven by FTIR and mechanical strength test.

Recommendation:

The successfulness of recycling the PVC as almost as similar to soft PVC is good in a way that the recycled PVC can be directly convert to desire product since the recycling manage to recover PVC together with the additives from the used PVC. However it is better if the process only recover the hard PVC (without additives) since there will be more freedom to compound the recycled PVC with other additives to convert it to variety of product with variety of chemical and physical characteristic.

Therefore, it is advised to revise the process either by introducing new steps, solvent and etc. so that this recycling technique will be able to recycle the PVC as similar to hard PVC.

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APPENDIX

APPENDIX 1: Mechanical strength test results

PENDIX 1.1: Specimen A

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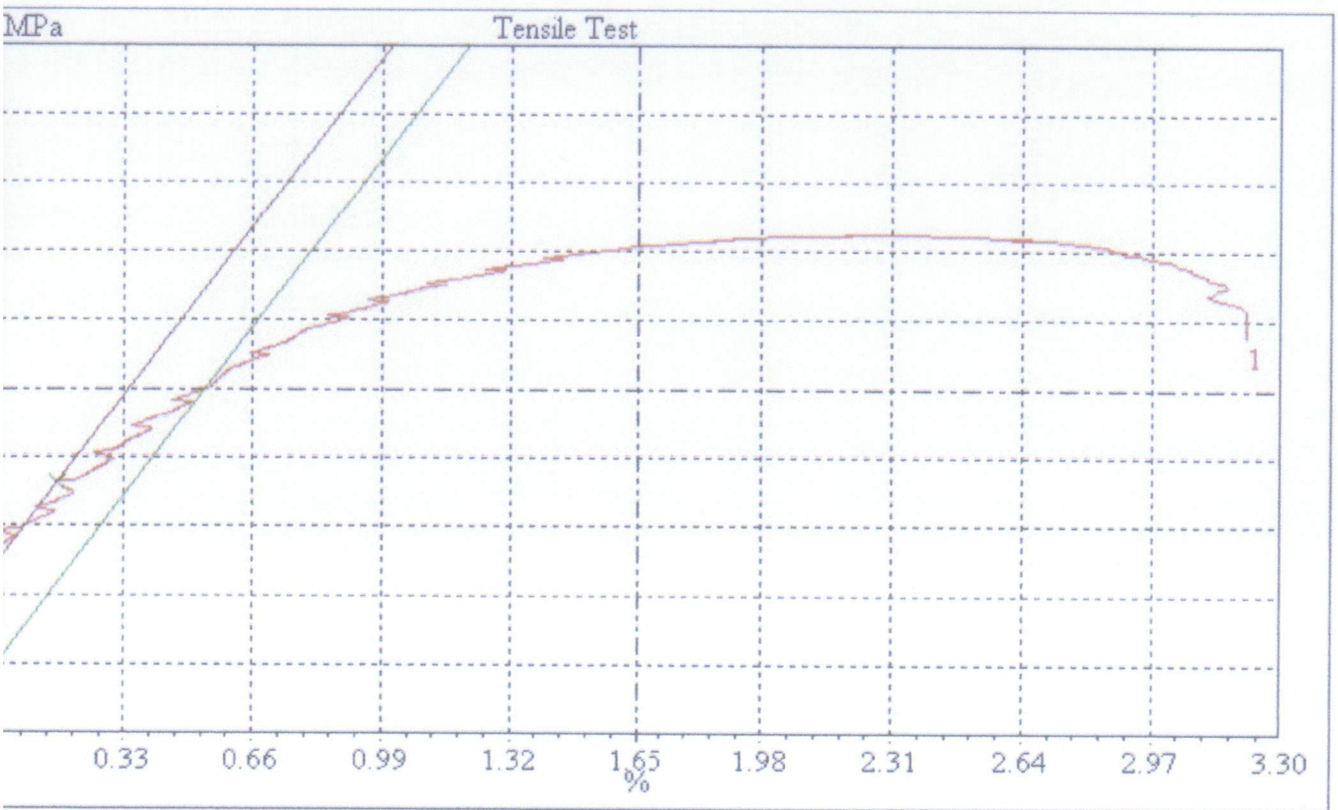
Tensile Test Report

BANDAR SERI ISKANDAR

:rial : PVC
Method : ASTM D638

Test Speed : 50.000 mm/min

No.	Width mm	Thickness mm	Area mm^2	Max. Load N	Yield strength N/m	Elongation@Break %	Tensile Strength N/mm^2
	12.196	-0.058	47.394	514.051	1321156.667	2.000	10.846
	---	---	---	---	---	---	---
	---	---	---	---	---	---	---
	---	---	---	---	---	---	---
	---	---	---	---	---	---	---
:age	12.196	-0.058	47.394	514.051	1321156.667	2.000	10.846
N-1)	0.000	0.000	0.000	0.000	0.000	0.000	0.000



ENDIX 1.2 : Specimen B

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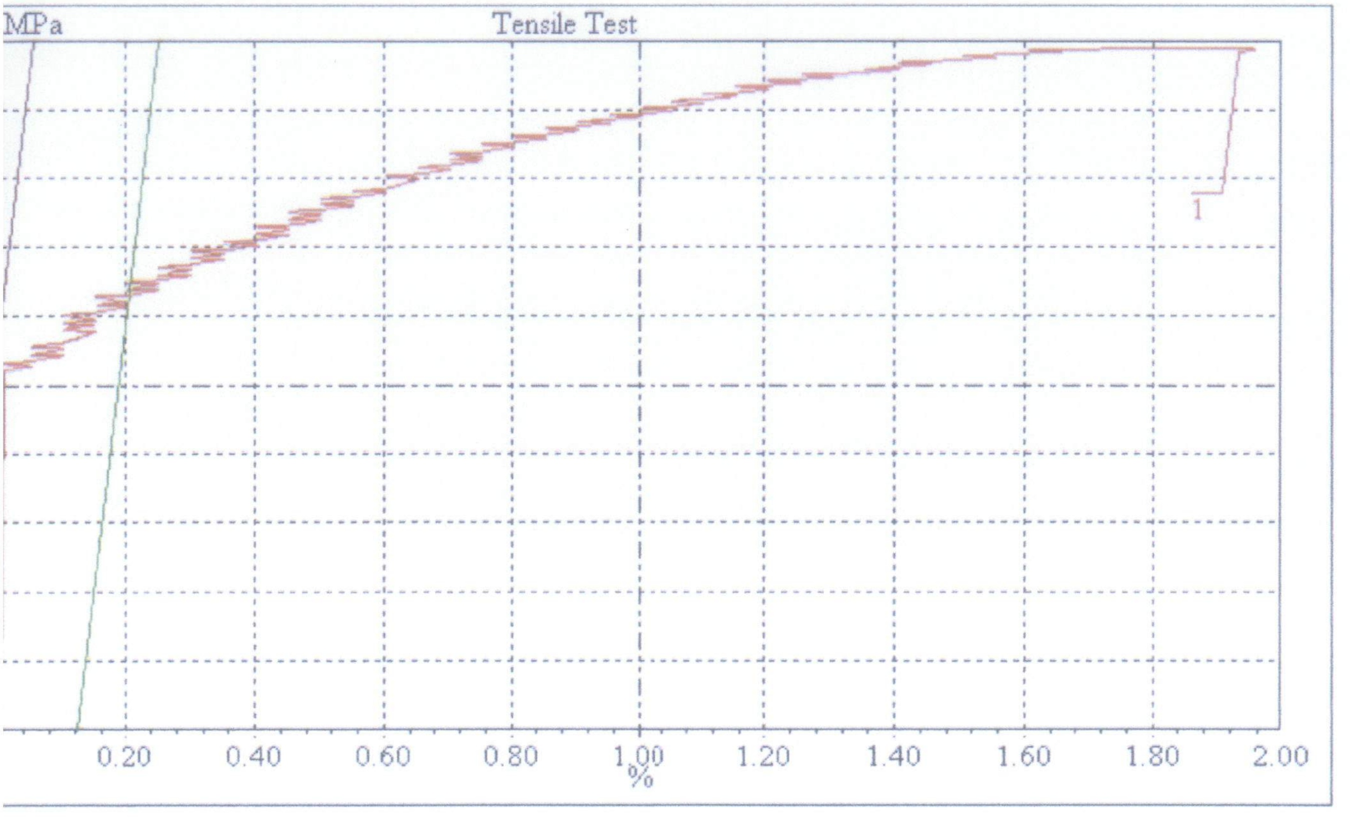
Tensile Test Report

BANDAR SERI ISKANDAR

rial : PVC
Method : ASTM D638

Test Speed : 50.000 mm/min

No.	Width mm	Thickness mm	Area mm²	Max. Load N	Yield strength N/m	Elongation@Break %	Tensile Strength N/mm²
	12.104	-0.153	48.343	954.674	6196362.001	2.000	19.748
	---	---	---	---	---	---	---
	---	---	---	---	---	---	---
	---	---	---	---	---	---	---
	---	---	---	---	---	---	---
rage	12.104	-0.153	48.343	954.674	6196362.001	2.000	19.748
I-1)	0.000	0.000	0.000	0.000	0.000	0.000	0.000



PENDIX 1.3: Specimen C

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Tensile Test Report

BANDAR SERI ISKANDAR

rial : PVC
Method : ASTM D638

Test Speed : 50.000 mm/min

No.	Width mm	Thickness mm	Area mm^2	Max. Load N	Yield strength N/m	Elongation@Break %	Tensile Strength N/mm^2
	12.082	0.393	46.975	719.944	2489955.662	2.000	15.326
	---	---	---	---	---	---	---
	---	---	---	---	---	---	---
	---	---	---	---	---	---	---
	---	---	---	---	---	---	---
rage	12.082	0.393	46.975	719.944	2489955.662	2.000	15.326
N-1)	0.000	0.000	0.000	0.000	0.000	0.000	0.000