RECYCLING OF ACRYLONITRILE BUTADIENE STYRENE FROM USED REFRIGERATOR MATERIAL

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By

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DECLARATION

I here declare that this thesis has been compiled by me and that it's a record of my research work. Never has it been presented in any previous application for higher degree and all the source of information is specifically acknowledged by means of references.

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Aminu Omar Aroke

CERTIFICATION

This thesis entitled "Recycling of ABS from used refrigerator material" by Aminu, Omar Aroke meets the regulations governing the award of Master of Science (Chemical Engineering) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

I dedicate this work to my late mother, Madam Rukayat Aminu and my late grandmother, Madam Aishat Zubair.

ACKNOWLEDGEMENT

All thanks and praises be to almighty Allah the master of the Day of Judgment for his guidance and protection upon me for making this work a success.

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ABSTRACT

Properties of recycled acrylonitrile-butadiene-styrene (ABS) from different brands of discarded refrigerators were investigated in this work. Solvent extraction method was adopted at room temperature. Three different solvents benzene, toluene and tetrahydrofuran were screened for the dissolution of the ABS. Tetrahydrofuran (THF) was found to be the most suitable solvent with solubility parameter of 9.79 cal/cm^3 which was close to the solubility parameter of Acrylonitrile-butadiene-styrene of 9.4cal/cm^3. Fourier Transmission Infrared (FTIR) analysis indicated presence of ABS in the materials recycled from all the refrigerator brands. However, the recycled ABS from Matsui refrigerator was found to have mechanical properties closest to those of virgin ABS, with tensile strength, modulus of elasticity and flexural strength of 31.66MPa, 1021MPa and 60.18MPa respectively, as compared to the virgin ABS tensile strength, modulus of elasticity and flexural strength of 48.3 MPa, 1312MPa and 65.75MPa respectively. The recycled ABS can be used directly for appliances production and as blend with other polymer materials.

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LIST OF ABBREVIATIONS DEFINITIONS AND SYMBOLS

ABS	Acrylonitrile-butadiene-styrene
ASTM	American Society for Testing Materials
CED	Cohesive energy density (cal/cm^3)
ΔE^v	Molar heat energy of vaporization
FS	Flexural strength(MN/m^2)
FTIR	Fourier transform infrared
ΔG	Gibbs free energy(cal/mol)
HDPE	High density polyethylene
Hv	Heat of vaporization(cal/g)
ΔH	Enthalpy changes
HIPS	High impact polystyrene
IR	Infrared
LDPE	Low density polyethylene
MS	Mass spectroscopy
MOE	Modulus of elasticity(MN/m^2)
NMR	Nuclear magnetic resonance
R	Universal gas constant(cal/(K)(gmol))
SAN	Styrene acrylonitrile
ΔS_m	Changes in entropy of mixing($calk^{-1}mol^{-1}$)
THF	Tetrahydrofuran
TS	Tensile strength(MN/m^2)

V_1	Volume of solution
V_2	Volume of solute
φ_1, φ_2	Volume fraction
δ	Solubility parameter(cal/mol)
ρ	Density(g/cm^3)
T	Absolute temperature (K)
M	Molecular weight

CHAPTER 1

1.0 INTRODUCTION

The large amounts of plastics being produced with the recent economic growth are generating high quantities of waste. This rapid development has coincided with the equally dramatic rise of many environmental problems, and in consequence industries have to be concerned with waste disposal strategies (Arostegui et al, 2006). Therefore, the recycling of polymeric material has generated considerable interest in society, which has caused efforts, aimed at facilitating the recycling of plastics on an increased scale.

Acrylonitrile-Butadiene-Styrene, a ter-polymer (ABS), is one of the most successful engineering thermoplastics. It consists of Styrene-acrylonitrile co-polymer (SAN) mixed with and to some extent grafted to polybutadiene rubber (Boldizar and Moller, 2002). ABS is widely used in the automotive industries, telecommunications, refrigerators and business machines because both the properties and price are intermediate between the lower priced commodity thermoplastics and the more expensive high performance engineering plastics. For the same reasons, ABS is also an interesting plastic material for recycling (Gothen, 2001).

European legislation required member states to remove and destroy ozone-depleting substances from refrigeration equipment before it could be scrapped (Defra, 2004).The typical processing system for fridges involves manual removal of cooling liquids and other components (such as the compressor) granulation and magnetic separation for recovery of steel and eddy current separation for nonferrous metal recovery. This leaves the plastic materials whose composition will vary depending on the manufacturer.

Jody et al (1997) described the process of density separation of high impact polystyrene (HIPS) and ABS, a 50% solution of acetic acid (density approximately 1055 kg/m^3, surface tension $38MNm^{-1}$ and pH 1.8). One implementation of density separation is the "sink float" method in which a stream of shredded material is passed through successive liquid baths of different densities. The material with a density greater than that of the bath liquid sinks to the bottom and the rest floats to the top. The sediments and float material stream are again processed in baths of different densities, and this process is continued until the target materials are isolated (Knight and Sodhi, 2000). Limonene (an oil produced from the skin of citrus fruits such as orange) is known to dissolve expanded high impacts polystyrene using a solid/liquid ratio of 1/10 at a temperature of 40^oC over a period of 90 min. (Pascoe, 2005).

Recycling involves processing used materials (waste) into new products to prevent waste of potentially useful materials. The process causes reduction in the use of "conventional" waste disposal methods such as incineration and land filling thereby air pollution, water pollution and lower green house effect. Furthermore, consumption of energy usage and fresh raw materials are reduced as compared to virgin production. Recycling is a key component of modern waste reduction and is the third component of the "Reduce, Reuse, and Recycle" waste hierarchy.

This project is aimed at a method of recycling which is based on dissolution of material. Solvent – based processes include size reduction followed by before treating with an

appropriate solvent, filtrating the solution to remove any insoluble contaminants and additives, and finally recovering the polymer by evaporation and drying.

1.1 PROBLEM STATEMENT

Scrapped refrigerators are found thrown into the environment causing pollution. This has been found to contain useful polymers which can have alternative uses if they can be retrieved. Acrylonitrile butadiene styrene is one of the major polymers that is contained in used refrigerators. This polymer is in high demand and it is wholly imported as it is not presently produced locally.

1.2 JUSTIFICATION

ABS has a very wide application because of its unique polymer properties such as high tensile and impact strength which makes it strategic to national development. ABS is wholly imported as it is currently not produced locally. Many research works have been carried out at departmental level on the technology of its production that proved abortive as the technology to produce ABS is complex.

Due to the availability of wastes from refrigerator materials made from ABS there is abundance of it which causes environmental effect.

1.3 AIM AND OBJECTIVE

The aim of this work is to recycle acrylonitrile-butadiene-styrene from used refrigerator materials, with the objectives of (i) identifying solvent(s) that can dissolve acrylonitrile-butadiene-styrene (ii) recycle acrylonitrile-butadiene-styrene from ABS containing material using the solvent extraction method and (iii) assess the mechanical properties and physical properties of recycled ABS in comparison with virgin ABS.

1.4 SCOPE OF RESEARCH

The scope of this work will cover (i) the selection of suitable solvent(s) to dissolve ABS from the inner lining of selected waste fridges (ii) filtering to separate the undissolved materials and additives from the polymer solution (iii) evaporating the solvent to have the recycled polymeric materials (iv) assessing the mechanical and physical properties of recycled ABS in comparism with virgin ABS.

CHAPTER 2

2.0 LITERATURE SURVEY

This chapter presents a survey of literature on polymers, polymer recycling and solubility parameters.

It has been shown that a waste plastic material can be recycled to a material of less demanding properties especially acrylonitrile butadiene styrene (ABS) in various ways ever since their introduction over a hundred years ago (John, 1999). However there are still technical and economic obstacles for a recycling process of waste plastics. Dissolution recycling has been done for low density polyethylene (LDPE) and high density polyethylene (HDPE), (Poulakis et al, 1999).

2.1 SOME BASIC CONCEPTS AND DEFINITIONS

The word polymer is derived from classical Greek “poly” meaning “many” and “mer” meaning “parts”. Thus a polymer is a large molecule (macro molecule) built up by repetition of small chemical units or polymeric material or resin with linear, branched or cross linked structure whose degree of polymerization exceeds 50 to 70. Copolymer is a polymeric material synthesized from more than a single monomer. Polymer blend is a mixture of at least two polymers or copolymers. Compatible polymer blend is a term indicative of commercially attractive polymer mixture, frequently with enhanced physical properties over constituents’ polymer.

2.2 CLASSIFICATION OF POLYMERS

Polymer can be classified in many different ways. The most obvious classification is based on the origin of the polymer i.e Natural Vs Synthetic. (Ebewele 2000). Other classifications are based on the polymer structure, polymerization mechanism, preparatory techniques, or thermal behavior.

2.2.1 Natural vs. Synthetic Polymer

Polymers may either be naturally occurring or purely synthetic. There are a large number of synthetic polymers consisting of various families: fibers, elastomers, plastics, adhesives etc; each family itself has subgroup members.

2.2.2 Polymer Structure: Linear, branched or cross-linked, ladder vs. functionality

The functionality of a molecule is simply its interlinking capacity or the number of sites it has available for bonding with other molecules under the specific polymerization condition.

A molecule may be classified as mono functional, bifunctional or polyfunctional depending on whether it has one, two, or more sites available for linking with other molecules. The structural units resulting from the reaction of monomers may in principle be linked together in any conceivable pattern. Bifunctional structure units can enter into two and only two linkages with other structural units. This means that the sequence of linkages between bifunctional units is necessarily linear. The resulting polymer is said to be linear. However, the reaction between polyfunctional molecules results in structural unit that may be linked so as to form non-linear structures. The resulting polymer

molecule are said to be branched. In other cases, growing polymer chains becomes chemically linked to each other resulting in a cross-linked system.

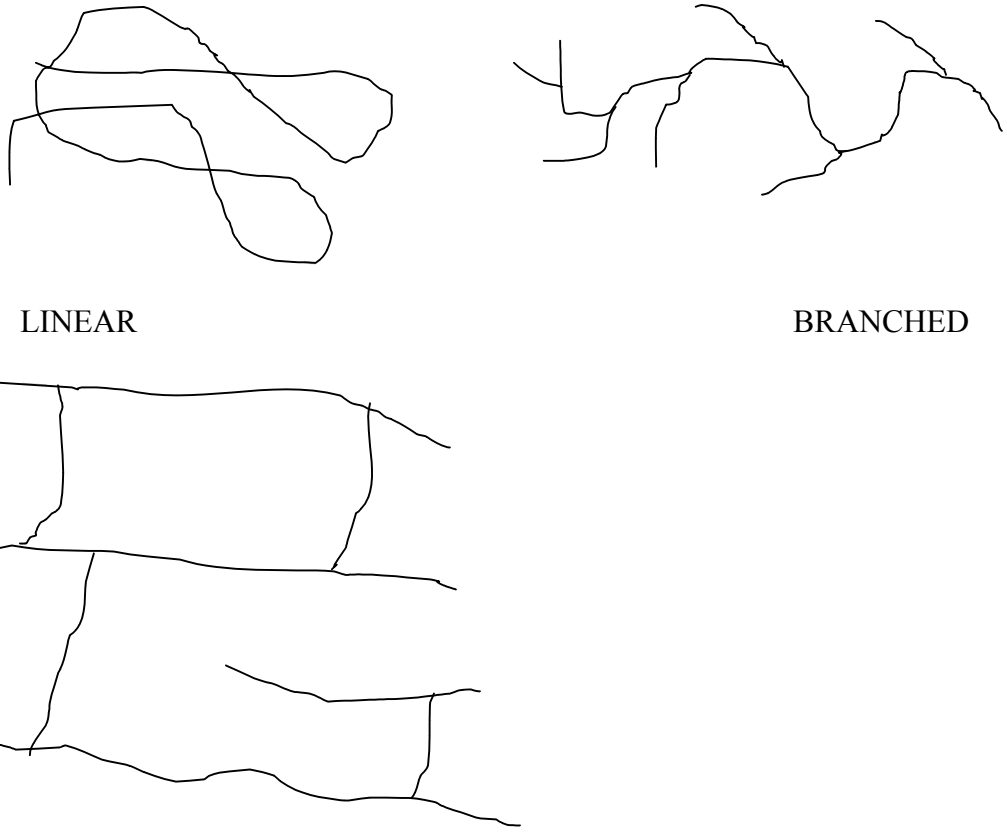


Figure 2.1: Schematic representation of polymer structures

2.3 PLASTIC MATERIALS

Plastic materials are made up of large, organic (Carbon-containing) molecules that can be formed into a variety of products. The molecules that compose plastics have many of their useful properties. In general, materials that are made up of long, chain like molecules are called polymers. The word plastic is derived from the words plasticus

(Latin for “capable of molding”), and plastikos (GREEK “to mold”, or “fit for molding”). Plastics can be made hard as stone, strong as steel, transparent as glass, light as wood, and elastic as rubber. Plastics are also lightweight, water proof, chemical resistant and produced in almost any color. More than 50 families of plastics have been produced, and new types are currently under development (Encarta, 2003).

2.3.1 Important Types of Plastics

A wide variety of both thermoplastic and thermosetting polymers are manufactured. These plastics have a spectrum of properties that are derived from their chemical compositions. As a result, manufactured plastics can be used in applications ranging from contact lenses to jet body components.

2.3.1.1 Thermoplastics polymers

Thermoplastics materials can be repeatedly softened and remolded. The most commonly manufactured thermoplastics are as follows: polyethylene, polyvinyl chloride, polypropylene, polystyrene, terephthalate, acrylonitrile butadiene styrene, polyamide, polymethylmethacrylate, . They are used in the production of computer casing, inner lining of refrigerators, pipes, sewers etc (Ebewele 2000)

2.3.1.2 Thermosetting polymers

Thermosetting polymers cross-link, after being heated, these plastics can be made into durable and heat resistant materials but are not easily remolded or recycled. The most commonly manufactured thermosetting plastics are: polyurethane, phenolics, melamine, formaldehyde, unsaturated polyesters, epoxy, reinforced plastics or composites.

Thermosets have a network structure formed exclusively by covalent bonds. Thermosets have a high density.

2.4 CHEMISTRY OF ABS PLASTICS

ABS plastics are made from three monomeric compounds these are; acrylonitrile (a liquid with a boiling point of 77.3^0C), butadiene (a gas at room temperature which boils at -4.4^0C) and Styrene (a liquid having a boiling point of 145.2^0C).

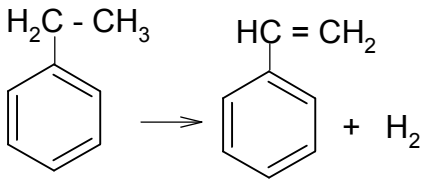
These monomers are prepared commercially by a number of catalytic methods: Acrylonitrile is normally synthesized by the addition of hydrogen cyanide to acetylene as follows:

$$HCN + HC{\equiv}CH \rightarrow H_2C{=}CHCN \qquad 2.1$$

Butadiene is prepared by the catalytic dehydrogenation of butane at elevated temperatures.

$$H_3C\text{-}CH_2\text{-}CH_3\text{-}\ CH \rightarrow H_2C{=}CH\text{-}CH{=}CH_2 + 2H_2 \qquad 2.2$$

Styrene is manufactured in a similar manner from ethylene benzene



2.3

Acrylonitrile by itself polymerizes quite readily to form a high melting crystalline type polymer with the following structure.

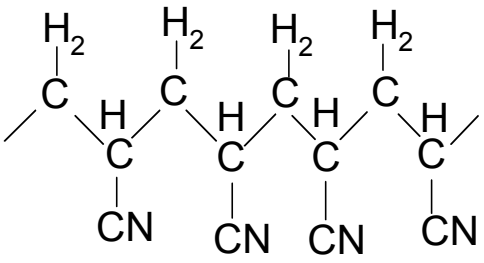


Figure 2.2: Structure of polyacrylonitrile

This polymer does not have a distinctive melting point but rather, it decomposes prior to melting. Polyacrylonitrile is extremely resistant to most chemicals, and only a very few highly polar chemicals will dissolve or attack it. Butadiene monomer polymerizes by itself to form polybutadiene which is a rubbery polymer at room temperature.

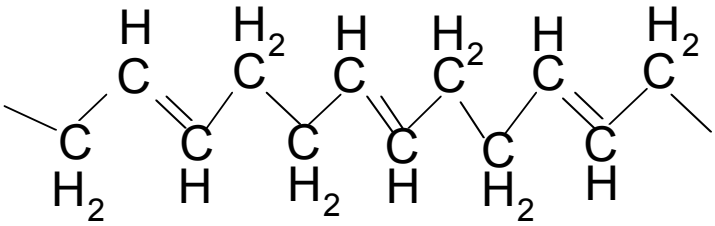


Figure 2.3: Structure of polybutadiene

Butadiene polymers contain unsaturated bonds which lend themselves to cross linking (vulcanization). Polybutadiene becomes hard and brittle at very low temperatures (below -75^0C).

For all practical purposes, it is an excellent rubber and is used in applications where its rubbery characteristics can be utilized.

Styrene monomer will polymerize very readily to yield polystyrene.

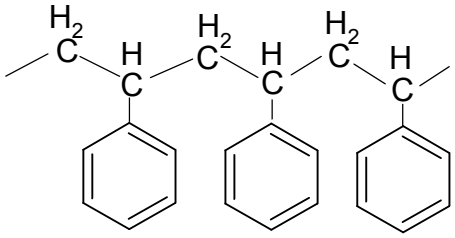


Figure 2.4: Structure of polystyrene

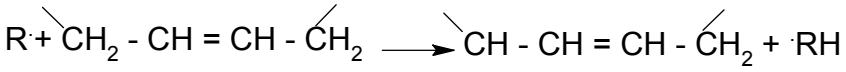
Polystyrene is a hard, glassy, amorphous solid which has a heat distortion temperatures, slightly above this heat distortion temperature, it starts becoming flexible and rubbery.

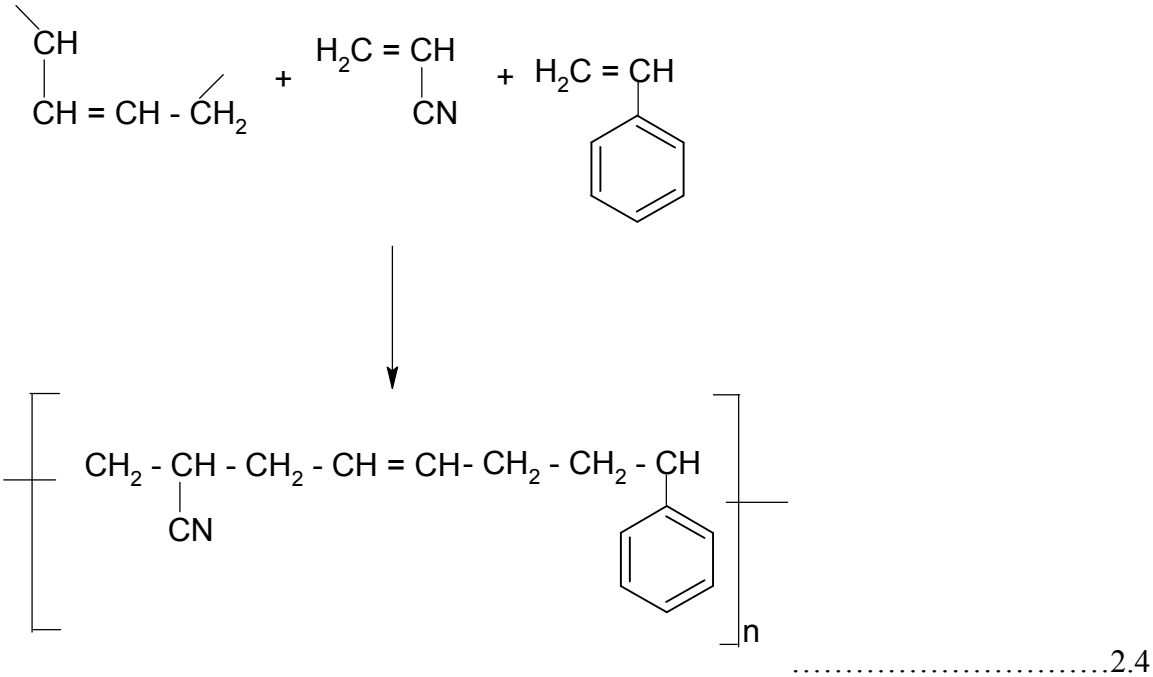
To obtain the family of ABS plastics, one cannot simply mix these three polymers expecting to get any desirable combination of properties. A mechanical mixture of these results in an amorphous poly-blends system which is completely unsatisfactory for any use whatsoever. However, as one can see, polymers from each monomer have certain advantageous properties. If these could be combined properly to take advantage of these good characteristics, a polymer system would result having extremely desirable properties.

ABS plastics are made by dispersing a rubbery phase, composed predominantly of butadiene polymer, into a rigid phase which is composed of styrene-acrylonitrile as a co monomer and it may not contain styrene-acrylonitrile grafted onto the rubbery backbone. When a composition similar to the rigid phase is grafted onto the rubbery phase, the rubber phase has a component chemically attached to it which is similar in composition to the rigid phase. The two different copolymers become attached to one another by the mutual solubility of the graft component and the rigid phase. This latter technique is used

by ABS manufacturers to make the modern and improved ABS plastics. The following reactions illustrate the initiation of the grafting reaction

Catalyst $\rightarrow 2R^{\cdot}$





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2.5 HISTORY OF ABS PLASTICS

Plastic materials made from acrylonitrile, butadiene and styrene was first introduced by U.S Rubber in the late 1940's, and U.S patent 2,439,202 was issued in 1948 to U.S Rubber. The product which they claimed in this patent was composed of a physical mixture of butadiene – acrylonitrile rubbery copolymer and styrene acrylonitile copolymer. Other patents were subsequently issued covering poly-blends of this type. Commercial products made by this process were used principally for the fabrication of

pipe by extrusion and in the making of sheets by calendaring. These sheets were used in a number of applications and were marketed under the trade name “Royalite”.

Improvements in polymer blending technology and the development of polymer grafting technology during the 1950’s have resulted in a significant improvement in acrylonitrile butadiene styrene polymer properties. As a result, ABS have been developed with improved flow, appearance, and thermal stability characteristics. With the attainment of these, more favorable properties of ABS plastics have expanded very rapidly in the field of injection molding sheet extrusion and thermoforming.

The relatively high cost of these ABS polymers during the early years of introduction showed the growth of this family of plastics. During the latter part of the last decade, new technology in the synthesis of acrylonitrile monomer was developed and the price of this monomer started declining. The prices of styrene and butadiene monomers also fell drastically. These drops in raw materials costs for ABS plastics helped bring about polymer price decrease. With other producers entering the field, such as Borg-Warner’s Marbon chemical Division. Monsanto Company and B.F Goodrich chemical company, the improved technology developed for making ABS polymers also helped in bringing about a rapid decrease in price, particularly the production capacities increased. These prices declines accelerated the development of new applications where the properties of ABS could be applied advantageously.

2.6 ENGINEERING THERMOPLASTICS

ABS polymers belong to the family of so-called engineering plastics. Other plastics such as nylons, polyacetal, polyvinyl chlorides fall into this category. Engineering plastics are high- performance polymers used in engineering applications because of their outstanding balance of properties. They are designed and fabricated with adequate properties for load-bearing of which ABS is one.

2.6.1 Properties of ABS Plastics

The two basic properties which characterize ABS plastics materials are:

Good-to-excellent toughness, and High mechanical strength.

All variations of ABS polymers have these two properties in common. The strength is supplied by the resinous component, whereas the shock absorbing capacity of the mixture is obtained from the rubbery portion. Combining these two important ingredients in various ratios produces polymers having a broad range of physical properties useful for many applications.

The shock absorbing capacity of polymers is also dependent on the method of fabrication and the design of the end item. If one uses fabrication condition whereby the product contain high stresses and strains due to the effect of high orientation, the product will be weak in these regions of excessive orientation. Therefore, its performance will be unsatisfactory and the product will not be utilizing the inherent properties of the plastic to the best advantage.

For a part to be strong, it must be capable of resisting deformation or failure when subjected to certain stresses. High mechanical strength properties are important for this particular property. When a part is subjected to impact, i.e. dropped or hit by a hard

object, the ability to resist this impact is also related to the toughness of the product. Other important properties include resistance to the effect of environment such as chemicals and food stuffs, temperature, abrasion and frequent uses.

2.6.1.1 General properties

The excellent combination of properties which ABS plastics offer has spurred the growth of these plastics into many applications. No one single property, but rather the combination of properties of ABS plastics has made them outstanding. Some of the properties which make this plastic extremely useful are, moderate price, ease of fabrication, good combination of toughness, rigidity and other mechanical properties, wide colorability, good dimensional stability, non toxicity, good water resistance and excellent chemical resistance.

The testing techniques which have been developed by the America Society for Testing Materials (ASTM) are commonly used to define the property characteristics of plastics and material suppliers of plastics materials usually publish most of their data which have been obtained by ASTM methods. However, this type of data should not be expected to predict the performance of a finished end item. ASTM methods simply specify conditions that are required in order to obtain data for comparison with other plastics of known performance. Specimen of certain dimensions and shape are prepared for testing. These samples are conditioned prior to testing to eliminate variations resulting from effect of temperature and humidity.

2.6.2 Engineering Properties

The prospective user of ABS polymers always faces the question whether the material will perform satisfactorily in the intended applications or not. A thorough understanding

of the conditions under which the part is expected to perform is required. Also, meaningful information about the performance characteristics of the ABS polymer is needed to determine whether it will perform properly in the intended applications. Some of these properties are presented in Table 2.1. Therefore the purpose of data on ABS properties should be to provide the engineer, the designer, and the user of ABS plastics with the kinds of engineering information which will improve the reliability of section of types of ABS plastics.

The area of mechanical properties, in its broadest sense encompasses the effects of applied forces on certain materials. The mechanical properties data which are of practical importance to the design engineer are usually defined within the useful temperature range at which load bearing occurs. Except in case of simple structures, it is not possible to apply design principles accurately.

Table 2.1: Mechanical properties of different grades of ABS (Basdekis, 1964)

Properties	Styrene Acrylonitrile Copolymer	ABS – Impact Types				
		Lowest Types I	Intermediates Types II	High Types III	Highest Types IV	ABS Heat resistant
Impact, Izod, Notched ½″ *by* ½″ bar ft lbs/inch@73^{o}F	0.4	1.1	2.0	3.2	4.3	2.0
@ 0^{o}F	-	0.8	1.4	1.7	2.0	-
@ - 40^{o}F	0.4	0.6	0.8	1.0	1.4	0.5 – 1.0
Elongation (%)	2.5	10 – 15	15 – 20	20 – 25	25 – 40	5 – 10
Tensile strength at yield (psi)	11,500	8,000	7,000	6,500	6,000	8,500
Flexural modulus psi x 10^{-5}	5.1	4.3	3.8	3.5	3.2	3.5 -4.0
Flexural strength at yield (psi)	15,000	13,000	11,500	10,000	9,000	12,000
Rockwell hardness (R scale)	122	113	110	95	90	112
Heat Distortion Temp.(^{0}F) 264 psi load	205	190 - 196	186 - 193	185 - 191	183 – 190	225

2.7 USES OF ABS

When the high impact polystyrene was developed, a significant increase in the growth rate of polystyrene plastics occurred in applications where polystyrene was unsuited because of its brittleness. In a similar way, ABS plastics are opening up new opportunities for styrene – containing polymers, particularly in appliance housing, communications and automotive uses. ABS is also replacing the more expensive plastic

in many applications. In some current application which utilize the less expensive high – impact polystyrene the more durable ABS polymers will be favored.

2.7.1 Appliances

2.7.1.1 Refrigeration Applications

At present the plastic which is most widely used by refrigeration industries is polystyrene, as both regular and impact types of polystyrene meet many of this industry's requirement. Unlike impact polystyrene, ABS materials are not attacked by the fluorocarbon (Freon) used to make polyurethane rigid foams. These types of foams are being more widely used for insulation in refrigerators.

The following are property advantages which make ABS suitable for refrigeration application: cyclic stress resistance at normal and low temperature, high modulus or rigidity, resistance to creep under very high stress level, resistance to the attack of Freon –11, ability to develop high gloss and freedom from surface blemishes, resistance to the attack of foodstuff and cleaners and ease of vacuum forming.

2.8 RECYCLING PLASTIC CONCEPTS

More and more plastics wastes are generated by industries and households. Plastics have become an indispensable part of modern life. Polymer recovery/recycling involve a variety of technologies, each of the technologies as technical, economic and institutional component. Recycling of waste electrical and electronic equipment (WEEE) is an important subject not only from the point of waste treatment but also from the recovery aspect of valuable materials. Using recycled materials in place of virgin materials results

in significant energy savings (Cui and Frossbe, 2003). It can also be used in development of composites and blends. (shu –kai yeh et al, 2009). .

2.8.1 Recycling Processes

Recycling may be defined as any activity involving reclamation, recovery, or reuse of materials or articles. In other words any method of extracting value in the form of energy or material from waste generated at any time in the cradle – to – grave life cycle of a product may be included in the definition.

2.8.2 Methods of Recycling

Nowadays, there are four main approaches to polymer recycling:

Primary recycling, secondary recycling, tertiary recycling and quaternary recycling

2.8.2.1 Primary recycling or reuse

This is the conversion of waste plastic from a product into a new product similar in character to the original one. It involves process scrap, or waste generated during production. An important sub class of primary recycling is known as “closed loop recycling” in which polymer from a single product or product type is collected and recycled into the same product.

2.8.2.2 Secondary recycling

This is the conversion of plastic waste into new products that have less demanding physical and chemical characteristics than the original product had. This uses reclaimed post consumer materials as a source of material for new products. This “cascaded performance” approach is easier to accomplish than primary recycling.

2.8.2.3 Tertiary recycling

This involves the chemical break down of materials which are then re – utilized for the backfeed in the feedstock chain. The technology is available to break down waste plastics to their original polymeric form, clean them, and produce a repolymerized resin.

2.8.2.4 Quaternary recycling

This involves burning plastic waste to recover its energy content. This is often termed energy from waste. Energy savings from quaternary recycling are much less than for secondary recycling, and tertiary recycling. All embodied energy will be lost if plastic wastes are land filled.

2.9 BULK RECYCLING SEPARATION PROCESSES

The binary separation processes used in bulk recycling utilizes differences in material properties, such as density, magnetic properties, conductivity, melting points, solubility and so on, to isolate the different materials. The usual sequence of processes for engineered products recycling is as follows:

2.9.1 Size Reduction

The initial process is size reduction (shredding), which may be done in several stages using a range of shredders – grinder combination. The purpose is to produce a mixture of flakes of materials of a reasonably uniform size, which must then be separated into the constituent materials. Shredding in practice produces a distribution of flakes sizes ranging from dust to the maximum size of the shredder screen. Ideally for material separation purpose, size reduction should result into particle or flakes consisting of a single material (Knight and Sodhi, 2000).

2.9.2 Methods of Separation in Bulk Recycling

Different methods are used in bulk recycling which utilizes properties such as density, magnetic attraction, solubility, conductivity, and melting point.

2.9.2.1 Magnetic separation

It is a highly effective process to extract ferrous materials from a mixture. Material extraction is dependent on a number of factors including particle size; non-magnetic ferrous materials are not removed by this process and will remain in the mixture after processing.

2.9.2.2 Eddy current separation

These separators utilize eddy current induced in conducting materials by magnetic induction to isolate mainly conductors from non conductors. Separation depends on the magnetic field levitating the conducting flakes, thus the ratio of conductivity to density is a good measure for discriminating between materials. Electrostatic separators behave in a similar manner but use electrostatic forces and again in practice separate conductors from non conductors.

2.9.2.3 Air classification

Fines and air classification extracts the light and fluffy materials, which could be problematic when, mixed with liquids in subsequent wet processing. Air classifiers separates such light materials using upward flowing air currents and can be arranged to differentiate between particles of different weights. For engineered products the separated materials have little values.

2.9.2.4 Density separation

The commonly used methods for separating mixed plastics utilize density differences between the various polymers. One implementation of density separation is the "sink float" method in which a stream of shredded material is passed through successive liquid baths of different densities. The material with a density greater than that of the bath liquid sinks to the bottom and the rest floats to the top. The sediment and float material streams are again processed in baths of different densities, and this process continued until all the target materials are isolated. Another similar separation process is the hydro – cyclone process in which materials are separated by large centrifuges. While the mechanics of separation are different, the operational characteristics are essentially the same as the sink – float method and thus models developed for the sink – float technology are applicable to hydro–cyclone methods.

2.10. SOLUBILITY PARAMETERS

2.10.1Theory Application

Choice of solvent in a particular situation involves many factors, including evaporation rate, solution viscosity, environment and health concerns, and often the effectiveness of a solvent depends on its ability to adequately dissolve one material while leaving other materials unaffected (John, 1984).

2.10.2 Solution and Molecules

A solvent, usually thought of as a liquid, is a substance that is capable of dissolving other substances and forming a uniform mixture called a solution. The substance dissolved is called the solute and is usually considered to be the component present in the smaller quantity. According to this definition, an almost – dry or slightly swollen resin film

comprises a solution of a liquid (the solute) in a resin (the solvent), even though conventionally the liquid is usually referred to as the solvent, and the resin as the solute (John, 1999).Liquids (and solids) differ from gases in that the molecules of the liquid (or solid) are held together by a certain amount of intermolecular forces. For a solution to occur, the solvent molecules must overcome these forces in the solute and find their way between and around the solute molecule. At the same time, the solvent molecules themselves must be separated from each other by the molecules of the solute. This is accomplished best between the molecules of both components are similar. If the attractions are sufficiently different, the strongly attracted molecules will cling together, excluding the weakly attracted molecules and immiscibility will result. These sticky forces between molecules are called Van der Waals forces.

Solubility parameter is a numerical value that indicates the relative solvency behavior of a specific solvent. It is derived from the cohesive energy density (CED) of the solvent, which in turn is derived from the heat of vaporization (H_v) which is the energy required to vaporize the liquid.

From thermodynamic consideration it is possible to predict whether or not a given solute will be soluble in a given solvent using the relations

$$\Delta G_m = \Delta H - T\Delta S_m \quad \text{.....2.5}$$

Where ΔG_m , ΔH_m, ΔS_m are free energy, heat, and entropy of mixing, respectively . Solubility will occur if the free energy of mixing ΔG_m is negative. The entropy of mixing is believed to be always negative. Therefore, the sign and magnitude of ΔH_m determine the sign of ΔG_m. If we consider an ideal solution of two small spherical molecules with

identical size and inter molecular forces, molecules of one type can replace neighbors with molecules of another type without changing the energy of the system. Dealing with ideal conditions, the heat of mixing ΔH_m is zero because the two types of molecules have the same force fields, and consequently, $\Delta G_m = -T\Delta S_m$. However, departure from ideality normally occurs because the intermolecular forces operating between similar and dissimilar molecules give rise to a finite heat of mixing. In this case, energy of mixing associated with the formation of contact between two dissimilar molecules can be shown to be positive therefore, mixing is generally endothermic for non-polar molecules in the absence of strong intermolecular attraction such as hydrogen bonding

$$\Delta H_m = V\phi,\phi_2\left[\left(\Delta E_1^v / V_1\right) - \left(\Delta E_2^v / V_2\right)^{\frac{1}{2}}\right]^2 \quad \text{.....2.6}$$

Where V_1 , V_2 are the volume of the solution and component and subscripts 1 and 2 denote the solvent and polymer, respectively. ΔE^V is the molar heat energy of vaporization $\phi_1\phi_2$ are volume fractions. In terms of the heat of mixing per unit volume, Equation 2.6 becomes

$$\frac{H_m}{V} = \phi_1\phi_2\left[\left(\Delta E_1^V / V_1\right)^{1/2} - \left(\Delta \frac{E_2^v}{V_2}\right)^{\frac{1}{2}}\right]^2 \quad \text{.....2.7}$$

The quantity $\Delta E / V$ is referred to as the cohesive energy density (CED).

From the heat of vaporization (calories per cubic centimeter) of liquid we can derive the cohesive energy density by the following expression

$$\text{CED} = \frac{\Delta H_v}{V_m} - \frac{RT}{V_m} \quad \text{.....2.8}$$

Its square root is the solubility parameter (δ).Thus

$$CED = \frac{\Delta E}{V} = \delta^2 \quad \text{.....2.9}$$

Equation 2.3 may be written as

$$\frac{\Delta H_m}{V} = \phi_1 \phi_2 [\delta_1 - \delta_2]^2 \quad \text{.....2.10}$$

To a first approximation and in the absence of strong inter molecular forces like hydrogen bonding, a polymer is expected to be soluble in a solvent if $\delta_1 - \delta_2$ is less than 1.7 - 2.0 . Equation 2.10 is valid when ΔH_m is zero or greater. It is invalid for exothermic mixing. In addition, the solubility parameter can be estimated from the molar attraction constant, E, using the structural formular of the compound and its density. For a polymer $\delta_2 = \frac{\rho \sum E}{M}$ 2.11

Where δ_2 is the solubility parameter, ρ is the density E is the molar attraction and M is the molecular weight of the polymer.

2.11 FILTRATION PROCESSES

The term filtration is the separation of solids suspension from a liquid by means of a porous medium or screen which retains the solids (residue) and allows the liquid (filtrate) to pass (Couldson and Richardson, 2002). It is commonly the mechanical or physical operation which is used for the separation of solids from the fluids (liquids and gases) by interposing a medium through which only the fluid can pass. Usually, the particles which are to be removed are smaller than the pores of the medium. Filtration is often carried out in the laboratory using the Buchner funnel, and the liquid is sucked through the thin layer

of particles using a source of vacuum, the suspension could also be poured into a conical funnel fitted with a filter paper. The liquid to be filtered is called the suspension, the liquid that passed through the filter is called the filtrate, and the solid material remaining on the filtrate is known as the residue.

2.11.1 Filtration Application

As a physical operation, it is an important unit operation for chemical engineering for the separation of materials of different composition; a solvent is chosen which dissolves one component, while the other does not.

By dissolving the mixture in the chosen solvent, one of the components will enter into the solution and pass through the filter while the other will be retained.

2.11.1.1 Filter media

There are two main types of filter media that are employed in the chemical laboratory: surface filter and depth filter.

2.11.1.2 Surface filter

In this type of filter, a solid sieve which traps the solid particles with or without the aid of filter paper (e.g. Buchner funnel, rotary vacuum, drum filter, cross filter). Here the residue is collected intact.

2.11.1.3 Depth filter

In this type of filter, a bed granular material which retains the solid particles as it passes. There is prone to clogging due to the greater surface area where the particles can be trapped. Filtration is a more efficient method for the separation of mixture than decantation.

2.11.1.4 Flow through the filter medium

Flow can only be achieved through a filter due to a difference in pressure. Fluid flows from the high pressure side to the low pressure side of the filter. In the laboratory, pressure in the form of compressed air on the feed side (or vacuum on the filtrate side) may be applied to make the filtration process faster though this may lead to clogging on the passage of fine particles.

2.12 POLYMER IDENTIFICATION

Techniques have been developed to assess the quality of polymers using spectroscopy. It is widely used in both research and industry as a simple and reliable technique for measurement, quality control, and dynamic measurement. By measuring at a specific frequency over time, changes in the character or quantity of a particular bond can be measured. Information obtained by the combination of mass spectroscopy (MS), Infrared (IR) and nuclear magnetic resonance (NMR) makes identification easier.

2.12.1 Fourier Transmission Infra Red Spectroscopy (FTIRS)

In this type of spectroscopy, infra red (IR) radiation is passed through a sample, some of the infra red radiation is absorbed by the sample and some passed through (transmitted).The spectra formed represents the molecular absorption and transmission, creating a molecular finger print of the sample. No two unique molecular structures produce the same infra red spectrum.

2.12.2.1Theory of infrared

Infrared radiation of frequencies less than about $100cm^{-1}$ is absorbed and converted by an organic molecule into energy of molecular rotation. This absorption is quantized, thus

molecular rotation spectrum consist of discrete lines. The IR of the electromagnetic spectrum is divided into three regions, the near-, mid- and far- infrared, named for their relation to the visible spectrum. The far IR, (approx.400-10 cm^{-1}) lying adjacent to the microwave region, has low energy and may be used for rotational spectroscopy. The mid IR (approx. 4000-400) may be used to study the fundamental vibrations associated rotational-vibrational structure, while the higher energy near-IR (14000-400cm^{-1}) can excite overtone or harmonic vibrations.

2.13 SAFETY CONTROL AND ENVIRONMENT

Health and safety of personnel and loss prevention have become an important issue in industries and laboratories since the beginning of the mid-nineteenth century. Injuries and property damage have high costs in business, interruptions and loss of trained personnel or equipment.

With a general trend towards designing systems to be inherently safe and hazard free and also the establishment and implementation of hazard and safety rules regulations, worker fatalities have tended to reduce over the decades. However property loss has tended to increase as a result of the increasing complexity, productivity, severity of conditions and automation of chemical plants. Another factor contributing to increase in hazards is the effort to reduce the formation of wastes and undesired by-products which frequently requires close approach to temperature and pressure limits, at which loss of control can be catastrophic.

CHAPTER 3

3.0 EXPERIMENTAL

This chapter gives the description of materials, equipment and instruments used in this work. The experimental procedures are also presented.

3.1 MATERIALS USED

Table 3.1: List of Materials used in the study

S/NO	Materials Used	Model/Specification
1	Used refrigerator material: Tec, Bauchnet, Matsui and Fides	
2	Tetrahydrofuran	Made in Germany lot D4270B
3	Benzene	May and Baker LTD Dagenham England
4	Toluene	Philip Harris LTD Shenstone Eng
5	Virgin Acrylontrile-butadiene-styrene	
6	Distilled water	

The waste refrigerator materials were collected from Danraka Street of Samaru-Zaria.

PLATE 3.2: Inner lining of waste refrigerator materials

3.2 INSTRUMENTS AND EQUIPMENT

The list of instruments and equipment used are presented in Table 3.1

Table 3.1: List of apparatuses, instruments and equipment used in the study

S/Number	Instrument/Equipment	Model/Specification
1	Hydraulic hot press	D288 pressure 0-40 on 4" diameter Ram, Temperature(0-200^{o}C)
2	Weighing balance	XP-600 Denver instrument (0-180g)
3	Tensile testing machine	Tensometer Ltd, England, HounsfieldW3179,20kN
4	Stop watch	PYE, England, Minutes and hour hands (1-12hours)
5	Suction pressure machine	ES100 Edward vacuum pump, Crawley, England

6	Buchner flask	Pyrex made in England, BS1739
7	Buchner funnel	Pyrex made in England
8	Oven	Zoetermeer-Holland (0-240^{o}C)
9	Fourier transform infrared spectrophotometer	FTIR 8400S
10	Conical flask and beakers	(50,100,150and500ml)
11	Micrometer screw gauge	(0-10mm)
12	Fume cupboard	
13	Glass Petri dish	Pyrex made in England
14	Metallic mold (Plate 3.2)	(21 x 16 x 4cm)

3.3 EXPERIMENTAL PROCEDURE

3.3.1 Disassembly of Waste Fridge

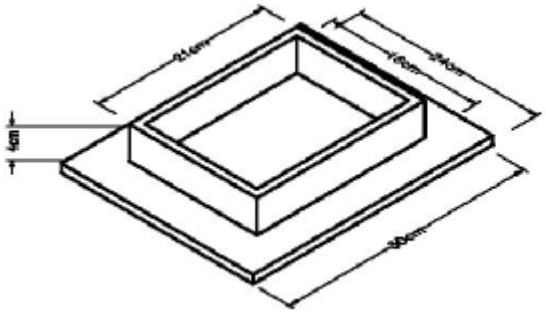
It is a systematic approach that allows the removal of a compound or a part or a group of parts or a subassembly from a product (i.e. partial disassembly), or separating a product into all of its parts (i.e. complete disassembly) for a given purpose.

3.3.2 ABS Waste Collection

The fridge which consisted of metals and polymers was dismantled manually to remove the metals from the polymers. The inner lining which was the ABS containing materials was stripped out.

The sorted waste ABS containing material was washed thoroughly with detergent to remove all dirts and paper labels then rinsed with water and spread to dry.

The dried materials were cut into flakes with an average dimension of about 2 – 4 mm with a sharp knife. This stage of size reduction was done to enhance the dissolution of the ABS materials.



(a) Metallic Mould used for the forming the Samples

(b) Pictorial Illustration of the Metallic Mould Used for forming the Samples

Plate 3.2: Diagram (a) and pictorial illustration (b) of the metallic mould used for forming the virgin and recycled ABS

3.3.3 Dissolution Process

The dissolution process involved dissolving the waste into a suitable solvent and this was determined by evaluating the difference in solubility parameter of the solvent and the polymer. Three different solvents (Benzene,Toluene and Tetrahydrofuran) were tested and THF was found to be the best because it has the closest value of solubility parameter to the value obtained for ABS. Therefore, the dissolution was carried out using THF in a fume cupboard. 75g of the ABS material was weighed and transferred into a beaker, 300ml of tetrahydrofuran (THF) was measured and poured into the beaker at room temperature for 1 hr, and this was stirred intermittently to homogenize the mixture.

3.3.4 Filtration

The stirred mixture of the ABS containing material was poured into the Buchner funnel of the filtration set up; it takes about 5 -10 mins to separate the filtrate and the residue. The filtrate was the material containing the ABS and the residue was made up of the insoluble contaminants and the additives.

3.4 SAMPLE PREPARATION

The mould was cleaned with a piece of cloth to remove all adhered particles and then coated with jelly, which served as a releasing agent for easy removal of the sample from the mould after drying. The filtrate was poured into the mould and allowed to stay for 2 days for the solvent to evaporate. The dried sample was removed from the mould and was further dried in an oven at a temperature of $80^{o}C$ for three hours in order to avoid possible moisture degradation reaction and complete the removal of the

remaining solvent (Arostegui et al, 2006). The sample was weighed and the weight recorded.

3.4.1 Compression

The procedure in Sections 3.3.1 – 3.4 was repeated for samples from other fridge brands, after which the compression of the samples into specimens for the characterization tests was done. The dried material was cut into flakes and poured into a metallic mould covered with aluminum plate. This was inserted into an electrically heated (Moore) hand operated compression moulding machine which was pre- heated for 10 mins. The pressure was 10 tons at a temperature of about 160-170^{o}C. This was left for 5min after which the mould was removed from the compression moulding machine and left to cool for 5min at ambient condition. The sample was then removed from the mould.

3.4.2 Testing of the Samples

The samples were cut into test specimen shapes and sizes as indicated in the sub-section. This was done for both the virgin and recycled samples of acrylonitrile-butadiene-styrene. The physical and mechanical properties of the specimens were determined using standard procedures.

3.4.3 Tensile Test

The specimen was cut into a dumb bell shape. ASTM D638M was adopted. During the test the specimen were inserted in the jaws of the testing machine one after the other. A gradually increasing load was applied to the specimen and the machine automatically plotted the load versus the extension values. The tensile strength,

elongation at break and modulus of elasticity (MOE) were obtained from the stress-strain curve.

3.4.4 Bending Test

The Flexural test was conducted by preparing the test samples according to ASTM D790M with the same test machine used for the tensile test. The maximum load was obtained and used to calculate the modulus of rupture (MOR). Equation 3.1 was used to evaluate the modulus of rupture.

$$MOR = \frac{3PL}{2bd^2} \quad \text{.....3.1}$$

MOR is the modulus of rupture, P is the breaking load, L is the length, b is the width and d is the depth of the test specimen.

3.4.5 Density Determination

The volume of the specimen was calculated from the dimensional measurement of the sample taken with a micrometer. The sample was weighed and the density obtained by dividing the weight by the volume (D2734).

3.4.6 Water Absorption

The sample was weighed dried and then immersed in water for about 24 hours at room temperature. The weight after 24 was taken and the percentage water absorption was calculated from the weight difference.

3.4.7 FTIR Analysis

The infrared energy was emitted from a glowing black-body source. This beam passed through an aperture which controls the amount of energy impinging on the sample, the beam entered into the interferometer where the spectral encoding took place. The resulting interferogram then exited the interferometer. The beam entered the sample compartment where it was transmitted at the surface of the sample, these were specific frequencies of energy which were unique characteristic of the sample and were absorbed and finally measured, the measured signal was digitalized and information took place.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

In this chapter, the solubility parameter analysis, the results of FTIR analysis, and the physical and mechanical properties of the recycled ABS from waste fridges and virgin ABS are presented. The results of mechanical and physical properties of virgin ABS experimentally obtained are also presented and compared with that of the recycled ABS.

4.1 ANALYSIS OF SOLUBILITY PARAMETER

Polymers generally do not dissolve in all organic solvents, to this effect the choice of solvent has to be made and this is simplified using solubility parameter. Usually a solvent is suitable for the dissolution of a selected polymer if the solubility parameter values for both are very close e.g. 1.7-2.0 (Ebewele, 2000). The solubility parameter of ABS was evaluated to be 9.49cal/cm^3 and those of the other solvents (benzene, toluene and THF) were also evaluated and compared for choice of solvent. The detailed calculation is presented in Appendix B. The difference in solubility parameter of ABS and that of THF calculated as 9.79cal/cm^3 was found to fall within the range suggested by literature. Therefore, THF was chosen as the solvent in preference to others.

4.2 FTIR ANALYSIS OF ABS FROM DIFFERENT SOURCES

Figures 4.1 – 4.5 present the spectral showing the functional groups obtained from the FTIR analysis of the ABS from various sources. The functional groups and vibration at various absorbance at which they occur are also presented in Table 4.1-4.5.

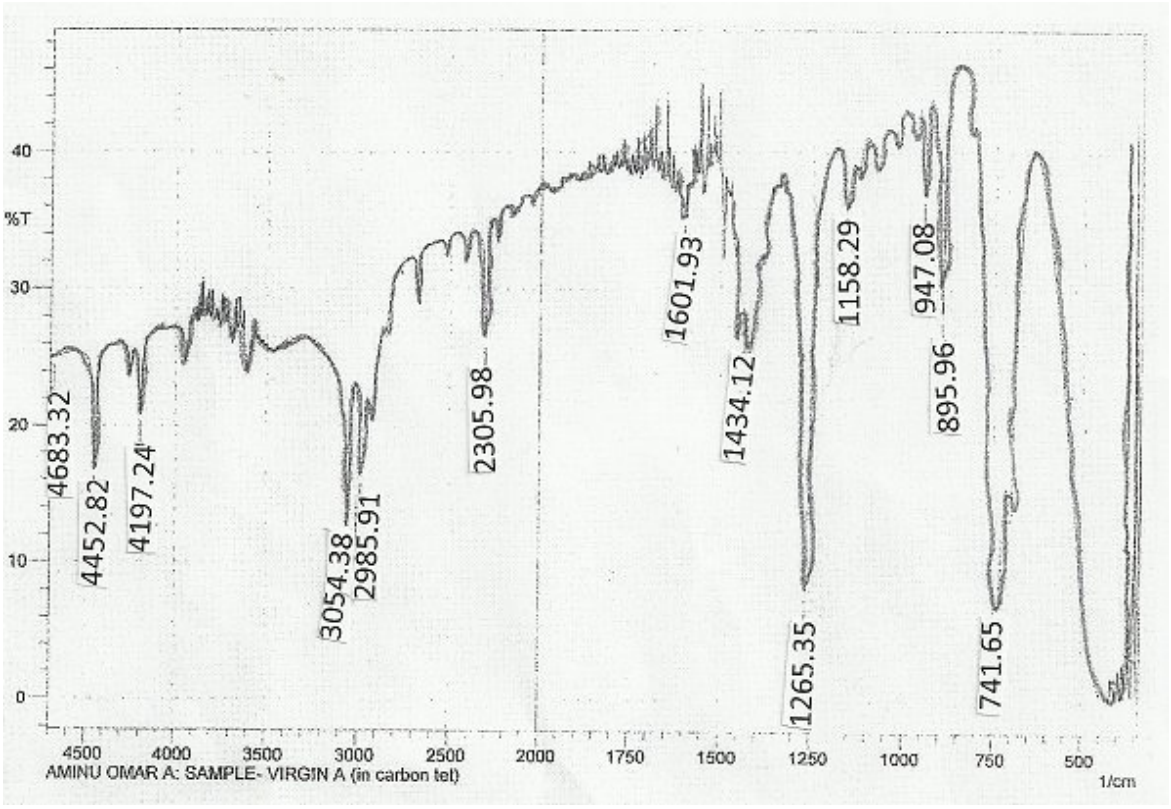


Figure 4.1: FTIR result of the virgin ABS

The chemical composition and structure of polymers after reprocessing can change due to a chemical reaction giving rise to a new product or remain unchanged (Bastida et al, 1995). These changes can be identified by different types of analysis. The presence of a functional group in a polymeric material is usually revealed by FTIR spectra (Arnold et al, 2009).

Figure 4.1 shows the spectra of virgin ABS and from this spectra obtained functional group, their vibration and absorbance are presented in Table 4.1.

Table 4.1: Identified functional groups, vibration and absorbance from FTIR analysis for virgin ABS

Group	Vibration	Absorbance (cm^{-1})
CN		2305.98
Benzene ring	Stretch	741
CH_2	Bend rocking	1434.12
$C(SP^2)$-H (aromatic)	stretch	3054.38
Aromatic	stretch	1601.93
Aromatic ring	Side ways	1434.12
C-C	Bend rocking	1158.29
Aromatic Hydrogen		741.65
$=CH_2$	Twist	895.96
CH_3	stretch	2985.91

As shown in Table 4.1 the acrylonitrile (CN) has its absorbance to be 2305.98cm^{-1}, the benzene ring that is associated with the polystyrene has its vibration bond to be stretched with the range of 741.cm-1, CH_2 has its vibration bond as bend rocking with the range as1434.12cm^{-1} (Brennan et al, 2001). Although there are few peaks that could not be matched with any of the expected functional brand, these could be additives that find their ways into the samples.

Figure 4.2 shows the spectra of recycled ABS from Fides fridge, the benzene ring was observed at 697.29cm^{-1},$=CH_2$ was seen as a stretch at 908.50cm^{-1},CN at 2240.54cm^{-1},

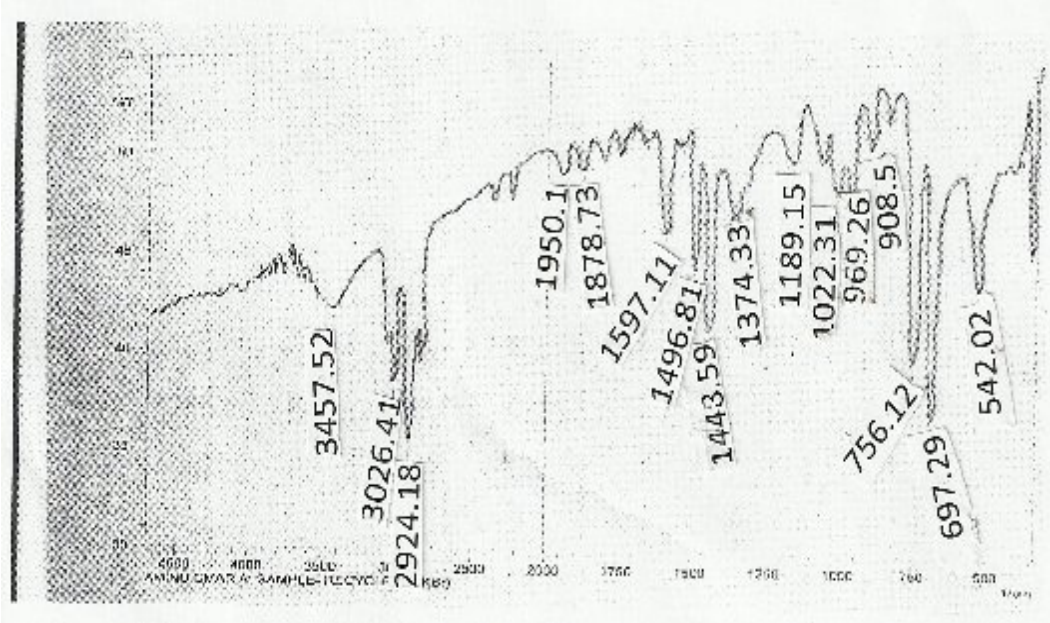


Figure 4.2 FTIR result of the recycled ABS from Fides fridge

Table 4.2: Identified functional groups, vibration and absorbance from FTIR analysis for Fides fridge.

Groups	Vibration	Absorbance(cm^{-1})
Benzene ring	Bend	697.29
Aromatic Hydrogen		756.12
$=CH_2$	stretch	908.50
CH_2	Bend	969.26
C-C		1189.15
CH_3	Bend	1374.39
CH_2	Bend rocking	1448.59
$C(sp^2)$-H (aromatic)	stretch	1496.81
Aromatic ring	stretch	1597.11
CN		2240.54
CH_3	stretch	2924.18
Aromatic ring	Bend	3457.52

Figure 4.3 shows the spectra of recycled ABS from Tec fridge. It was observed that acrylonitrile (CN) has absorbance peak at 2252cm^{-1}, and the benzene ring which is associated with polystyrene, has peak of 697.29-756.12 cm^{-1}, the $=CH_2$ bond is observed at a bend vibration and a range of 908.5cm^{-1},CH_2 was observed at a bend rocking

vibration with symmetric type and a range of 1448.59cm^{-1} However there were other functional groups such as C-C which was observed as a bond stretch vibration with the range of 1189cm^{-1}. Most of these groups were also identified with the virgin ABS

The essence of the Fourier transform infra red (FTIR) analysis was to establish the presence of ABS in the samples and this is shown in their respective figures. From the peak values therefore, it was evident that there were presence of acrylonitrile, butadiene and styrene functional groups as revealed by the spectra. This confirmed the presence of ABS in the samples. The Tec fridge had its own acrylonitrile peak (CN) at the range of 2240-2305 cm^{-1} , the aromatic ring peak was at 739.73cm^{-1} and 1446.66 cm^{-1} , the CH_2 had a bend rocking at 1446.66 cm^{-1} ,C=C was observed as a stretch at 1600.01 cm^{-1}and at 3056.31 cm^{-1} $CH_2C(SP^2)$-H was seen.

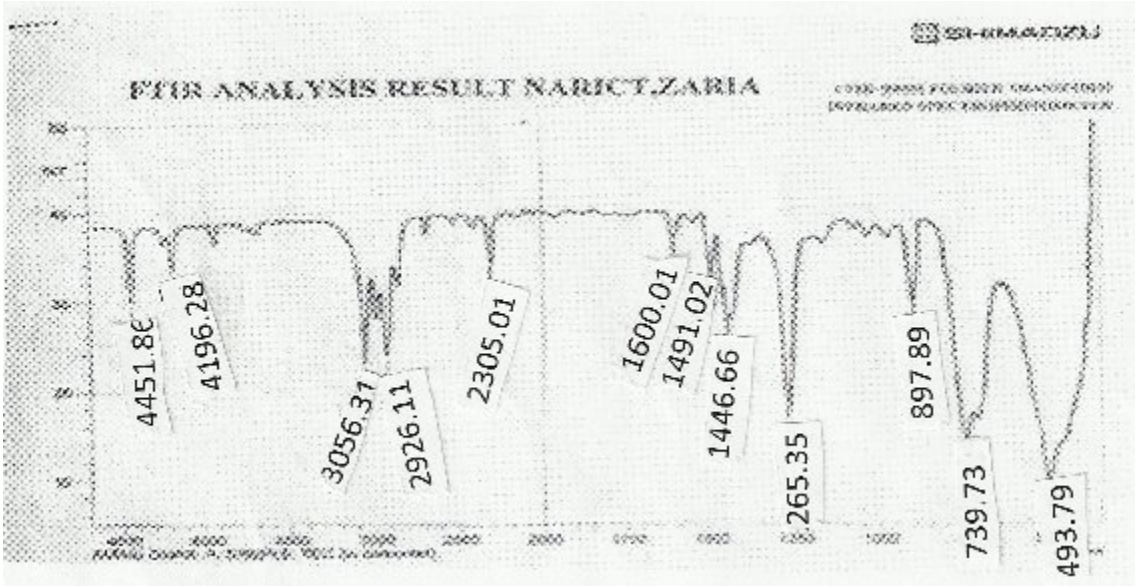


Figure 4.3: FTIR of the recycled ABS from Tec fridge

Table 4.3: Identified functional groups, vibration and absorbance from FTIR analysis for TEC fridge

Groups	Vibration	Absorbance (cm^{-1})
Aromatic ring	Bend	739.73
$=CH_2$	twist	897.89
CH_2	Bend rocking	1446.66
$C(sp^2)$-H (aromatic)	stretch	1491.02
Aromatics ring	stretch	1600.01
CN		2305.01
CH_3	stretch	2926.11
$C(sp^2)$-H	stretch	3056.31

The Matsui fridge also possessed the aromatic peak at 736.76cm^{-1} ,CN at 2305.1cm^{-1} , CH_3 was observed at 2928.04cm^{-1} , CH_2 has bend rocking at 1425.44 $cm^{-1}$and $=CH_2$ was observed at 896.93cm^{-1} . They have most of the groups found in the virgin ABS

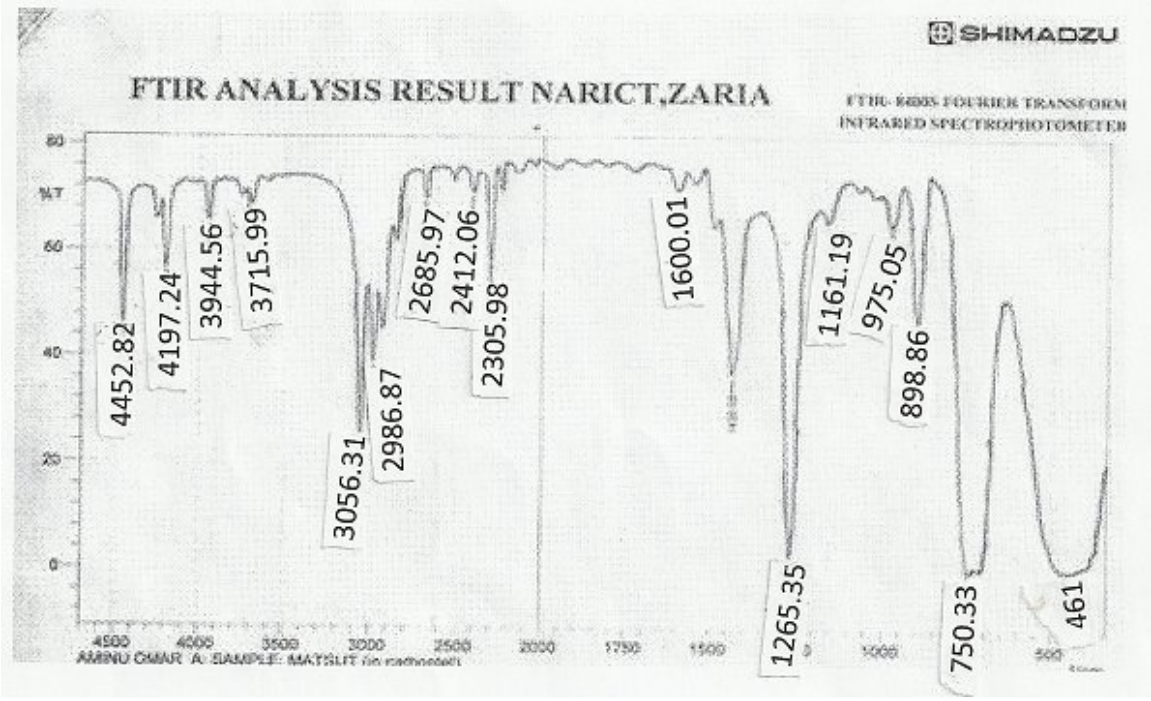


Figure 4.4: FTIR result of recycled ABS from Matsui fridge

Table 4.4: Identified functional groups, vibration and absorbance from FTIR analysis for Matsui fridge

Groups	Vibration	Absorbance (cm^{-1})
Aromatic ring	Bend	750.33
$=CH_2$		898.86
CH_2	stretch	1435.09
$C(sp^2)$-H	Ring stretch	1600.01
CN		2305.98
$C(sp^2)$-H(aromatic)	stretch	3056.31
CH_3	stretch	2986.87
C-C	stretch	1161.19

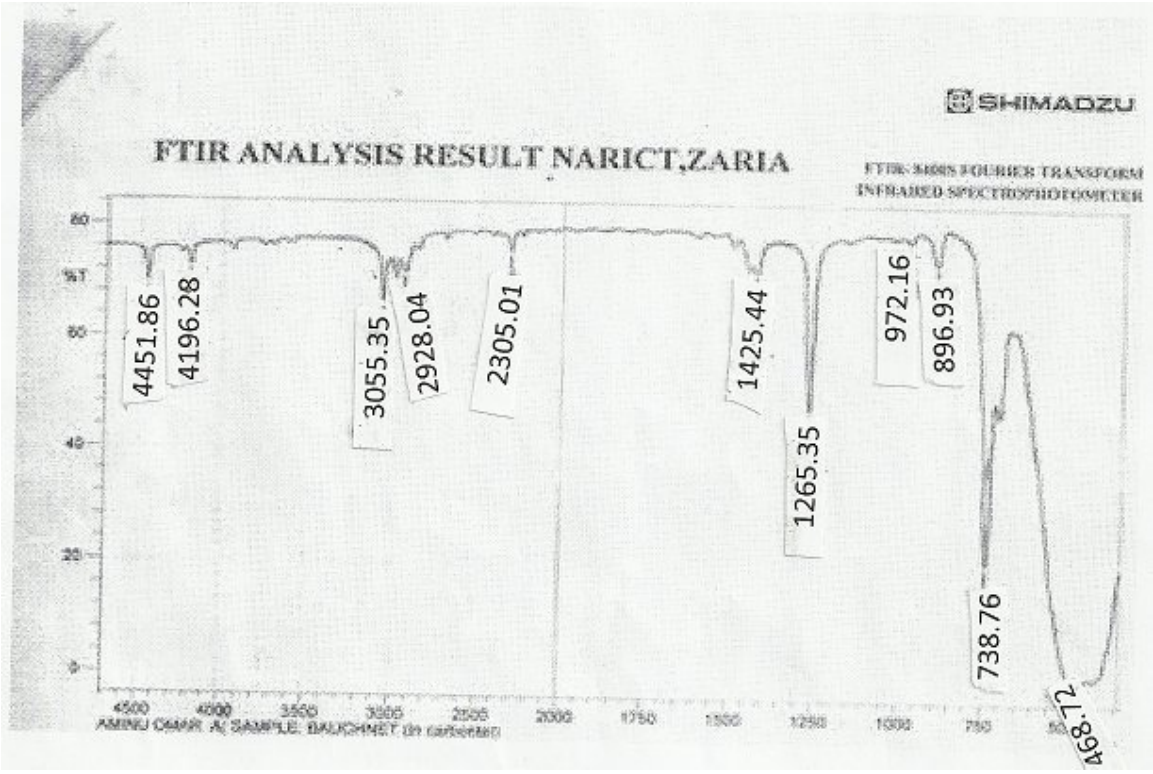


Figure 4.5: FTIR result of recycled ABS from Bauchnet fridge

Table 4.5: Identified functional groups, vibration and absorbance from FTIR analysis for Bauchnet fridge

Groups	Vibration	Absorbance(cm^{-1})
Substituted benzene		542.02
Aromatic ring	Bend	697.26
$=CH_2$	Twist	908.50
C-C	stretch	1189.15
CH_3	Bend	2924.18
CH2,C(sp^2)-H	stretch	3026.41
CN		2204.43
C-H	Bend	1374.33
Aromatic ring	Bend	1189.15
Aromatic ring	Stretch	1448.59
C(sp^2)-H		1597.11

Benzene ring was observed at 542.02cm^{-1},$=CH_2$ was obtained to be twist at 908.50cm^{-1} and CN was seen at 2204.43cm^{-1}, C-H as bend at 1374.33cm^{-1}, several other aromatics were seen at different absorbance. These were also observed with the virgin ABS

4.3 MECHANICAL AND PHYSICAL PROPERTIES OF ABS FROM DIFFERENT SOURCES

Table 4.6 presents the summary of the mechanical properties of recycled and virgin ABS obtained experimentally. The details are presented in Appendix A, Table A.1 to A.4.

The results indicated that recycled ABS from Bauchnect fridge and Matsui fridge had the highest tensile strength while recycled ABS from Fides, Tec, had almost the same tensile strength. Probably, this difference in tensile properties of the recycled ABS may have

resulted from the different grades of ABS that are available for the manufacture of the fridges and also the application purposes (Basdekis, 1964). The wide difference in tensile

Table 4.6: Mechanical properties of recycled and virgin ABS

Refrigerator brand	Tensile strength (MPa)	Modulus of elasticity (MOE) (MPa)	Flexural strength (MPa)	Elongation (%)
Fides Fridge	30.89	820	57.50	4.11
Tec fridge	27.63	925	51.20	3.71
Matsui fridge	31.66	1021	60.18	4.80
Bauchnet fridge	29.71	935	55.25	4.40
Virgin ABS	41.3	1312	65.75	13.37

properties of recycled ABS as observed in, Matsui fridge and their counterpart Fides, Tec and Bauchnect fridges may have resulted from the initial grades of ABS used for their manufacture. However the effect of aging cannot be ruled out. This is because it has been established that aging results into the degradation of polybutadiene components of the ABS and this could affect the overall properties (Boldizar 2003 and Tiganis et al, 2002). Previous service life and application conditions also have been established to affect properties achievable from recycled materials (Vilaplana et al, 2006 and Boldizar 2003). The tensile properties obtained for all the recycled ABS samples were less than the experimentally determined values and also the literature values. Equally the experimentally determined value for the virgin ABS was lower than the literature value,

this could be attributed to the effect of recycling because polymer generally can loss some additives or anti-oxidant when in contact with solvent and this can accelerate changes in properties during the recycling process (Arostegui et al, 2006).

For the modulus of elasticity (MOE) Matsui fridge had the highest value, while Bauchnect and Tec fridge have very close values, the fides fridge has the least values. The reason for this trend can not be readily explained, but on a general note the reasons advanced for the tensile strength may hold in this case. However, for the flexural strength also known as modulus of rupture(MOR) the values for all the samples were very close but still lower than the experimentally determined value of virgin ABS but they all fall within the literature values (Ebewele, 2000). For the elongation at break Matsui fridge had the highest value very close to the experimentally determined values of ABS which fall within the literature value while the values obtained for the Tec and Bauchnect fridge were lower than the literature value. Some variation between samples was noticed but it was not generally much as the standard deviations of the test were mostly less than 10%. Table 4.7 presents the water absorption and the density of the recycled and virgin ABS, with the details presented in Appendix A, Table A.5 and A.6.

Table 4.7: Physical properties of recycled and virgin ABS

Materials	Density (g/cm^3)	Water absorption (%)
Fides fridge	1.06	0.2569
Tec fridge	1.07	0.3934
Matsui fridge	1.01	0.2625
Bauchnet fridge	1.03	0.3211
Virgin ABS	1.04	0.3048

The virgin ABS has water absorption of about 1.6 % which is higher than the literature value of 0.3%. The recycled ABS from Bauchnet fridge and Tec Fridge has water absorption higher than the virgin ABS and reported literature value. This could be as a result of presence of impurities that could not be removed completely. The Fides fridge and Matsui fridge has low water absorption relative to the virgin ABS and reported value which implies that they are better since one good quality of a polymer is low water absorption, probably the type of impurities present in this recycled from the fridges were not susceptible to water absorption.

The density of Bauchnet fridge which was $1.03/cm^3$ was very close to the experimentally determined value for virgin ABS, ($1.04g/cm^3$). Both fell within the literature values of $1.02\text{-}1.04g/cm^3$. However the values obtained for both Fides and Tec fridges were $1.06g/cm^3$ and $1.07g/cm^3$ respectively were both higher than experimentally determined ABS and literature values while the value for matsui Fridge was $1.01g/cm^3$and was lower than both literature value of $1.02\text{-}1.04g/cm^3$ and the experimentally determined ABS

values, these deviations could be attributed to absorption of solvent or other causes such as presence of some other impurities.

Changes in density of a specimen may be due to changes in crystallinity, loss of plasticizer, absorption of solvent, or to other causes (Anonymous 2005,).

Chapter 5

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The following conclusions may be drawn from the investigations carried out in this work

1. Acrylonitrile-butadiene-styrene (ABS) was successfully recycled from used refrigerator material.
2. Tetrahydrofuran (THF) was found to be the suitable solvent among the candidate solvents for the dissolution of acrylonitrile-butadiene-styrene from waste refrigerator material at room temperature.
3. The mechanical properties of the recycled ABS were quite low when compared to virgin ABS. The mechanical properties of recycled ABS from Matsui had closest values to the virgin ABS.
4. The physical properties for all the recycled acrylonitrile-butadiene-styrene agrees with the values obtained for the virgin ABS.

5.2 RECOMMENDATIONS

1. Solvent method of recycling should also be investigated in other waste electrical appliances such as for the recovery of acrylonitrile-butadiene-styrene contained in them.
2. Attempt should be made to recover the solvent during recycling so that it can be reused for subsequent dissolution.
3. Effect of temperature should be studied on the dissolution of acrylonitrile-butadiene-styrene in the appropriate solvent.

4. Equipment for material testing should be provided in the department to enable ease characterization.

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Appendix A

Table A1: Tensile strength of recycled and virgin ABS

Materials (ABS)	Specimen (MPa)	Average (MPa)	Standard Deviation	Coefficient of Variance (COV)
fides	30.89 31.10 30.68	30.89	0.21	0.68
Tec fridge	28.70 27.63 26.56	27.63	1.07	3.8
Matsui fridge	31.65 31.66 31.64	31.65	0..01	0.03
Bauchnect fridge	29.50 28.60 31.83	29.71	1.67	0.56
Virgin ABS	40.00 42.40 41.50	41.30	1.21	2.51

Table A2: Modulus of elasticity (MOE) of recycled and virgin ABS

Materils(ABS)	Specimen (MPa)	Average (MPa)	Standard Deviation	Coefficient of Variance(COV)
Fides fridge	827 821 812	820	7.54	0.92
Tec fridge	926 920 929	925	4.58	0.49
Matsui fridge	1025 1007 1031	1021	4.36	0.33
Bauchnect fridge	938 932	935	3	0.32
Virgin ABS	1312 1307 1317	1312	12.49	1.22

Table A3: Elongation at break of recycled and virgin ABS

Materials (ABS)	Specimen (%)	Average	Standard Deviation	Coefficient of Variance (COV)
Fides fridge	4.00 4.10 4.23	4.11	0.11	2.81
Tec fridge	3.94 3.69 3.50	3.71	0.22	5.95
matsui fridge	5.90 3.70 4.80	4.80	0.89	16.03
Bauchnect fridge	4.21 4.52 3.90	4.40	0.46	10.23
Virgin ABS	13.50 12.60 14.01	13.37	0.71	5.34

Table A4: Flexural strength of recycled and virgin ABS

Materials(ABS)	Specimen (MPa)	Average (MPa)	Standard Deviation	Coefficient of Variation (COE)
Fides fridge	58.60 57.20 56.70	57.30	0.98	1.71
Tec fridge	51.2 50.95 51.25	51.20	0.23	0.45
Matsui fridge	60.20 60.12 60.22	60.18	0.05	0.09
Bauchnect fridge	55.20 55.40 55.15	55.25	0.13	0.24
Virgin ABS	65.75 65.76 65.74	65.75	0.19	0.33

Table A5: Density of recycled and virgin ABS

Materials(ABS)	Specimen (g/cm^3)	Average (g/cm)	Standard Deviation	Coefficient of Variation (COE)
Fides fridge	1.02 1.11 1.07	1.06	0.04	3.77
Tec fridge	1.05 1.10 1.06	1.07	0.02	1.86
Matsui fridge	1.01 1.01 1.02	1.01	0.005	0.49
Bauchnect fridge	1.03 1.04 1.02	1.03	0.01	0.97
Virgin ABS	1.04 1.04 1.03	1.04	0.005	0.45

Table A6 : water absorption of recycled and virgin ABS

Materials(ABS)	Specimen (%)	Average	Standard Deviation	Coefficient of Variation (COE)
Fides fridge	0.3961 0.3876 0.3967	0.3934	0.005	1.2
Tec fridge	0.2561 0.2721 0.2425	0.2569	0.01	3.8
Matsui fridge	0.2612 0.2443 0.2821	0.2625	0.01	3.8
Bauchnect fridge	0.3210 0.3450 0.3021	0.3227	0.02	6.2
Virgin ABS	0.3012 0.3112 0.3021	0.3048	0.005	1.6

Appendix B

SOLUBILITY PARAMETER CALCULATION

THF (C_4H_8O)

Molecular mass = (12 x4) +(8x1) +16 =72

Density of THF = 0.88g/cm^3 at 25^{o}C

Heat of vaporization (H_v) =116.1cal/g

Universal gas constant(R) = 1.984cal/(k)(gmol).

$$CED = \rho_s\left(\Delta H_v - RT\right)$$

Where ρ is the density,

R =1.984 cal/g, T = 25 + 273 =298K

RT = (1.984/m) x 298 cal /g =591.2/m(cal/g)

Molecular weight of THF = 72

CED =0.88 g/cal (116.1 – 591.2/72) = 94. 94 cal/cm^3

But CED = δ^2

Therefore solubility parameter (δ) = 9.74cal/cm^3

Benzene(C_6H_6)

Molecular mass = (12x6) + (6x1) =78

Density of Benzene = 0.8765g/cm^3 at 25^{o}C

Heat of vaporization (H_v) = 98.053 cal/g

RT =591.2/m (cal/g)

CED = 0.8765(98.053 – 591.2/78) = 79.2978 cal/cm^3

But CED = δ^2

Therefore solubility parameter (δ) = 8.9cal/cm^3

Toluene($C_6H_5CH_3$)

Molecular mass =(12x7) + (1 x8) = 92

Density of Toluene = 0.8669g/cm^3

Heat of vaporization (H_v) = 98.875 cal/g

RT = 591.2/m (cal/g)

CED = 0.8669(98.875 – 591.2/92) = 80.1437 cal/cm^3

But CED = δ^2

Therefore solubility parameter (δ) = 8.95cal/cm^3

For the polymer ABS, $\delta_2 = \rho \frac{\sum E}{M}$

Molecular mass of ABS

(CH_2-CH-CN-CH_2-CH=CH-CH_2-CH_2-CH-C_6H_5) n

(12 x 15) + 17 + 14 = 211

1 CN at 354.5 = 354.5

3 CH at 86 = 258

4 CH_2 at 131.5 = 526

1 phenyl at 585 = 585

1 CH< at 98 = 98.

Σ F = 1821.5

= 1.1(1821.5/211) = 9.49 cal m^3

APPENDIX C

The results of the physical properties viz water absorption and density of the samples are presented in this appendix thus

C.1 Water absorption

Weight of dry sample = 10g

Weight of sample in water at room temperature for 24 hrs = 10.0324

% water absorption = $\frac{10.0324 - 10}{10} x100 = 0.0324$

C.2 Density Determination

Weight of sample in air = 2g

Volume of sample =length x breadth x thickness = 4 x 2 x 0.245 = 1.96 cm^3

Density $= \frac{mass}{volume} = \frac{2}{1.96} = 1.02 g / cm^3$