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Bio- Based Co- Plasticizer for PVC in Addition with Epoxidised Soyabean Oil to Replace Phthalates.

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ABSTRACT

Studies showed that phthalate plasticizers are carcinogenic. The concerns raised about toxicity led to a large demand of producing non-toxic and bio-based plasticizers. Currently, ESBO can only replace 30% DOP in the PVC formulations. We investigated benzyl ester (BE) synthesized by dehydrated castor oil fatty acid and benzyl alcohol in presence of catalyst at 170-180°C as plasticizer for poly(vinyl chloride) (PVC) to replace commercially used combination of plasticizer (di-octyl phthalate (DOP) and epoxidized soyabean oil (ESBO). The structure of the BE was confirmed by ¹H NMR, FTIR, acid value, hydroxyl value. The modified plasticizer was used as plasticizer in PVC in different proportions for the replacement of DOP in samples prepared from PVC- DOP- ESBO combination, keeping ESBO proportion constant in all samples. The incorporation of BE displayed good plasticizing performance and also resulted in, reduction in viscosity and viscosity pick-up, improved mechanical, exudation, thermal degradation and chemical resistance properties (upto wt. 65%). The presence of BE showed reduction in whiteness index due to presence of conjugated double bonds in the structure. No variation in DSC and shore hardness properties was observed when compared to those of DOP plasticized sheets which can contribute to the conclusion that BE can be used as a co-plasticizer in PVC along with ESBO upto wt. 65% to replace DOP.

INTRODUCTION

Poly (vinyl chloride) (PVC) is used extensively as a kind of plastic material because of its outstanding advantages; the performance can be changed according to the amount of different kinds of fillers and additives, and it has a low cost and a broad range of properties. Therefore, it is widely used in wall coverings, cables, medical devices, and computers [1,2,3]. Furthermore, the great part of PVC is used as plasticized PVC. Hence, the plasticizer is a vital part of PVC is used as plasticized PVC; it can improve the flexibility and processing of PVC and overcome its inherent brittleness without changing the chemical properties of the PVC matrix [4,5,6].

Plasticizers are used to make PVC (and other materials) flexible. The Council of the International Union of Pure and Applied Chemistry defined a plasticizer as a substance or material incorporated in a material (usually a plastic or elastomer) to increase its flexibility, workability, or distensibility [7]. (By this definition) A plasticizer may reduce the melt viscosity, lower the temperature of a second order transition, or lower the elastic modulus of the product. There are many kinds of plasticizers, including di-octyl

phthalate (DOP), as di-n-butyl phthalate (DnBP), butyl benzyl phthalate (BBP), aliphatic dicarboxylic acids, benzoate, citrate, epoxides and triglycerides [8,9,10,11].

Recent screening studies in industrialized countries for contaminants in human urine samples have revealed the extensive exposure of people to the group of phthalate plasticizers [12,13,14]. As phthalates are not chemically bound to the products they easily diffuse to the surrounding media during its life time, particularly those with high fat content [14-16]. As a consequence, phthalates contaminate indoor environments and human food and belong to the ubiquitous environmental contaminants and present difficulties in toys [13,18]. Several phthalates and especially di-ethyl hexyl phthalate (DEHP) known as di-octyl phthalate (DOP) are suspected of having carcinogenic and toxic effects [17,18,19,20]. In 2008, di butyl phthalate (DBP), DEHP, and benzyl butyl phthalate (BBP) were listed within the 14 SVHC (Substances of Very High Concern) by ECHA (European Chemicals Agency), as toxic for human infertility [21]. Recently, many plasticizer producers promoted several alternatives in order to substitute DEHP due to the health effects as a shift from low to high molecular phthalates or even to other compound classes (adipates, succinates, glucarates, terephthalates, trimellitates, and citrates) has taken place for the use in PVC applications [22].

Manufacturers and consumers are increasingly worried about this issue, considering the perspectives for expanding plasticized PVC applications. This caused an increasing pressure from both public authorities and customers to shift towards the use of phthalate-free alternatives. In the global search for less toxic DOP alternatives, several classes of chemicals have emerged [23]. They have been suggested by both concerned interest groups and the plastic industry, and many are already under investigation for PVC compatibility and potential toxicity. Some of the most popular candidates include citrates, adipates, trimellitates, phosphates, benzoates, and vegetable oil derivatives. Even though several commercial alternatives have appeared they usually have not been able to match the phthalate esters as more or less 'universal' plasticizers. Thus, there is need for more research to find high performance plasticizers that are safe and environment friendly [24].

Currently, Epoxidized soyabean oil (ESBO) is mainly used as a plasticizer or stabilizer to modify the properties of plastic resins such as PVC [25]. We therefore, have investigated the role of modified castor oil derivative as a simple, biodegradable and non-toxic alternative to esters of phthalic acid. Castor oil contains large proportion of ricinoleic acid. Thus, the fatty acid mixture derived from castor oil possess two reactive groups, ie. carboxyl and hydroxyl group in addition to the unsaturations present. These functionalities can be further used to prepare wide variety of materials such as di- esters while the dehydrated castor oil fatty acid (DCOFA) can be used to prepare monoesters. In our recent project, we have prepared a series of monoesters and di- esters derived from DCOFA and COFA respectively and investigated their plasticizing performance. In this paper, we report Bio- based co- plasticizer for PVC in addition with Epoxidised Soyabean Oil (ESBO) to replace phthalates. The benzyl ester (BE) was prepared by one step esterification of DCOFA and benzyl alcohol in presence of a catalyst. The plasticizing performance of the product added to PVC at various proportions was then evaluated against PVC/ DOP/ ESBO blend.

EXPERIMENTAL

Materials

The dehydrated castor oil fatty acid (DCOFA) was provided by Shalimar Paints Ltd., Nasik, India. This was evaluated for hydroxyl and iodine numbers before proceeding for the reaction. Benzyl alcohol(BA), anhydrous sodium sulphate and di-butyltin dilaurate (DBTDL) were purchased from SD Fine Chemicals, Mumbai and were used as received. DOP was procured from a local supplier had specific gravity 0.9861. The PVC used in this study with K-value 60 was a stabilized, commercially available emulsion grade material, provided to us by Phiroze Sethna Pvt. Ltd., Thane, India.

Methods

Synthesis of Benzyl Ester (BE)

Benzyl ester of DCOFA was synthesized in bulk from DCOFA and benzyl alcohol using DBTDL as a catalyst as shown in Figure 1. DCOFA and benzyl alcohol were added to the three necked round bottom reaction flask in a molar ratio of 1:1 along with 0.3% (w/w) DBTDL catalyst. The reaction flask attached to Dean Stark, water condenser, temperature controller and nitrogen gas inlet was heated to 170-180 °C. Xylene was used as an azeotropic solvent to remove water of condensation formed during the reaction. Samples were withdrawn at regular interval of 1 hour until acid value dropped below 5 mg of KOH /gram of

sample. After the reaction was completed, the reaction mixture was cooled down to room temperature. It was further washed with methanol till neutral pH was achieved. The organic layer was then dried over anhydrous sodium sulphate to remove any traces of water. The purified product was then evaluated for its physical and chemical characteristics.

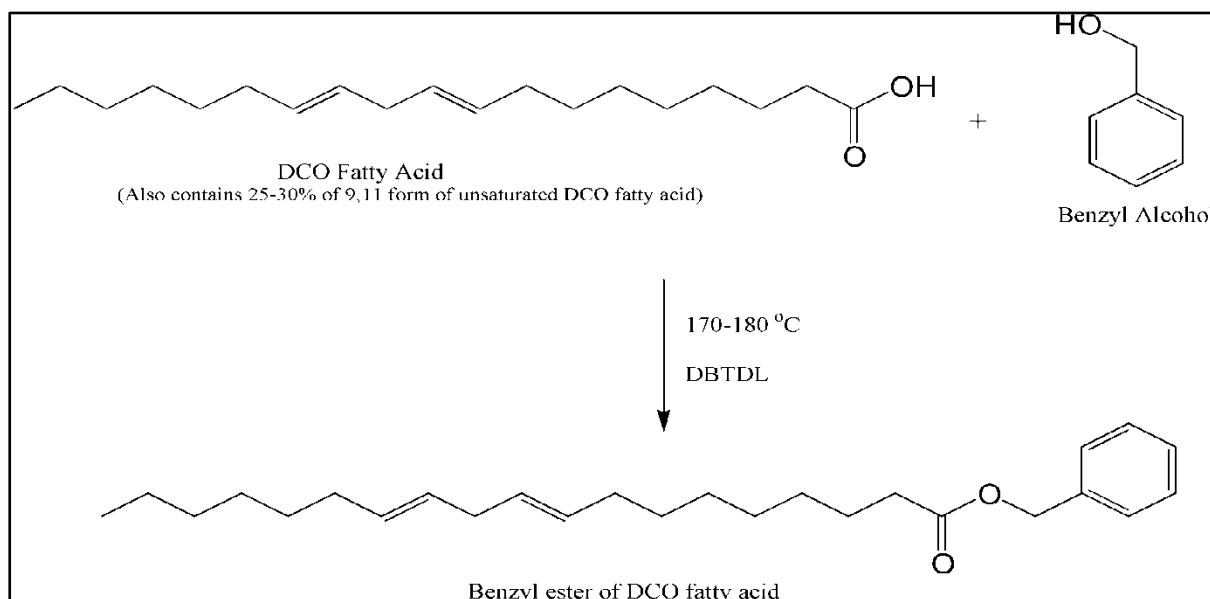


Figure 1: Schematic representation of synthesis of benzyl ester.

Preparation of PVC sheets

The plasticized PVC sheets were prepared using emulsion grade PVC, DOP, ESBO and BE. Various combinations (on weight basis) of DOP ESBO and BE were prepared and used as plasticizing mixture. In each case, 50 parts of this mixture was mixed with 100 parts of PVC. The different combinations used for preparation of PVC sheets (plasticized PVC; PPVC) are as shown in Table 1. The viscosity and viscosity build-up of these mixture was also measured.

Table 1: Formulation of PVC Plasticization (grams per 100 grams of PVC)

Sample Name	DOP (gm)	BE (gm)	ESBO (gm)
PPVC 1	36.4	00	15.6
PPVC 2	27.3	09.1	15.6
PPVC 3	18.2	18.2	15.6
PPVC 4	9.1	27.3	15.6
PPVC 5	00	36.4	15.6

The plastisol mixtures prepared for different combinations were further mixed for 15 minutes by using a two roll mill at temperature 140 °C to obtain a homogeneous compound.

Compression Moulding

The various combinations of PPVC were compression moulded to get sheets in desired dimensions. These were pressed into compressed sheets (2mm thick) in a steel mould for 10-12 minutes under pressure of 230 bars. These were then cut into required shapes from further evaluation. The prepared PVC sheets were evaluated for different optical, mechanical, chemical and thermal characteristics.

Characterization and Testing

The prepared benzyl ester was evaluated for specific gravity, acid value and hydroxyl value. The viscosity of the different plastisol mixtures was determined in accordance with standard ASTM D-445 method using Brookfield-Viscometer [26]. Viscosities of DOP and BE were also measured using Brookfield Viscometer (Rheotec; spindle: L2; speed: 150 RPM) at room temperature (28-30°C).

Acid Value

Acid value is a measure of carbonyl acid present in a compound. The acid number is the number of milligrams of potassium hydroxide required for the neutralization of free acid present in one gram of a substance. The acid number is determined in accordance with ASTM D-1980 (mg KOH/g) [27].

Hydroxyl Value

The hydroxyl number is determined in accordance with ASTM D- 1957 (mg KOH/ g). Hydroxyl Number (or hydroxyl value) is an indication of degree of acetylation and is a measure of the number of hydroxyl groups present in a polymer. The hydroxyl number is the number of milligrams of potassium hydroxide corresponding to hydroxyl groups in one gram of polymer [28].

Specific Gravity

Specific gravity of the BE product is determined in accordance with ASTM D- 891. [29]

Fourier Transform Infrared spectroscopy (FTIR)

Fourier transform infrared spectroscopy (FTIR) analysis for BE sample was carried out using a Spectrum One—FTIR spectrometer (Perkin Elmer, Waltham, USA). Sodium chloride cell was used for the characterization along with chloroform as a solvent for the samples. A background spectrum was first collected at 16X to remove any errors from the sample spectrum. The spectra were acquired in the range of 4000-600 cm^{-1} at a resolution of 4 cm^{-1} .

Nuclear Magnetic Resonance Spectroscopy (NMR)

NMR spectra were recorded on Mercury Plus NMR spectrometer (400 MHz, Varian, USA) using CDCl_3 as solvent. The chemical shifts in the discussion are reported in parts per million.

Yellowness Index

Yellowness index of all PPVC samples were compared using Color Quest XE colorimeter, available from Hunter Lab; 20mm transmission cell; Hunter Lab Universal software, version 4.10 or equivalent; Black and White color reference available from Hunter Lab.

Hardness

Shore-A and Shore-D hardness for all the PPVC sheets were determined in accordance with ASTM D- 2240 [30].

Chemical Resistance Test

Chemical resistance of the PPVC samples were determined in accordance with ASTM D 1239 [31]. To appraise critical conditions of the plasticizer application, chemical resistance of the plasticizer from samples were carried out. The liquids selected as penetrants were xylene and mineral turpentine oil (MTO). Chemical resistance experiments were performed in closed flasks with 50 ml of each penetrant at room temperature. Periodically, the samples were removed and dried for measurement of weight loss and migration rate.

Exudation Test

Exudation of the plasticizer was evaluated by placing a sample of film between two pieces of tissue paper. The combined system (sample + paper) was then placed in a room temperature for 48 hrs. After this period, the increment in weight of the paper was determined simultaneously weighing the sample and the extent of plasticizer exudation was calculated.

Tensile Test

For each PPVC sample minimum three dumbbell shaped specimens were prepared (thickness = 2mm) by using pneumatic cutter containing dumbbell shaped die. Before testing the samples were

conditioned for 6 days at 25 °C. The thicknesses of the specimen were measured using thickness meter. The mechanical properties of the samples were tested by Lloyd Instrument – LR10K equipped with pneumatic grips as per standard ASTM D- 638 [32]. The initial grip separation was 50 mm while the cross head speed was 50 mm/min with the load cell 100N. Elongation of testing specimen was calculated from grip separation by the software automatically. The tensile strength was expressed as the maximum force at break divided by the initial cross-sectional area of the film strip and the elongation at break as a percentage of original length.

Differential scanning calorimetry (DSC)

Differential scanning calorimetry analysis was performed under nitrogen atmosphere with DSC Q-100 equipment (TA Instrument, USA) calibrated with n-octane and indium. All the samples were heated from -50 °C to 10 °C at a heating rate of 10°C/min.

Thermogravimetric analysis (TGA)

Thermogravimetric analysis was performed under nitrogen atmosphere on DSC Q-100 instrument for the temperature range of 100-650°C at heating rate of 10°C /min.

RESULTS AND DISCUSSIONS

A plasticizer is a compound incorporated in a polymer matrix to lower its rigidity and improve the properties of the commercial plastic product. Therefore, the addition of the plasticizer often lowers the melt viscosity, glass transition temperature (T_g), and elastic modulus of the polymer.

The present work was carried out to investigate the application of benzyl ester (BE) prepared from benzyl alcohol and dehydrated castor oil fatty acid as a partial replacement of DOP- ESBO blend for plasticizing PVC. The physicochemical properties of the BE product were analysed by acid value, hydroxyl value, specific gravity measurement, FTIR, ¹H NMR technique. The initial acid and hydroxyl values of the reaction mixture were calculated to be 139.55 and 139.55 mgKOH/g respectively. The acid, hydroxyl and saponification values of the purified BE product were found to be 8.1, 12.3 and 131.2 mgKOH/g which confirmed successful completion of the reaction. The measured specific gravity of the product sample was observed to be 0.9454. The color of the product as measured on Gardner scale was observed to be 4 →5. The viscosities of DOP and BE samples measured using Brookfield Viscometer were observed to be 54 and 48 cPs at 28°C.

FTIR

The FTIR spectrum obtained for the BE sample and mixture of raw materials (benzyl alcohol + DCOFA) is as shown in the Figure 2 (A & B). Here, the aliphatic C-C bonds could be confirmed by presence of sharp bands at 2929 and 2854 cm⁻¹ in both the spectra. Presence of long chain aliphatic double bonds could be attributed to transmission band at 1457 cm⁻¹. A sharp transmission band at 1709 cm⁻¹ in spectrum of sample was due to the carbonyl moiety from the carboxyl group of DCOFA while it shifted to 1729 cm⁻¹ for BE sample confirming that the ester bonds were successfully formed. Peak observed at 3057 cm⁻¹ was due to the insertion of aromatic moiety in the long chain fatty backbone. The broad band observed at 3407 cm⁻¹ in mixture sample due to carboxyl and hydroxyl group from initial raw materials changed to small peak at 3466 cm⁻¹ which can be attributed to traces of unreacted fatty acid present in the product. The FTIR analysis carried out confirmed that the esterification reaction resulted in benzyl ester from DCOFA and benzyl alcohol.

NMR

The structure of BE product was further confirmed by ¹H NMR. The chemical shifts observed at 1.29 and 1.33 ppm could be attributed to the aliphatic –CH₂– present in the long chain fatty acid structure. Presence of aliphatic double bond could be confirmed by the signals observed between 5.4 and 6.0 ppm. The NMR spectra also confirmed presence of 9,11 and 9,12 form of DCO fatty chain as shown in Figure 3. Formation of benzyl ester was confirmed by the presence of aromatic structure in the chemical backbone which can be confirmed by chemical shift observed at 7.2

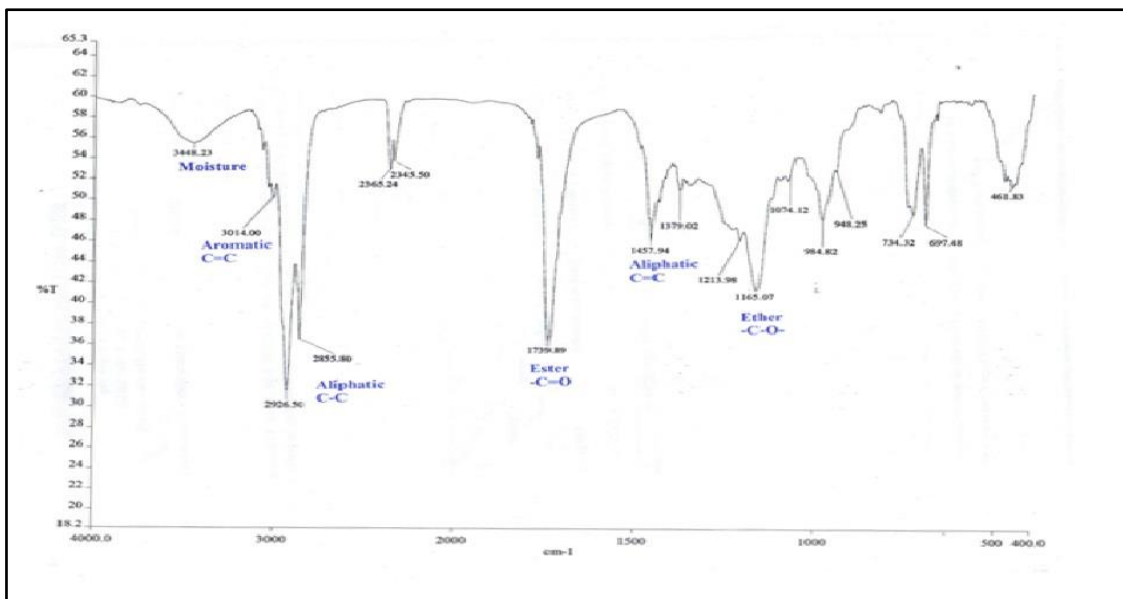


Figure 2: FTIR spectra of BE analysed in chloroform solvent.

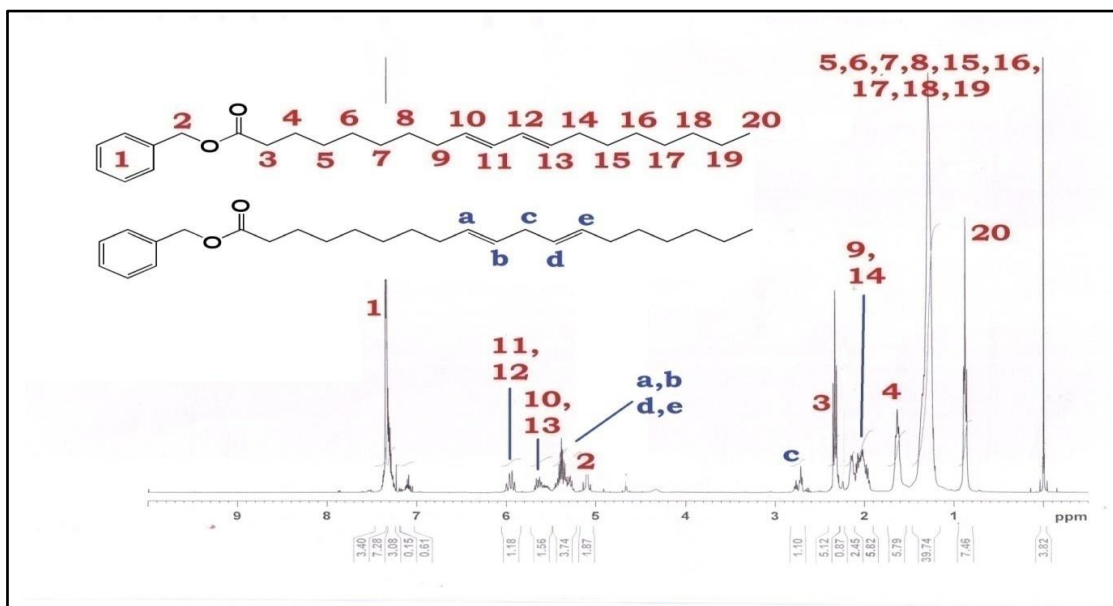


Figure 3: ^1H NMR of BE in CDCl_3 .

Further, no protons were detected either from carboxyl group or hydroxyl group suggesting that the esterification reaction was completed and the product was completely purified during its subsequent washing with lukewarm water and methanol. The detailed representation of all the chemical shifts observed and its co-relation with the structure is as shown in the NMR spectra.

Absorption values for PVC

The plasticizer demand for PVC sample was calculated as per ASTM D 1755 standard method of evaluation of plasticizer absorption value. This test measures the amount of plasticizer that a resin can absorb at the standard laboratory temperature. Plasticizer absorption is one method of judging the dry blending properties of the resin. The absorption values of polymer for BE and DOP were measured to be 48.72 and 52.13 per 100 gm sample. The lower absorption value for BE can be attributed to its lower viscosity which helped its penetration through the polymer chains and hence resulted in improved wetting [33].

Compatibility of BE with DOP

To investigate the compatibility of these two components, five different mixtures with variable proportions of the three plasticizer (from 00:70:30 to 70:00: 30 (w/w) of BE: DOP: ESBO) were prepared in test tubes. The samples were then mixed with vigorous shaking to form homogeneous mixture and were kept for 24 hr. All the mixtures showed complete miscibility with each other after 24 hr, forming homogeneous solutions which could be attributed to their similar chemical nature.

The compounding of the PVC samples was done with 50 phr of plasticizer content. The primary plasticizer, DOP, was replaced with BE product at variable proportions. The mixed formulations resulted in homogeneous mixture without any visible separation.

Viscosity and viscosity build- up

Table 2: Viscosity and mechanical testing of Plasticized PVC samples

Sample	Viscosity (Cp)	% Increase In Viscosity After 7 Days	Tensile strength (MPa)	Elongation at break (%)
PPVC 1	18946	47.45	5.71 ± 0.16	22.725± 1.7
PPVC 2	15316	46.68	6.9 ± 0.22	46.69± 2.5
PPVC 3	10912	44.57	9.05 ± 0.15	84.62± 2.1
PPVC 4	9347	40.42	5.6 ± 0.19	20.74± 3.4
PPVC 5	8287	34.81	3.14 ± 0. 18	9.8±3.1

The viscosity and viscosity buildup of the formulated PVC mixtures was measured to study the effect of low molecular weight BE on the thinning properties of the mixtures. All the viscosity measurements were done after 1 hr of the formulation mixing. It was observed that the viscosity of the combinations decreased significantly as the BE proportion in the formulation was increased. This could be due to the effective thinning effect offered by BE component. It is known that DOP results in the viscosity build-up of the prepared PVC plastisol mixture [24]. To investigate the effect of BE product on the viscosity build-up, the viscosities of all the combinations were measured after 7 days as shown in Table 2. The study conducted showed that the PPVC 1 sample exhibited maximum viscosity pick-up. The mixture resulted in high viscosity mass which had no flow-ability. However application of shear resulted in drop down in the viscosity close to its initial value. The viscosity of the PPVC 2 sample was also relatively higher than other samples excluding PPVC 1 but possessed significant flow-ability compared to PPVC 1. Further, the viscosity pickup decreased as the BE proportion was increased with PPVC 5 showing the least build-up. This could be attributed to presence of BE component in the formulation which reduced the interaction between DOP and PVC backbone. This characteristic property of the BE component could help in reducing the processing related difficulties without use of external shear to reduce the viscosity.

PVC sheets

Plasticized PVC films prepared by compression moulding were white in color, homogeneous, smooth and opaque with average thickness of 2 ± 0.5 mm for various compositions of films.

Yellowness Index

Table 3: Yellowness index and hardness test of PPVC samples

Sample	Yellowness	Whiteness	Haze	Shore A	Shore D
PPVC 1	5.555	-39.959	56.566	93	48
PPVC 2	16.509	-33.975	16.698	94	48
PPVC 3	14.639	-26.414	19.395	95	49
PPVC 4	13.251	-19.040	25.934	96	50
PPVC 5	18.449	-14.809	41.487	97	50

The presence of unsaturation in the BE product was expected to result in yellowing of PVC sheets. As the proportion of the BE was increased, the yellowness of the PVC sheets gradually increased, as shown in Table 3. The whiteness of PVC sheets prepared with BE and DOP combinations was observed to be lower than that prepared of DOP only. However, there was substantial difference in the whiteness index in each of these samples. As expected, the fatty acid backbone resulted in reduced whiteness as compared to 100 % DOP, but did not show much deterioration even after 50% replacement of DOP. The non- linear behaviour in yellowness index could be the human error and the error occurred during the processing of plasticized PVC sheets.

Exudation test

Table 4: Exudation test of plasticized PVC samples

Sample	Initial weight of sample (gm)	% Weight loss of sample after 48 hrs
PPVC 1	1.007	0
PPVC 2	1.038	0
PPVC 3	1.169	0
PPVC 4	1.151	3.1754
PPVC 5	1.014	7.2721

In the exudation test, Plasticized PVC films did not present any significant mass loss of PPVC 1, PPVC 2 and PPVC 3 during the experimental period (48 h, room temperature) as shown in Table 4. This could be attributed to the excellent compatibility of both the plasticizer components with each other and with PVC backbone resulting in excellent plasticizing effect without any mass loss. Whereas, PPVC 4 and PPVC 5 showed leaching of plasticizer on the paper. The leaching of plasticizer from PPVC films is greater in PPVC 5 than in PPVC 4, it is because of the increase in oleochemical nature of the plasticizer as the content of BE increased in the blends.

Mechanical Testing

The mechanical properties of PVC films are shown in Table 2. The tensile strength (TS) accounts for the sheets mechanical resistance due to the cohesion between the chains, while the elongation at break (E) measures its plasticity, which is the capacity of the film to extend before breaking.

We had investigated the effects of benzyl ester on the mechanical properties of PVC/ (BE/ DOP/ ESBO) blends as shown in Table 2. All the samples were evaluated in triplicates to confirm the repeatability of the results. PPVC 3 showed highest tensile strength and elongation at break amongst the series. The initial tensile strength and elongation appears to be higher (PPVC 1- PPVC 3) and then it gets reduced at PPVC 4 and PPVC 5, suggesting that tensile strength is not linear. The non- linear nature of tensile strength as the content of BE increased can be explained by the exudation. The elongation at break showed gradual increase till PPVC 3 and then it decreased for PPVC 4 and PPVC 5.

Chemical Resistance

Besides mechanical and exudation properties, plasticizers should also be resistant to chemicals. Chemical resistance was evaluated by the amount of plasticizer migrated out of samples to the liquid phase (extract ability) or to the gaseous phase (volatility) under atmospheric conditions.

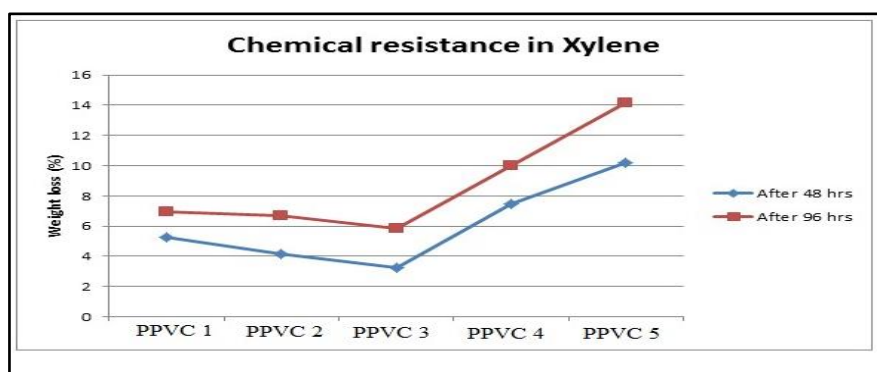


Figure 4: % weight loss plasticizer in Xylene.

The migration of plasticizer is expressed in terms of the percentage weight loss after immersion. An increase in weight indicates that the chemical has penetrated the samples, whereas decrease in weight indicates that some additives are volatilized. The mass variation data of all the samples versus the time of contact with solvents i.e. xylene and MTO are given in Figure 4 & 5. Percentage weight loss of total plasticizer from PPVC films was more in xylene as compared to MTO. It was observed from the sample results that chemical resistance increases with increase in DOP content in the systems. PPVC 3 showed maximum chemical resistance in both xylene and MTO, whereas PPVC 5 showed the least chemical resistance. When the polymer matrix comes in contact with the solution, the solution attacks the polymer matrix and penetrates through it and plasticizer - PVC bond is weakened to an extent wherein the plasticizer tries to leach out and the extraction solution further enters the matrix and slowly fills the vacant locations in the matrix. As a result of this, PVC can shrink and become hard and stiff exhibiting cracks on the surface and subsequently resulting in increasing weight loss of the sample.

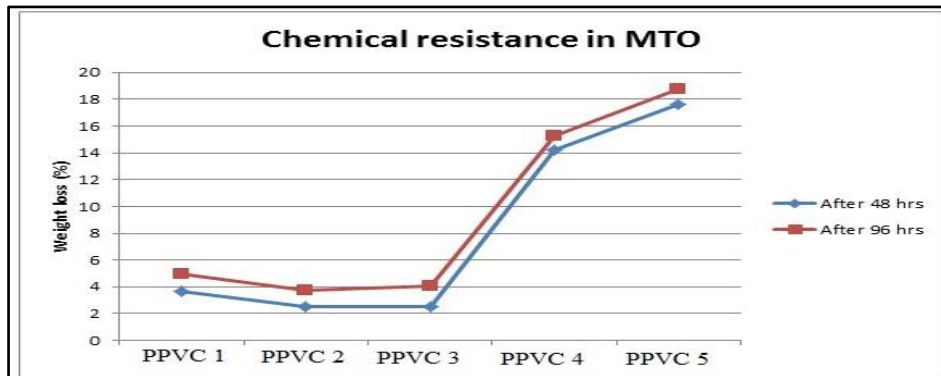


Figure 5: % weight loss of plasticizer in MTO.

Hardness

The plasticized PVC with a single plasticizer has been discussed extensively in the literature. However, its real application, to optimize properties two or more plasticizers are frequently used. The total plasticizer content is 60 phr in the blend. The variation in the hardness of the plasticized PVC is shown in Table 3. Hardness test did not show any noticeable difference with increase in BE content in the polymer matrix. The average value of Shore D hardness was found to be 49. Shore A hardness was lower for PPVC 1 than other samples.

Differential Scanning Calorimetry (DSC)

The glass transition temperature (T_g) of all the polymer blends was determined by using Differential Scanning Calorimetry (DSC). DSC curves of all the blends are shown in Figure 6. All the samples exhibited a single T_g characterized as an endothermic deviation on the baseline. The analysed plasticized PVC films showed T_g values ranging between 58.86°C to 61.98°C. The presence of BE plasticizer in PVC films did not alter its T_g to a large extent.

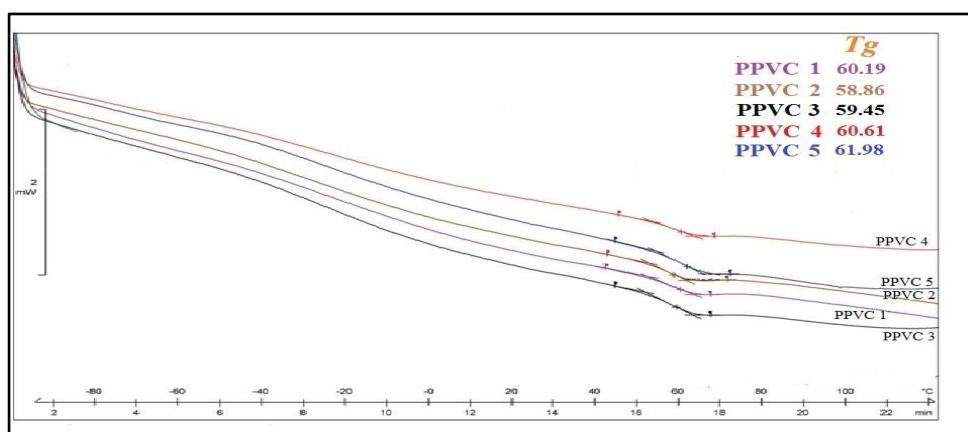


Figure 6: DSC of PPVC samples

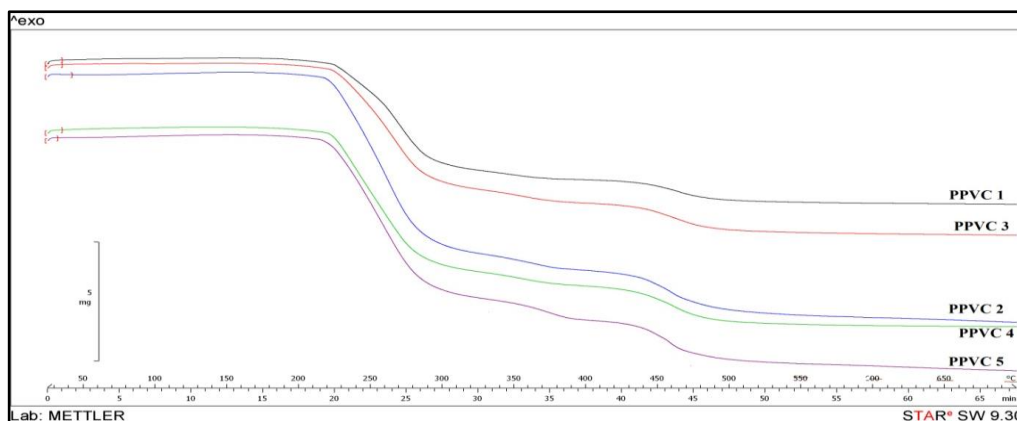


Figure 7: TGA of PPVC samples

At low temperature, molecular dehydrochlorination plays a fundamental role whereas at higher temperature the radical mechanism becomes relevant. HCl formed further catalysed the degradation process releasing more HCl and the forming polyenes.

The loss of HCl makes the allylic chlorine more active in the polymer chain and its unzipping results in polyene linkage, till the conjugated structure is stabilized by resonance. During the first decomposition stage of various systems, 56.86 – 70.56% sample was decomposed. It was observed that the decomposition rate decreased with increase in BE content in the system. At about 250 °C, PPVC1 resulted in maximum decomposition of 70.56%, whereas 56.86% decomposition occurred in PPVC 6 sample. Last decomposition stage was observed at 400 - 450 °C resulting in degradation of the complete polymeric backbone. The study conducted revealed that the initial decomposition could be lowered with increasing BE proportion in the plastisol formulation.

CONCLUSION

A facile, clean and environment friendly method for the esterification of dehydrated castor oil fatty acid has been developed. BE is able to be used as partial replacement of DOP at up to 65 wt % along with ESBO, displaying enhanced mechanical properties and chemical resistance in xylene and MTO. Benzyl ester obtained in this study shows good incorporation and plasticizing performance into PVC formulation resulting in lower viscosity and viscosity pick up which leads to reduction in processing related difficulties without use of external shear. The thermal studies conducted for plasticized PVC samples showed no significant change in properties. Shore hardness was observed to be increased with increase in BE concentration but not significantly. Plasticizer migration was not observed in proportion to the amount the plasticizer replaced (65 wt %).

The benzyl ester plasticizer obtained in this study showed good incorporation and plasticizing performance into the PVC polymer matrixes thus making the castor oil based plasticizer an environment friendly substitute for the PVC systems.

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