

## The Influence of a Variety of Plasticisers on Properties of Poly (vinyl chloride)

M Davallo\* and H Pasdar

Faculty of Chemistry, North Tehran Branch, Islamic Azad University, P.O.Box 19136, Tehran, Iran

### ABSTRACT

Poly (vinyl chloride), PVC is widely used because it is easy to process, high productivity low cost and versatility. PVC can be only used for a few applications without the addition of a number of compounds to the basic material so that it can be processed and converted into a finished product. In this research various type of plasticisers were incorporated into PVC and their influence on the properties of PVC, such as tensile properties, low temperature flexibility, volatility, and flame resistance were investigated. The study showed that using tritolyl phosphate as a plasticiser increased tensile strength, modulus of elasticity and flame resistance of the PVC but with reduction of % elongation at break. Where as, dioctyl sebacate showed lower ductile-brittle transition temperature and with lower volatility loss in comparison with other plasticisers used.

**Keywords:** Thermal stability, PVC, Thermal degradation of PVC, Mechanical properties of PVC, Impact properties of PVC.

### INTRODUCTION

Poly (vinyl chloride), PVC is currently the third most widely produced plastic, after polyethylene and propylene due to its valuable properties, wide application, high chemical resistance, barrier properties and low cost. On the other hand, processibility and thermal stability of PVC is inferior compared with common polymers. These properties can be enhanced by compounding PVC with a number of additives. The most usefull additives in PVC are plasticisers, heat stabilizers, lubricants, fillers, and pigments. It is observed that heating PVC at temperatures above 70°C has a number of adverse effects on the properties of the polymer. At processing temperatures used in practice (150-200 °C) sufficient degradation may take place during standard processing operations to render the product useless [1-8]. It has been found that incorporation of certain materials known as stabilisers retards or moderates the degradation reaction so that useful processed materials may be obtained. To impart flexibility to PVC, plasticisers are added. They are low molecular weight compounds which are selected to be completely miscible and compatible with the basic material. The type and plasticisers content on PVC can affect the properties of PVC. To aid melt flow of PVC during processing and prevent adhesion to metal surfaces, lubricants are also added. However, fillers are mainly added to lower the cost of PVC compounds [9-18]. In this work a variety of plasticisers were used to study their effects on the properties of PVC such as tensile properties, low temperature flexibility, volatility, and flame resistance.

### MATERIALS AND METHODS

The PVC used in this study is a suspension resin with solution viscosity k-value 65, from Arvand Petrochemical Co, Iran. Three different types of plasticisers (referred to as 1, 2 and 3) used in this study which were compatible with PVC are all industrial grade products. The additives used are shown in Table 1. The PVC compounds formulations are shown in Table 2. These are based on a lead carbonate stabilised formulation, from Ciba-Geigy, but without the fillers. All compounds were added with pigment. The numbers indicates parts per 100 resin (phr) in the formulations.

### Sample preparation

A high speed laboratory mixer (Fielder 8L) was used to mix PVC and the additives. To produce moulded flat sheet, the dry compounds of PVC and additives were first sheeted on a two roll-mill before being compression moulded at the set temperature of 160<sup>o</sup> C. Samples for tensile testing were cut from the compressed sheet according to the size specified in ASTM-D638 (1990). For low temperature flexibility testing, the Charpy impact tests were carried out according to the size specified in ASTM-D256 (1990). Dumb-bell specimens and dummy bars for tensile testing and for low temperature testing were obtained on a tungsten carbide cutter using template, respectively. The samples were eventually subjected to the following tests:

1. Stress/strain testing.
2. Low Temperature Flexibility Testing.
3. Volatility testing.
4. Flammability testing.

**Mechanical Testing.** Tensile data (tensile strength, modulus of elasticity and elongation at break) for the PVC samples were obtained at 25±2<sup>o</sup>C using a Santam, universal tensometer (5T). Tests were conducted on at least five specimens, at a cross-head rate of 50 mm min<sup>-1</sup>.

**Low Temperature Flexibility Testing.** Low Temperature Flexibility Testing for the PVC samples were obtained using a conventional Charpy test. Tests were performed using an impactometer (Ceast Italy) according to ASTM-D256. Samples were immersed in a mixture of methanol/solid CO<sub>2</sub> at the required temperature range of +20<sup>o</sup>C to -60<sup>o</sup>C. The samples were left in the environmental chamber (Rosand Temperature Control Unit) for at least 15 min at the specified temperature range prior to testing. Tests were conducted on at least five specimens. The results are presented in terms of the impact strength.

**Volatility Testing.** In order to determine volatile loss of plasticised PVC, samples were placed in an oven at 80<sup>o</sup> C for 7 days and weight loss were measured to represent volatilisation of plasticisers.

**Flammability Testing.** In order to determine flame resistance of plasticised PVC Flammability of PVC samples were carried out according to ASTM-D635 (1985).

## RESULTS AND DISCUSSION

**Tensile Testing.** The typical tensile-strain curves obtained for plasticised PVC (PPVC) using different plasticisers are shown in Figure 1. The mechanical properties of PPVC using five standard tensile test pieces are shown in Table 3. As it can be seen from Figure 1 and Table 3, the tensile properties of plasticised PVC were influenced by the type of plasticiser used. Sample PVC1 has slightly higher tensile strength and modulus of elasticity in comparison to sample PVC2 and PVC3. However, higher the tensile strength of the polymer the lower the % elongation. The explanation for this is that plasticiser (dioctyl sebacate) has been able to increase significantly the ductility and flexibility of PVC system which is accompanied by a reduction in tensile strength and modulus of elasticity.

**Low Temperature Flexibility.** Figure 2 shows the impact strength at various temperatures for PVC using different plasticisers. In general the impact strength of all samples decreases as the temperature decreases and when it reaches the ductile-brittle transition the impact strength drops sharply. Sample PVC1 is the first to undergo the transition as the temperature decreases in the range between +10<sup>o</sup>C and -10<sup>o</sup>C. The sample PVC3 has the lowest ductile-brittle transition temperature ranging between -35<sup>o</sup>C and -40<sup>o</sup>C followed by Sample PVC2 ranging between -18<sup>o</sup>C and -30<sup>o</sup>C (which its ductile to brittle transition temperature lies between sample PVC1 and that of PVC3). As it can be seen from Figure 2, as the temperature decreases to -50<sup>o</sup>C, all the samples show similar impact strength values. It is important to realise that polymer PVC1 may be tough when exposed to tensile strength test but not tough when exposed to impact test at low temperature. However, it should be mentioned that plasticisers in effect reduces the glass transition temperature (T<sub>g</sub>) of the polymers (PVC) but the degree of reduction of later is dependant upon the type of plasticiser used.

**Volatility Test.** Determination of loss in weight of samples after 7 days at 80<sup>o</sup> C are shown in Table 4. The weight loss of samples indicate that PVC3 has the lowest weight loss (lower volatility) than others as indicated by results obtained (Table 4). However, from Table 4, it can be seen that when tritolyl phthalate and dialphanyl phthalate were used as plasticisers in PVC their volatility were some what higher due to these plasticisers having lower heat stability. In contrast, dioctyl sebacate showed lower volatility loss probably due to this plasticiser having higher compatibility and greater molecular interaction with PVC. When PVC is subjected to heat above 70<sup>o</sup> C it has a

number of adverse effects on the properties of polymer. The mechanism by which PVC is degraded is believed to be due to dehydro-chlorination of the polymer as shown below:



Table 1

Additives	Types
Plasticiser-1	Tritolyl phosphate
Plasticiser-2	Dialphanyl phthalate
Plasticiser-3	Dioctyl sebacate
Heat Stabiliser	Lead carbonate
Lubricant	Calcium stearate

Table 2

Ingredient	PVC1	PVC2	PVC3
PVC	100	100	100
Plasticiser-1	50	-	-
Plasticiser-2	-	50	-
Plasticiser-3	-	-	50
Heat Stabiliser	4.0	4.0	4.0
Lubricant	1.0	1.0	1.0

Table 3

Sample	Tensile strength (MPa)	Tensile Modulus (MPa)	Strain (%)
PVC1	22.50±2.0	20.10±3.0	136.00±8.0
PVC2	20.70±2.5	11.30±1.0	162.00±11.5
PVC3	16.80±1.5	8.30±2.0	224.00±14.0

Table 4

Sample	Weight before test (g)	Weight after test (g)	Weight loss (g)	PWL <sup>1</sup>
PVC1	1.330	1.324	0.0060	0.45
PVC2	1.539	1.534	0.0050	0.32
PVC3	1.082	1.0805	0.0015	0.13

<sup>1</sup>PWL denotes percent weight loss which was calculated according to the following equation:  $PWL = (wt_b - wt_a) / wt_b \times 100$ . Where  $wt_b$  is the weight before test, and  $wt_a$  is the weight after test.

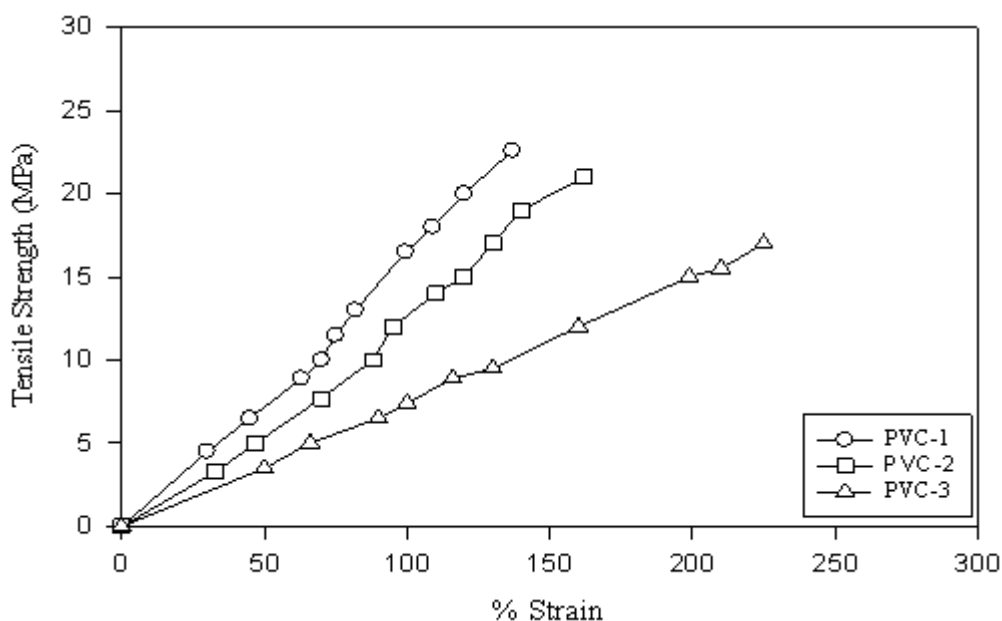


Figure 1. Tensile strength versus % strain of PVC using various plasticisers.

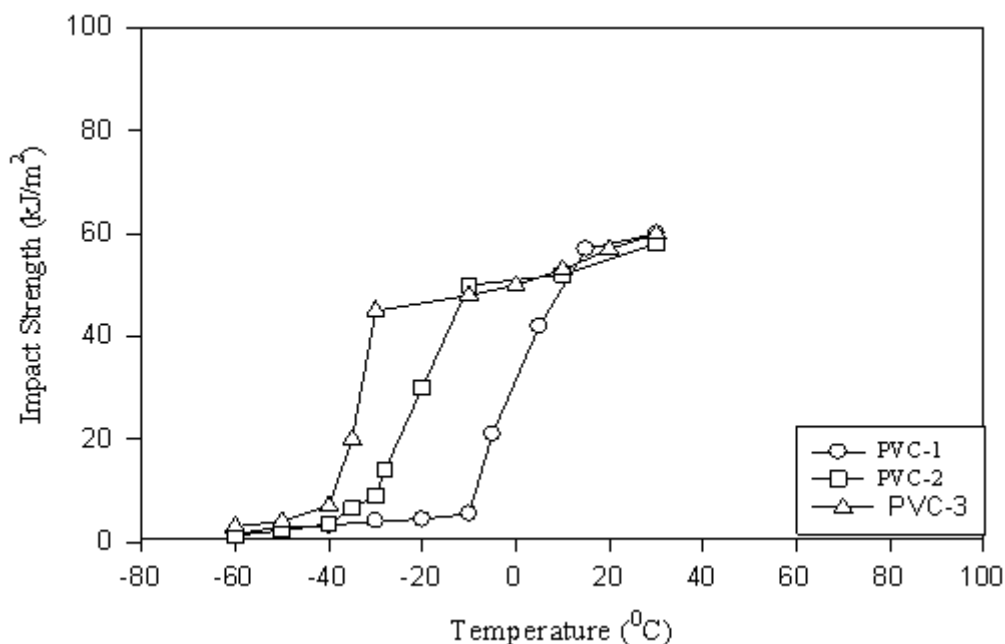


Figure 2. Impact strength versus temperature of PVC using various plasticisers.

Table 5

Sample	Flammability
PVC1	Did not support combustion
PVC2	One second then extinguished
PVC3	Two second then extinguished

The liberated HCl accelerates further decomposition and if oxygen is present it would increase the reaction and moreover it causes both chain scission and cross-linking. It also can accelerate the colour formation of PVC [5].

**Flame resistance.** Flame resistance of samples by flammability test are shown in Table 5. From Table 5 can be seen that sample PVC1 has better flame resistance than other polymers. PVC polymers have in general excellent resistance to flammability and they are self-extinguishing compounds. But due to the incorporation of plasticisers which reduce flammability by restricting the supply of the requirement for a fire (i.e incorporation of plasticisers which interfere with the flame reaction). The presence of chlorine (Cl) in the structure of polymers can be regarded as retardant in which provides a gaseous blanket in effect reduces access of air to the flame. However, it should be mentioned that unplasticised PVC (UPVC) polymers have better flammability resistance than that of PPVC. This depends upon the type and amount of plasticiser used.

## CONCLUSION

The study of a variety of plasticisers on the properties of PVC showed that mechanical properties of PVC can be influenced by the type of plasticiser used. It was found that using tritoyl phosphate as a plasticiser increased the tensile strength, tensile modulus and showed better flame resistance of the PVC but with decreased percentage elongation at break. From results obtained it was found that dioctyl sebacate in comparison with tritoyl phosphate and dialphanyl phthalate showed lower ductile-brittle transition temperature and with lower volatility loss compared with other plasticisers. For all the samples studied the addition of plasticisers to PVC produced flexibility and extensibility which depends upon the type of plasticiser used.

## REFERENCES

- [1] Bucknall, C.B. Toughened Plastics, Applied Science, London **1977**.
- [2] Wilkes, C.E.; Summers, J.W.; Daniels, C.A.; Bernard, M.T. PVC Handbook, Hanser Verlag **2005**.
- [3] Polyvinyl Chloride (PVC), Report, ChemSystems, **2008**.
- [4] Jakubowicz, I. *Polym Test* **2001**, 20:545.
- [5] Hjertberg, T.; Sorvik, E.M. Thermal Degradation of PVC, in Degradation and Stabilisation of PVC ed by Owen, ED; Elsevier Applied Science, New York **1984**.
- [6] Teli, D.M.; Kale, R.D. *Adv. Appl. Sci. Res* **2011**, 2 (4):491-502

- [7] Tomar, A.K.; Suman, M.; Kumar, S. *Adv. Appl. Sci. Res* **2011**, 2 (4):65-71
- [8] Chauhan, A.; Kaith, B. *Der Chemica Sinica* **2011**, 2 (3):20.
- [9] Nass, L.I. Encyclopedia of Poly(vinyl chloride) Vol 1, Mercel-Dekker, Inc, New York **1976**.
- [10] Nielsn, L.E. Mechanical Properties of Polymers and Composites 2, Mercel-Dekker, Inc, New York **1974**.
- [11] Ratnam, C.T.; Nasir, M.; Baharin, A. *Polym.Test* **2001**, 20:485.
- [12] Wenquang, M.; Mantia, F.P.L. *J. Appl. Polym. Sci* **1996**, 59:759.
- [13] Pita, V.J.R.R.; Sampaio, E.E.M.; Monterio, E.E.M *Polym. Test* **2002**, 21:545.
- [14] Yarahmadi,N.; Jakubowicz, I.; Hjertberg, T. *Polym. Degr. Stab* **2003**, 82:59.
- [15] Hassan, A.; Haworth, B. *J. Mater. Process. Tech* **2006**, 172:341.
- [16] Arnold, J.C.; Manud, B.; Isaac, D.H. *J. Mater. Process. Tech* **1996**, 56:475.
- [17] Chen, N.; Wan, C.; Zhang, Y. *Polym. Test* **2004**, 23:169.
- [18] Fenollar, O.; García, D.; Sánchez, L.; López J.; Balart, R. *Eur. Polym. J* **2009**, 45:267.