MECHANICAL AND FLAMMABILITY PROPERTIES
OF ABS/PVC BLENDS

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For my dearest parents, siblings and See How
who wonder what I do all day...........

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ABSTRACT

Blending of polymers is often used as a means to develop new materials with the desired properties. The main objective of this research is to study the effect of different PVC molecular weight (K-58 and K-66) and acrylic grafted PVC on different grades of ABS in terms of mechanical and flammability properties. Morphological, thermal and rheological properties of the blends were also investigated. Three grades of ABS were used; high rigidity, medium impact and super high impact. Using a single screw extruder, blends of ABS/PVC in various compositions ranging from 100 - 80% ABS were prepared and injection moulded. Interestingly, a synergist effect is observed whereby the impact strength of the ABS/PVC blends is higher than the pure polymer. With increasing PVC content, the impact strength of the blends increased. The impact strength was also found to be dependant upon PVC molecular weight, with the higher K-value, the higher the impact strength. Acrylic grafted PVC is more effective in increasing the impact strength than the non grafted PVC. The impact strength enhancement increases with increasing rubber content in the ABS. The result also shows that the highest impact strength occurs when acrylic grafted PVC was added into super high impact ABS. However, it was observed that when PVC is incorporated in ABS, there is a marginal decrease in flexural modulus. The flexural modulus of the blends was also found to be dependant upon PVC molecular weight, with the lower K-value, the higher the flexural modulus. With increasing PVC content, the flexural modulus of the blends decreased. The highest flexural modulus among the blends is high rigidity ABS/ PVC K-58. The DMA study confirmed that the SAN component of ABS is highly miscible with PVC. The miscibility between SAN component of ABS has improved the interfacial adhesion between PVC and ABS. The flammability of the blends determined by the LOI test shows that the flammability of the blends decreased with increasing PVC content. The most optimum formulation in terms of cost and mechanical properties is 80 super high impact ABS/20 PVC K-66.

ABSTRAK

Pengadunan polimer dibangunkan demi mengeluarkan bahan baru yang mempunyai sifat-sifat yang diingini. Objektif utama penyelidikan ini adalah untuk mengkaji kesan berat molekul PVC, iaitu jenis K-58, K-66 dan PVC bercangkuk akrilik ke atas akrilonitril butadiena stirena (ABS) terhadap sifat mekanikal dan kebolehbakaran. Sifat-sifat morfologi, terma dan reologi adunan turut dikaji. Tiga jenis ABS digunakan: ketegaran yang tinggi, hentaman sederhana serta hentaman paling tinggi. Dengan penyemperit skru tunggal, adunan ABS/PVC disediakan mengikut komposisi dalam julat 80 -100 % ABS dan diacu-suntikan. Menariknya, adunan ABS/PVC mempunyai kekuatan hentaman yang lebih tinggi daripada polimer tulen. Kekuatan hentaman bertambah dengan peningkatan kandungan PVC. Selain itu, kekuatan hentaman juga dipengaruhi oleh berat molekul PVC, semakin tinggi nilai-K, semakin tinggi kekuatan hentaman. PVC bercangkuk akrilik lebih efektif dari segi peningkatan kekuatan hentaman berbanding dengan PVC lain. Kekuatan hentaman meningkat apabila komposisi getah dalam ABS meningkat. Keputusan menunjukkan adunan antara ABS berhentaman tinggi dan PVC bercangkuk akrilik berjaya menghasilkan kekuatan hentaman yang maksimum. Walau bagaimanapun, penurunan nilai modulus lenturan yang sikit diperolehi apabila PVC dicampur ke dalam ABS. Modulus lenturan juga dipengaruhi oleh berat molekul PVC, semakin rendah nilai-K, semakin tinggi nilai modulus. Apabila komposisi PVC bertambah, modulus lenturan bagi adunan ABS/PVC turut munurun. Nilai modulus lenturan yang tertinggi wujud apabila PVC K-58 dicampur bersama ABS bertegaran tinggi. DMA membuktikan komponen SAN dalam ABS adalah hampir serasi dengan PVC. Keserasian ini berjaya meningkatkan pelekatan antara permukaan PVC dan ABS. Kebolehbakaran adunan diuji dengan teknik indeks oksigen terhad (LOI) menunjukkan kebolehbakaran semakin menurun apabila komposisi PVC semakin meningkat. Formulasi yang optimum dari segi kos dan sifat mekanikal ialah 80 ABS berhentaman paling tinggi/20 PVC K-66.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABS	-	Acrylonitrile-butadiene-styrene
AN	-	Acrylonitrile
ASTM	-	American Standard Test Method
$CaCO_3$	-	Calcium carbonate
Cast	-	Calcium stearate
DMA	-	Dynamic mechanical analysis
DSC	-	Differential scanning calorimetry
E'	-	Storage modulus
E"	-	Loss modulus
EPDM	-	Ethylene-propylene-diene terpolymer
EPM	-	Ethylene-propylene copolymer
FeOOH		Ferum trioxide
FR	-	Flame retardant
FRSS	-	Flame retardant smoke suppressants
HDT	-	Heat deflection temperature
H_f	-	Heats of fusion
Hst	-	Stearic acid
L/D	-	Length to diameter
LOI	-	Limiting oxygen index
MFI	-	Melt flow index
$MgCO_3$	-	Magnesium carbonate
min	-	Minutes
MPa	-	Mega pascal
NBR	-	Butadiene-acrylonitrile rubber

PBD	-	Polybutadiene
PC	-	Polycarbonate
phr	-	Part per hundred
PMMA	-	Poly(methyl methacrylate)
PVC-U	-	Unplasticised Poly(vinyl chloride)
r.p.m.	-	Revolutions per minute
RH	-	Rockwell hardness
SAN	-	Styrene-acrylonitrile copolymer
SEM	-	Scanning electron microscopy
SMA	-	Styrene maleic anhydride
Tan δ	-	Tangent delta
T_g	-	Glass transition temperature
TGA	-	Thermogravimetric analysis
T_m	-	Melting temperature
T_R	-	Crystallization peak
TPU	-	Thermoplastic polyurathane
UF	-	Urea formaldehyde
VCM	-	Vinyl chloride monomer
$W_{1/2}$	-	Width of the peak at half height
ΔH_c	-	Heat of crystallization

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CHAPTER I

INTRODUCTION

1.0 Introduction

The first completely synthetic plastic, phenol-formaldehyde, was introduced by Baekeland in 1909, nearly four decades after Hyatt had developed a semisynthetic plastic-cellulose nitrate (Chanda and Roy, 1993). In 1927 poly(vinyl chloride) (PVC) and cellulose acetate were developed, and 1929 saw the introduction of urea-formaldehyde (UF) resins (Chanda and Roy, 1993). The development of new polymeric materials proceeded at an even faster pace after the war. Epoxies were developed in 1947, and acrylonitrile-butadiene-styrene (ABS) terpolymer in 1948 (Chanda and Roy, 1993). The next two decades saw the commercial development of a number of highly temperature-resistance materials. More recently, other new polymer materials were introduced, including several exotic materials which are mostly very expensive.

There are hundred of homopolymers commercially available today. Since one type of polymer does not possess all the physical and mechanical properties desired in a finished product, blending of polymers were introduced to meet the requirements. The continuing pressure to improve productivity and quality has generated the research in polymer blends. Blending also offers the possibility of tailor-make products to meet specific end needs. For this reason, much attention was received from academia and industry and thus blending of polymers are experiencing significant growth. From the economic point of view, blend development is far less costly and time consuming than the development of new polymers (Datta and Lohse, 1996).

This present study focuses on the blending of ABS with PVC. The large diversify of end uses makes ABS one of the most successful of the engineering thermoplastics available. It is a bridge between commodity plastics (e.g., polystyrene) and higher-performing engineering thermoplastics (e.g., polycarbonate). Its position in terms of both properties and price between the more highly priced, high performance engineering plastics and the lower priced commodity plastics makes ABS the material of choice for many applications (Adams *et al.*, 1993).

ABS resins are composed of over 50% styrene and varying amounts of butadiene and acrylonitrile. Styrene provides rigidity and ease of processability, acrylonitrile offers chemical resistance and heat stability, and butadiene supplies toughness and impact strength. ABS having high rubber content possesses higher impact strength than those with low rubber content. Increase in rubber content results in greater ductility of these blends. Large-volume applications for ABS resins include plastic pipe and automotive and appliance parts. Although ABS has many desired properties as engineering thermoplastic, its still has some limitation for example, easily burn with high flammability value and poor resistance to outdoor UV light (Chanda and Roy, 1993).

ABS itself is already a blend of polybutadiene and styrene acrylonitrile (SAN). It can be further blended with other materials to introduce new and improve resin grades. Thus, the scope of possible applications is broadened (Jin *et al.*, 1998), and resulting in overall demand growth for ABS. Demand in the U.S. for ABS is projected to advance 4% per year through 2006 to 1.6 billion pounds, valued at $3.1 billion (Freedonia Industry Study, 2002).

The low price of PVC renders its use desirable in many applications. Besides, this material is popular with its inherent flame retardancy and UV stability. When blended with ABS, the result is a material with good impact strength, toughness and inherent flame resistance (Hofmann, 1985). ABS/PVC is used in a wide variety of applications which include electrical components, appliances, business machine housings and automotive parts (Manson and Sperling, 1976). The inherent flame retardancy of PVC makes it suitable for applications where the more expensive flame retardant ABS could be employed (Landrock, 1983).

Blending of ABS with other polymers is widely reported. Many studies have been carried out on ABS/Polycarbonate (PC) blend (Chiang and Hwang, 1987; Lee *et al.*, 1988; Steeman and Maurer, 1994; Ogoe *et al.*, 1996; Jin *et al.*, 1997; Balakrishnan and Neelakantan, 1998; Lim and Bertilsson, 1999 and Choi *et al.*, 2000) Among the interesting finding of these studies are that ABS provides the benefits of economics, processability and more reliable impact resistance, while PC contributes the improvements of tensile, flexural, thermal properties and flammability to the blends.

The study on ABS/PVC blend had received less attention compared to ABS/PC blend. According to Adam *et al.* (1993), ABS/PVC blend possessed U.S. annual consumption growth rate (1990-1996) of 12-18% or 3-9% higher than ABS/PC blend (Growth rate: 9%). Thus, more research study should base on ABS/PVC blend since it has a convinced growth rate but less research study is being reported.

The studies on polyblend of PVC and ABS were conducted by Maiti *et al.* (1992). PVC compositions ranging from 50 to 100% were used. Maiti *et al.* discovered that this polyblend possesses advantages like the tensile strength and rigidity of PVC and impact strength of ABS. TGA analysis revealed a substantial improvement in thermal stability of PVC/ABS blends over that of PVC.

The compatibility enhancement of ABS/PVC blends was also conducted by Jin *et al.* (1998). The composition for PVC was ranging from 50 to 100 %. When a compatibilizer, SAN 25 was added into the blend, the compatibility was enhanced and about twofold increase of impact strength was observed.

Bensemra and Bedda (2001) studied the properties of PVC/ABS blends. Blends with variable composition, 0 to 100 wt % PVC were used. The researchers concluded that addition of plasticizer, di(ethyl-2hexyl) phthalate into the blends greatly improved the impact properties where the higher the PVC content, the higher the impact value.

Besides studying the mechanical properties of ABS/PVC blend, flammability of the blend was also investigated by Carty and White (1994). According to Alexander (2000), the annual loss of life and the property caused by fire around the world is extraordinary, since thousand of death and billion of property were loss each year. Most of the fires involve the combustion of polymeric materials. So, the method to reduce the flammability of polymers and hence reduced the loss of life and the property has been the subject of increasing interest over the past several years. As mentioned, one of ABS main drawbacks is its inherent flammability and therefore a need exist to improve this property by incorporation of halogenated polymers, such as PVC.

In the study conducted by Carty and White (1994), ABS/PVC blends containing up to 30 phr of PVC were examined. In this work, addition of PVC into ABS has successfully reduced the flammability of ABS, where the LOI value increased from 18.3% to 33.8%. The flame retarded ABS currently has a great deal of interest in the computer and business equipment market. Alexander (2000) also mentioned that European regulators were considering requiring flame retarded polymer in electronic equipments and other products.

1.2 Problem Statement

As mentioned earlier, the studies on ABS/PVC blend have received less attention compared to PC/ABS blend. The previous studies on PVC/ABS blends concentrate mainly on the use of ABS as the added polymers, with PVC as the main component (Maiti *et.al*, 1992; Jin *et.al*, 1998; Bensemra an Bedda, 2001). The present study will focus on the effect of adding PVC into ABS. The effect of adding PVC of different molecular weight into different types of ABS (with different ratios of monomer content) has not yet been reported. It is expected that both, PVC molecular weight and polybutadiene content in ABS will influence the properties of

ABS/PVC blend. The study on blending acrylic grafted PVC with ABS has also not been reported. This proposed study hopefully will further the knowledge in the area of ABS/PVC blend and extend the applications of ABS.

1.3 Objectives

The main objectives of the proposed research are as follows.

- to study the effect of PVC molecular weight and content, and acrylic grafted PVC on the mechanical and flammability properties of ABS/PVC blends.
- to study the effect of different grades and composition of ABS on the mechanical and flammability properties of ABS/PVC blends.
- to determine the optimum ABS/PVC content in terms of mechanical properties, flammability, and cost.

1.4 Scope

The study involved preparing various samples of ABS/PVC at blend composition of 100/0, 90/10, 85/15 and 80/20. A mixer, single screw extruder and injection moulding were used for sample preparation. The types of the testing and analysis are as follows:

(a) Mechanical Properties

Two types of mechanical properties were conducted, that is Pendulum Izod impact and flexural test.

Pendulum Izod impact was used to determine the impact strength of each blend.

Flexural test was also carried out to determine the stiffness of the ABS/PVC blend.

(b) Flammability

Oxygen Index Test was used to determine the flammability properties of the blends.

(c) Thermal Properties

Heat deflection temperature (HDT) was used to determine the temperature at which it loss the rigidity.

(d) Material Characterization Test

DMA (Dynamic Mechanical Analysis) was used to correlates the T_g with the miscibility of the blends.

SEM (Scanning Electron Microscopy) analysis was carried out to correlate the surface fracture with the impact strength results.

MFI (Melt Flow Index) test was conducted to obtain the melt flow rate and to determine the processibility of the ABS/PVC blends.

a) Using higher content of PVC
b) Incorporation of different types of flame retardant (not more than 10 phr) into ABS/PVC blends such as:

Iron compounds	1) FeOOH – Bayferrox yellow 3905 (Bayer)
	2) Fe_3O_4 – ferrosoferric (magnetic) black iron oxide (BDH)
	3) FeOCl – iron (III) oxychloride
	4) Iron (III0 molybdate
Brominated materials	1) Octabromodiphenyl oxide
	2) 1,2 – bistribromophenoxy ethane
	3) Tetrabromobisphenol A
	4) Poly-dibromostyrene

c) Incorporation of Sb_2O_3 as synergist in flame retardant ABS/PVC polymer.
d) Varies the particles size of Sb_2O_3.

ii) The initial work on flammability properties has given interesting results. This method can be further investigated by developed a correlation between LOI and smoke density (smoke production). Char determination can also be carried out by using DTA/TGA technique to record accurately heat and mass change.

iii) Incorporation of flame retardant will reduce the mechanical properties of the blends. In order to minimize the reduction, compatibilizer should be added to study the effect of coupling agents in flame retarded ABS/PVC blends.

iv) To investigate the effects of compatibilizer on flame retarded ABS/PVC blends.

REFERENCES

Adams, M. E., Buckley, D. J., Colborn, R. E., England, W. P., and Schissel, D. N. (1993). *Acrylonitrile-Butadiene-Styrene Polymers*. United Kingdom: Rapra Preview Reports. 3-4.

Adams, M. E., Buckley, D. J., Colborn, R. E., England, W. P., and Schissel, D. N. (1993). Freedonia Industry Study. (2002). *Engineered Plastics*. U.S.A: CEH Marketing Research Report. In *Acrylonitrile-Butadiene-Styrene Polymers*. United Kingdom: Rapra Preview Reports. 2-3.

Alexander H. T. (2000). Plastics Additives' Steady Evolution. *Business*. **78:** 21-31.

Andreas, H. (1984). PVC Stabiliser. In Gächter, R. and Müller (ed). *Plastics Additives Handbook*. New York: Hanser Publishers. 193-246.

Azman bin Hassan. (1996). *Impact Modification and Properties of Solid and Foamed PVC-U*. University of Loughborough, United Kingdom: Thesis Ph.D.

Bach, H. C. and Knorr, R. S. (1989). *Encyclopedia of Polymer Science and Engineering Volume 1*. John Wiley & Sons. 388-423.

Bair, H. E., Boyle, D. J. and Kelleher, P. G. (1980). The Effect of Light and Heat on the Rubber Content and Impact Strength of ABS. *Polymer Engineering and Science*. 20(15): 995-1001.

Balakrishnan, S. and Neelakantan, N. R. (1998). Mechanical Properties of Blends of Polycarbonate with Unmodified and Maleic Anhydride Grafted ABS. *Polymer International*. 45: 347-352.

Bensemra, N. B. and Bedda, A. (2001). Study of the Properties of PVC/ABS Blends. *Macromolecule Symposia*. 176: 145-153.

Billmeyer, F. W. JR. (1984). *Textbook of Polymer Science 3rd Edition*. Toronto: John Wiley& Sons. 301-345.

Blanco, A. (2000). Polyolefins 2000: Mergers & Acquisitions Define the Future. *Society of Plastic Engineers*. 56(5): 41.

Bonner, J. G. and Hope, P. S. (1993). Compatibilisation and Reactive Blending. In M. J. Folkes and P. S. Hope. ed. (1993). *Polymer Blends and Alloys*. London: Blackie Academic & Professional. 46-74.

Bramfitt, J. E. and Heaps, J. M. (1962). Advance in PVC Compounding and Processing. In Brydson, J. A. *Plastics Materials Sixth Edition*. Oxford : Butterworth-Heinemann Ltd.

Brisimitzakis, A. C. (1994). Styrenic Resins. In Modern Plastic Magazine ed. *Encyclopedia Handbook*. United States of America : McGraw-Hill, Inc. 52-53.

Broutman, L. J. and Kobayashi, T. (1971). AMMRC CR 71-14, Army. Material Mechanical Res. Ctr. Watertown, Massachussetts. In Sridharan, N. S. and Broutman, L. J. (1982). Fracture Analysis of Acrylonitrile-Butadiene-Styrene Resins. *Polymer Engineering and Science*. 22(12): 760-765.

Brydson, J. A. (1995). *Plastics Materials Sixth Edition*. Oxford : Butterworth-Heinemann Ltd. 77.

Bucknall, C. B. (1977). *Toughened Plastics*. England: Applied Science Publishers Ltd. 90-94.

Bucknall, C. B. and Smith, R. R. (1965). Stress-Whitening in High-Impact Polystyrene. *Journal of Polymer*. **6**. 437-446.

Burgress, R. H. (1982). Suspension Polymerization of Vinyl Chloride. In *Manufacturing and Processing of PVC*. British: Applied Science Publishers LTD. 1-37

Carty, P and White S. (1994). The Importance of Char-Forming Reactions in Thermoplastic Polymers. *Fire and Materials*. **18:** 151-166.

Chanda. M., and Roy. S. K. (1993). *Plastic Technology Handbook*. New York: Marcel Dekker, Inc. 561-566.

Chang, F. C. (1997). Compatibilized Thermoplastic Blends. In Olagoke Olabisi. *Handbook of Thermoplastics*. New York: Marcel Dekker, Inc. 491-523.

Charles, B. A. (1996). Multiphase Toughening of Plastic. In Charles, B. A. ed. *Polymer Toughening*. New York: Marcel Dekker, Inc. 61-84.

Cheng, J. T. and Mantell, G. J. (1989). Unassigned. Journal of Applied Polymer Science. 23. 1733. In Brandrup, J and Immergut, E. H. *Polymer Handbook*. 3rd Ed. Canada: John Wiley and Sons.

Chiang, W. Y. and Hwung, D. S. (1987). Properties of PC/ABS blends. *Polymer Engineering and Science*. 27(9): 632-639.

Ching, Yern Chee. (2001). *Mechanical and Morphological Properties of Impact Modified PP*. University Technology Malaysia, Malaysia: Thesis Master.

Choi, H. J., Park, S. H., Kim, J. K. and Jun, J. I. (2000). Effects of Acrylonitrile Content on PC/ABS Alloy Systems with a Flame Retardant. *Journal of Applied Polymer Science*. **75:** 417-423.

Coaker, A. W. and Wypart, R. W. (1993). Vinyl Chloride Resin: Suspension, Emulsion, Microsuspension and Bulk (Mass). In Wickson , E. J. *Handbook of Polyvinyl Chloride Formulating.* New York: John Wiley and Sons Inc. 15-55.

Crawford, R. J. (1987). *Plastics Engineering 2nd Edition.* Oxford: Pergamon Press. 18-25.

Codgell, J. F. and Hardesty, R. M. (1958). SPE Journal. **14**. 25. In Norbert, M. B. ed. (1971). *Mechanical Properties of Polymers*. New Jersey: Wiley Interscience. 175-222.

Datta, S and Lohse, D. J. (1996). *Polymeric Compatibilizers Uses and Benefits in Polymer Blends*. New York: Hanser Publishers. 191-193, 317-319.

Dayal, S., Malthotra, V. P. and Vat, J. L. (1998). The Dynamic Mechanical Analysis, Impact and Morphological Studies of EDPM-PVC and MMA-g-EPDM-PVC Blends. *Journal of Applied Polymer Science*. **71:** 1959-1968.

Deanin, R. D. (1990). Practical Benefits of Polymer Blending. *Macromolecules*. 1-23.

Deanin, R. D. and Moshar, C. (1974). Untitled. ACS Polymer Prepr. **15**(1). 403 In Bucknall, C. B. (1977). *Toughened Plastics*. England: Applied Science Publishers Ltd. 90-94.

Dear, J. P., Graham, J. C. and Brown P. (1997). Comparison of the Toughness of Different Acrylonitrile-Butadiene-Styrene Copolymers. *Polymer*. 39(11): 2349-2354.

De Coste, J. B. & Hansen, R. H. (1962). *SPE Journal*. 18(4): 431-9.

Demma, G., Martuscelli, E., Zanetti, A. and Zorzetto, M. (1983). Morphology and Properties of Polyurethane-Based Blends. Journal of Material Science. **1.** 89-102. In Adams, M. E., Buckley, D. J., Colborn, R. E., England, W. P. and Schissel, D. N. (1993). *Acrylonitrile-Butadiene-Styrene Polymers.* United Kingdom: Rapra Preview Reports. 21.

Doak, K. W. (1984a&b). *Unassigned.* (U. S. Pat. 4. 469, 844, 845).

Donald, E. W. (1986). Resin Structure and Properties. In Nass , L. I.. and Heiberger, C. A. *Encyclopedia of PVC.* New York: Marcel Dekker, Inc. 336-338.

Ferrigno, T. H. and Wickson, E. J. (1993). Carbonate Fillers. In Wickson, E. J. *Handbook of PVC Formulating.* New York: John Wiley and Sons Inc. 395-429.

Ferry, J. D. (1980). *Viscoelastic Properties of Polymers.* New York: John Wiley.

Fox, D. W. and Allen, R. B. (1985). Compatibility. In Mark, H. F., Bikales, N. M., Overberger, C. G. and Menges, G. *Encyclopedia of Polymer Science and Engineering.* 2nd ed. New York: John Wiley & Sons. 785-774.

Frank, L. F. (1991). *Combustibility of Plastics.* New York: Van Nostrand Reinhold. 122-179.

Fried, J. R. (1995). *Polymer Science and Technology.* USA: Prentice Hall, Inc. 251-263.

Gao, J. G., Li, D. L., Wang, D. Y. and Yang, L. T. (2000). Rheological behaviour and Mechanical Properties of Blends of Chlorinated Polyethylene with Poly(Acrylonitrile-Styrene-Methyl Methacrylate). *European Polymer Journal.* **36:** 2517-2522.

Glenn, B., Hilton and Cathleen, A. J. (1985). Acrylonitrile –Butadiene-Styrene. In James, M. Margolis. ed. *Engineering Thermoplastics Properties and Applications*. New York : Marcel Dekker Inc. 335-371.

Gobstein, S. (1990). Rigid Poly(Vinyl Chloride) (RPVC). In Rubin, I. I. *Handbook of Plastic Materials and Technology*. USA: John Wiley & Sons. 525-566.

Grassie, N. ((Ed). (1977). *Developments In Polymer Degradation – 1*. London: Applied Science Publishers. 1-42, 171-204.

Green, J. (1989). Flame Retardant and Smoke Suppressants. In John T. Lutz, Jr. *Thermoplastic Polymer Additives*. New York: Marcel Dekker, Inc. 93-204.

Grossman, R. F. (1989). Lubricants. In John T. Lutz, Jr. *Thermoplastic Polymer Additives*. New York: Marcel Dekker, Inc. 281-314.

Hirschler, M. M. (2000). Chemical Aspects of Thermal Decomposition of Polymeric Materials. In Grand, A. F. and Wilkie, C. A. *Fire Retardancy of Polymeric Materials*. New York: Marcel Dekker, Inc. 28-75.

Hofmann, G. H. (1985). Polymer Blend Modification of PVC. In D. J. Walsh, J. S. Higgins, and A. Maconnachie. ed. *Polymer Blends and Mixtures*. Netherlands: Martinus Nijhoff Publishers, Dordrecht. 117-148.

Jalbert, R. L. (1991). *Plastics Additives and Modifiers Handbook.* New York: Van Nostrand Reinhold. 152-162

Jenkner, H. and Köln. (1983). Flame retardants for Thermoplastics. In Gächter, R and Müller, H. *Plastics Additives Handbook*. New York: Hanser Publishers. 537-540.

Jin, D.W. H, Shon, K. H., Jeong, H. M. and Kim, B. K. (1997). Compatibility Enhancement of ABS/PC Blends. *Journal of Applied Polymer Science*. **69**. 533-542.

Jin, D.W. H, Shon, K. H., Kim, B. K., and Jeong, H. M. (1998). Compatibility Enhancement of ABS/PVC Blends. *Journal of Applied Polymer Science*. **70**. 705-709.

Johnson, D. (1998). SPE Thermoforming Conference Sets Attendance Mark. *Society of Plastic Engineers*. 54(11): 56-58.

Johnson, D. (1999). Additives '99. *Society of Plastic Engineers*. 55(11): 30.

Katz, M., Shkolnik, S. & Ron, I. (1976). *34th ANTEC SPE Proceedings*. 511.

Kauder, O. S. (1989). Stabilizers. In John T. Lutz, Jr. *Thermoplastic Polymer Additives*. New York: Marcel Dekker, Inc. 281-314.

Khanna, S. K. and Congdon, W. I. (1983). Engineering and Moulding Properties of Poly(vinyl Chloride), Acrylonitrile-Butadiene-Styrene and Polyester Blends. *Polymer Engineering and Science*. 23(11): 627-631.

Kim, C. H., Park, J. K., Hwang, T. S. (1996). Effect of Intramolecular Interactions on the Miscibility Windows of PVC Blends with Modified SAN Copolymers. *Polymer Engineering and Science*. **36:** 535-540.

Kim, J. H., Keskkula, H. and Paul, D. R. (1990). Unassigned. J. Appl. Polym. Sci. 40: 183. In Charles, B. A. ed. *Polymer Toughening*. New York: Marcel Dekker. 61-84.

Klaric, Roje, U. and Bravar, M. (1996). Thermooxidative Degradation of Poly(vinyl Chloride)/ Acrylonitrile-Butadiene-Styrene Blends. *Journal of Applied Polymer Science*. 61: 1123-1129.

Krause, S. (1989). Compatible Polymers. In Bandrup, J. and Inmergut, E. H. *Polymer Handbook 3rd ed.* Canada: John Wiley & Sons. VI/347-348.

Kumbhani, K. J. and Kent, E. G. (1981) Improving Polyolefin Properties with Butyl. In (1988). *Advances in Polymer Blends and Alloys Technology.* USA: Technomic Publishing. 87-100.

Kunststoffe (1989). *Polyvinyl Chloride (PVC).* German Plastics. 79.896-900.

Kuriakose, B. and De, S. K. (1985). Studies on the Melt Flow Behaviour of Thermoplastic Elastomers from Polypropylene/Natural Rubber Blends. *Polymer Engineering and Science.* 25: 630-634.

Kuryla, W. C. and Papa, A. J. ed. (1973). Flame Retardancy of Polymeric Materials, Volume 3. New York: Marcel Dekker. In Chanda. M., and Roy. S. K. (1993). *Plastic Technology Handbook.* New York: Marcel Dekker, Inc. 61.

Landrock, A. H. (1983). *Handbook of Plastics Flammability and Combustion Toxicology.* New Jersey: Noyes Publications. 18-26, 36-41.

Lavengood, R. E. and Silver, F. M. (1987). *New Nylon/ABS Alloys: Structure-Property Relationships.* I. Antec 87 Plastic. Los Angeles:SPE. 1369-1374.

Lee, M. S., Kao, H. C., Chiang, C. C. and Su, D. T. (1988). Degradation during Blending of ABS/PC and its Impact Strength Variation. *43rd Annual Conference, Composite Institute.* February 1-5. Society of Plastic Industry. 25-34.

Lee, C. H., Lee, S. K., Kang, S. W., Yun, S. H., Kim, J. H. and Choe, S. (1999). Impact Strength in ABS-PPO Blends Compatibilizedd with Styrene-Acrylonitrile-Glycidil Methacrylate Terpolymers. *Journal of Applied Polymer Science.* 73: 841-852.

Lian, Y. X., Zhang, Y., Peng, Z. I., Zhang, X. F., Fan, R. L., and Zhang, Y. X. (2001). Properties and Morphologies of PVC/Nylon Terpolymer Blends. *Journal of Applied Polymer Science*. 80: 2823-2832.

Liang, J. Z. and Li, R. K. Y. (2000). Rubber Toughening in Polypropylene: A Review. *Journal of Applied Polymer Science*. 77: 409-417.

Lindner, C. and K.-H. Ott. (1989). *Bayer*. (U. S. Pat. 4, 859, 744).

Liu, X. D and Bertilsson, H. (1999). Recycling of ABS/PC blends. *Journal of Applied Polymer Science*. 74: 510-515.

Macknight, W. J., Karasz, F. E. and Fried, J. R. (1978). Solid State Transition Behaviour of Blends. In Paul, D. R. and Newman, S. *Polymer Blends*. New York: Academic Press. 186-234.

Maiti, S. N., Saroop, U. K., and Misra, A. (1992). Studies on Polyblends of Poly(vinyl Chloride) and Acrylonitrile-Butadiene-Styrene Terpolymer. *Polymer Engineering and Science*. 32(1): 27-35.

Manson, J. A. (1986). PVC Blends, Blocks, Grafts, and Interpenetrating Polymer Networks. In Leonard, I. N. and Charles, A. H. *Encyclopedia of PVC*. New York: Marcel Dekker, Inc. 336-338.

Manson, J. A. and Sperling, L. H. (1976). *Polymer Blends and Composites*. London: Heyden & Son Limited. 51-72, 83-88.

Meredith, F. L. and L. E. Ferguson. (1988). *Borg-Warner*. (U. S. Pat. 4. 764, 563).

Mertz, E. H., Clever, G. C. and Baer, M. (1956). Studies on Heterogeneous Polymeric System. *Journal of Polymer Science*. **22:** 325-341.

Mesch, K. A. (1994). Lubricants. In Modern Plastic Magazine. ed. *Encyclopedia Handbook.* United States of America : McGraw-Hill, Inc. 107-108.

Mill, N. J. (1986). *Plastics Microstructure, Properties and Application.* London: Edward Arnold. 24-37.

Mitsuru, Y, Shinichi, S and Yasuji, K. (1983). Comparison of Poly(styrene, polystyrene/Acrylonitrile), High Impact Polystyrene and Poly(acrylonitrile/Butadiene/Styrene) with Respect to Tensile and Impact Properties. *Journal of Applied Polymer Science.* 28: 2209-2216.

Modern Plastic Magazine. ed. (1994). *Encyclopedia Handbook.* USA: McGraw-Hill, Inc. 5-6.

Moh Ching Oliver Chang, Benny, D., Trishna Ray-Chaudhuri, Liqing L. Sun, and Russell P. Wong. (1997). Acrylonitrile-Butadiene-Styrene (ABS) Polymers. In Olagoke Olabisi. *Handbook of Thermoplastics.* New York: Marcel Dekker, Inc. 135-160.

Molinaro, H. ed. (1999a). Lounging Aboard Coextruded Polymers. *Society of Plastic Engineers.* 55(7): 6.

Molinaro, H. ed. (1999b). ABS Resin Speeds Motorbike to Market. *Society of Plastic Engineers.* 55(2): 7

Molinaro, H. ed. (1999c). "ABS Heightens Design Impact, Reduces Weight of Trailer." *Society of Plastic Engineers.* 55(10): 7.

Molinaro, H. ed. (1999d). New Beetle Gets Outfitted in ABS. *Society of Plastic Engineers.* 55(12): 6.

Molinaro, H. ed. (1999e). Children's Chair Gets High Marks in Economy. *Society of Plastic Engineers.* 55(1): 6.

Molinaro, H. ed. (1999f). Polyvinyl Chloride. *Society of Plastic Engineers*. 55(4): 73.

Molinaro, H. ed. (1999g). PVC Pumps Stand Up to Chemicals, Rough Use. *Society of Plastic Engineers*. 55(4): 6.

Molinaro, H. ed. (1999h). High Impact PVC Sparks Electric Fence. *Society of Plastic Engineers*. 55(3): 8.

Molinaro, H. ed. (2000). GAM Report. In Moulding News. *World Plastic Technology 2000.* 41.

Molinaro, H. ed. (2000). Vinyl Outsoles Resist Harsh Chemicals and Oils. *Society of Plastic Engineers*. 56(6): 6

Monks, R. (1992). PVC: The Next Engineering Thermoplastic? *Plastic Technology*. 6: 65-69.

Moore, E. R. ed. (1989). *Encyclopedia of Polymer Science and Engineering*. John Wiley & Sons. 319-321.

Murayama, T. (1990). Dynamic Mechanical Properties. In Kroschwitz, J. I. *Concise Encyclopedia of Polymer Science and Engineering*. Canada: John Wiley & Sons. 287-289.

Nelson, G. L. (1995). Fire and Polymers: An Overview. In *Fire and Polymers II. Materials and Tests for Hazard Prevention*. Washington: American Chemical Society. 1-25, 65-75.

Newman, S. and Strella, S. (1965). Stress-Strain Behaviour of Rubber-Reinforced Glassy Polymers. *Journal of Applied Polymer Science*. 9: 2297-2309.

Nielson, L. E. (1974). *Mechanical Properties of Polymers and Composites, Vols. I and II.* New York: Marcel Dekker.

Nielson, L. E. and Landel, R. F. (1994). *Mechanical Properties of Polymers and Composites 2nd ed.* New York: Marcel Dekker, Inc. 401-411.

Norbert, M. B. (Ed). (1971). *Mechanical Properties of Polymers.* New Jersey: Wiley Interscience. 175-222.

Ogoe, S. A., Greele, P. F., Watkins, T. J., Masloski, P. J. and Kallman, M. A. (1996). Go with the Flow!: Advantages of High Melt Flow Rate Ignition Resistant PC versus IR PC/ABS Blends. *Polymer Degradation and Stability.* 54: 181-188.

Olabisi, O. (1982). In Grayson and Eckroth, D. ed. *Kirk-Othmer Encyclopedia of Chemical Technology, TM.* New York: Wiley Interscience. 443.

Owen, S. R. and Harper, J. F. (1998). Mechanical, Microscopical and Fire Retardant Studies of ABS Polymers. *Polymer Degradation and Stability.* 64: 449-455.

Pál, G. and Macskásy, H. (1991). *Plastics, Their Behaviour in Fibres.* New York: Elsevier Science Publishers. 56-60.

Patridge, I. K. (1992). Rubber Toughened Polymers. In Miles, I. S. and Rostami, S. *Multicomponent Polymer Systems.* Longman Scientific and Technical.

Perry, N. L. (1977). The Compounding of PVC. In Nass , L. I.. *Encyclopedia of PVC.* New York: Marcel Dekker, Inc. 847-900.

Petr Svec, Ladislav Rosik, RNDr. Zdenek Horak and Frantisek Vecerka (1990). *Styrene-Based Plastics and Their Modification.* London : Ellis Horwood. 145-161.

Pillichody, C. T. and Kelly, P. D. (1990). Acrylonitrile-Butadiene-Styrene (ABS). In Rubin, I. I. *Handbook of Plastic Materials and Technology*. USA: John Wiley & Sons. 25-42.

Potter, K. G. and Tweedale, C. R. (1992). Compatibility between HCFC Expanded Polyurethanes and Materials for Refrigerator Interiors. *Macroplas*. 141: 161-164.

Rabinovitch, ZE. B., Lacatus, E. and Summers, J. E. (1984). The Lubrication Mechanism of Calcium Stearate/Paraffin Wax Systems in PVC Compounds. *J. Vinyl Technol.* 6: 98-103.

Riew, C. K.,Rowe, E. H. and Siebert, A. R. (1976). In Toughness and Brittleness of Plastics. In Deanin, R. D. and Crugnola, A. M. ed. *Advances in Chemistry 154*. Washington: American Chemical Society. 326.

Rosík, L. and Večerka, F. (1985). Toughness Modification. In Petr Svec, Ladislav Rosik, RNDr. Zdenek Horak and Frantisek Vecerka (1990). *Styrene-Based Plastics and Their Modification*. London : Ellis Horwood. 109-128.

Sani Amril bin Samsudin. (2002). *Mechanical Properties and Chemical Resistance of Polystyrene/Polypropylene Blends: Effect of SEBS as a Compatibilizer*. University Technology Malaysia, Malaysia: Thesis Master.

Schmitt, J. A. and Keskulla, H. (1960). Rubber-Modified Polystyrene. *Journal of Applied Polymer Science*. 3: 132-141.

Schwarz, H. F. and Bley, J. W. F. (1988). Design of Alloys of PVC with NBR Copolymers to Produce Thermoplastic Elastomers. In *Advances in Polymer Blends and Alloys Technology*. USA: Technomic Publishing. 101-130.

Scobbo, Jr. J. J. (1991). Dynamic Mechanical Analysis of Compatibilized Polymer Blends. *Polymer Testing*. **10:** 279-290.

Seymour and Raymond, B. (1975). *Modern Plastics Technology*. Reston

Sharma, Y. N., Anand, J. S., Kulshreshtha, A. K., Xavier, S. F. and Chakrapani, S. (1988). Development and Characterisation of PVC/ABS Polyblends. *International Journal of Polymeric Materials*. 2: 165-183.

Sivaneswaran, K. K. (2002). *Effect of Rice Husk Ash Fillers on Mechanical Properties of ABS Impact Modified Unplasticised PVC*. University Technology Malaysia, Malaysia: Thesis Master.

Sperling, L. H. (1992). *Introduction to Physical Polymer Science*. New York: John Wiley & Sons. 1-18.

Steeman, P. A. M and Maurer, F. H. (1994). Dielectric Properties of Blends of PC and ABS Copolymer. *Polymer Engineering and Science*. 34(9): 697-705.

Sudhakar, K. and Singh, R. P. (1992). Unassigned. *Journal of Vinyl Technoogyl*. 14: 213-225.

Svec, P., Rosik, L., Horak, R. Z. and Vecerka, F. (1990). *Styrene-Based Plastics and Their Modification*. London : Ellis Horwood. 145-161.

Titow, W. V. (1990). *PVC Plastics: Properties, Processing, and Applications*. New York: Elsevier Science Publishing CO., Inc. 3, 8-17, 61-73, 111, 294-296.

Tobolsky, A. V. (1960). Properties and Structure of Polymers. New York: Wiley. In Manson, J. A. and Sperling, L. H. (1976). *Polymer Blends and Composites*. London: Heyden & Son Limited. 83-88.

Triacca, V. J., Ziaee, S., Barlow, J. W., Keskkula, H. and Paul, D. R. (1991). Reactive Compatibilisation of Blends of Nylon 6 and BS Materials. *Polymer*. 8: 1401-1413.

Troitzsch, J. (1980). *International Plastics Flammability Handbook.* New York: Hanser Publisher. 17-61.

Uhlmann, J. G., Oelberg, J. D., Sikkema, K. D. and Nelb, R. G. (1993). Effect of Flame Retardant Structure and Properties on ABS Performance. *Plastic Compounding.* 3: 38-46.

Van Krevelen, D. W. and Hoftyzer, P. J. (1976). *Properties of Polymers.* New York: Elsevier Scientific Publishing Company. 488.

Vishu, S. (1998). *Handbook of Plastics Testing Technology.* 2nd ed. New York: John Wiley & Sons.

Wan Aizan Wan Abd. Rahman. (1996). *SMR/ENR50/PVC Ternary Blends: Preparation, Blending Characteristics and Compatibilization Studies.* University Technology Malaysia, Malaysia: Thesis Ph.D.

Wetton, R. E. and Corish, P. J. (1988/9). DMTA Studies of Polymer Blends and Compatibilty. *Polymer Testing.* 8(5): 303-312.

Wickson, E. J. (1993). *Handbook of PVC Formulating.* New York: John Wiley and Sons Inc. 1-15.

Yee, Joon Wee. (2001). *Effect of Calcium Carbonate Fillers on Mechanical Properties of Impact-Modified Unplasticised PVC.* University Technology Malaysia, Malaysia: Thesis Master.