# INVESTIGATION ON THE EFFECT OF COMPOSITION OF CALCIUM CARBONATE, CPW AND DOP ON TENSILE STRENGTH OF PVC WIRE JACKET HAVING 45 % PVC RESIN

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## Abstract

*One of the biggest challenges in wire insulation industries is the proper governance of its raw materials to form the standardized product. The use of plasticizers has been well investigated and their utilization is very abundant. The ratio of $CaCO_3$, CPW and DOP plays a very important role in determination of the tensile strength of PVC insulation. This paper focuses on the effect of $CaCO_3$, CPW and DOP on the tensile strength of the PVC compounding having PVC resin at hold value of 45%. Unlike other papers this paper enumerates the effect of several components of the mixture simultaneously. The $CaCO_3$ content ranges from 23.50-29.82 %, CPW ranges 8.7-13.04 % and DOP 10.0-15.04 % by weight. The optimum results for Ultimate Tensile Strength came out with 23.52% CaCO3, 13.0% CPW and 14.75% DOP.*

***Keywords:*** *PVC Resin, $CaCO_3$, CPW, DOP, PVC compounding, Ultimate Tensile Strength*

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## 1. INTRODUCTION

The one of the common problem in extrusion process of PVC which leads to defective products is due to Improper Materials Addition [1]. The quality of cable depends more on the quality of the insulating material. Plasticized PVC is flexible and has rubber like material but still is tough and rigid. Plasticized PVC is in use right from the Second World War. The use of CPW and DOP has become very common these days. By variation of these components in the mixture can result in a very remarkable effect on the mechanical properties of PVC. The greatest threat to the quality of a cable, especially to end users, is that of insulation breakdown which invariably leads to short circuit. Flexible PVC compounds can contain 25 to 80 Phr (parts per hundred resins) of plasticizers. The use of plasticizers sometimes requires the use of biocides to inhibit microbiological attack that may result in discoloration or loss of properties [2].The formulations of flexible PVC require a large number of formulations that include other additives in addition to the polymer resin. Plasticizers softens the PVC by weakening the intermolecular interaction, while incorporating the filler the effect is completely reversed as the filler increases the hardness of the PVC. Increasing plasticizer content results in decreasing tensile strength and specific gravity but increasing in elongation at break but they also increase flexibility and extensibility of the product [3-4].

$CaCO_3$ filler is properly introduced into the formulation, the desired tensile strength and elastic qualities of the product can be achieved, and it significantly improves the adhesion between the filler particles and the matrix [5-6]. The decrease in tensile strength of the PVC products diminishes the tensile strength relevant friction part and causes decreasing sturdiness. For non plasticized PVC, it is seen that the tensile strength shows a steep increase followed by a rapid decrease and a stable value until the test specimen breaks during the tensile test. That can be seen in the course of the raw material [7]. Each manufacturer optimizes the composition of their products, but in literature there is no information about the optimal composition and effect of combination of different brands of additives on the properties of the product [8]. Various stabilizers are used to give a particular effect to the compound. PVC without any additives, at room temperature, is a rather rigid material. It is often used in place of glass. But if it is heated above the temperature of 87°C a change occurs, PVC becomes flexible and rubbery [15].

## 2. LITERATURE REVIEW

There is a considerable impact of various additives on tensile strength and other mechanical properties of plasticized PVC. The addition of plasticizers and filler materials severely changes the quality of the product. Several research works are carried out to find out the optimum composition so as to attain the desired properties.

Safwan Altarazi [16] on his research on “Optimization of Materials Cost and Mechanical Properties of PVC Electrical Cable’s Insulation by Using Mixture Experimental Design Approach” considering the ASTM Designation (D) 6096, he took different blends of PVC. He considered the composition of Recycled PVC which can be made by re extrusion of the previously made PVC. His analysis was based on Design of Experiment. The results analysis showed that, for maximum UTS the compound should consist of: 17.5% DOP, 62.5% virgin PVC and 20.0% $CaCO_3$ of particle size 5 microns.

Imran Nazir Unar [3] investigated the effect of Various Additives on the Physical Properties of Poly Vinyl Chloride Resin. He made several conclusions based upon his analysis. He found that increasing plasticizer content results in decreasing tensile strength and specific gravity but increasing in elongation at break. On the other hand, increasing the filler content increased the tensile strength but reduced the elongation at break in the absence of plasticizers. It is finally concluded that the addition of various additives in the PVC have great effect on the mechanical properties.

M Davallo [4] inspected the Influence of a Variety of Plasticizers on Properties of PVC. It was found that using tritolyl phosphate as a plasticizer 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 tritolyl phosphate and dialphanyl phthalate showed lower ductile-brittle transition temperature and with lower volatility loss compared with other plasticizers.

Fernando [6] studied the effect of precipitated calcium carbonate on the mechanical properties of PVC. In this case there was found to be a significant reduction in tensile strength, which was attributed to poor adhesion between the filler particles and the matrix. Elongation-to-break, and hence the ductility of the samples, increased with decreasing particle size.

Omprakash H. Nautiyal [17] did molding of PVC Air Soles with Modified Formulation. Molding of PVC Air soles was produced with the formulations of Resin (25 Kg), DOP/DBP ( 8+8 Kg), CPW (3 Kg), R9 (0.750 Kg), Ivamol (0.500 Kg), Stearic acid (0.500 Kg), Foaming ADC (0.350 Kg), MBR (8kg) and $CaCO_3$. On the basis of the quality evaluations the soles invented with naphthenic oil were found to have superior qualities as compare to the one with CPW and stearic acid. The results also have shown that the customers would certainly prefer to buy the soles with low abrasion, high elongation and tensile strength.

I. Kemal [18] investigated the toughening of unmodified Poly vinyl Chloride through the addition of nano particulate calcium carbonate. He observed that the presence of nanometer-sized $CaCO_3$ particles led to a slight decrease in the tensile strength but improved the impact energy, the storage modulus and the fracture toughness.

## 3. PARENT MATERIALS USED

Not only components of a material, but its properties and various parameters decide the resultant mechanical behavior of the product. The quantity of PVC resins used for each of the mixture is the same. Two types of plasticizers, COP and CPW were used. The following sub points represent the specification and types of materials used.

### 3.1 PVC Resin

Basically known by its common name Ethyne-octene copolymer, is the base material in PVC. The behavior of plasticized PVC resins has a way different property than PVC Resin alone [3]. Proper flexibility, tensile strength, low abrasion, electrical resistance, etc can be achieved with the addition of proper additives. PVC Resins having K- Value of 67 were used. They were bought from LG Chem which has the characteristics as shown in Table-1.

**Table-1:** Parameters of PVC Resin

| Parameter | Value |
|---|---|
| K-Value | 67 |
| Particle Size | 99.8 microns |
| Bulk Density | 0.5 g/cm³ |
| Specific Gravity | 1.4 |

### 3.2 Calcium Carbonate

Among the various fillers, calcium carbonate ($CaCO_3$) is used as important reinforcing filler in thermoplastic industry and has been studied by many researchers who have reported large improvements in mechanical properties such as strength, modulus and toughness [19].

**Table-2:** Specifications of Calcium Carbonate used

| Product | Type | Specification |
|---|---|---|
| $CaCO_3$ | Precipitated, Uncoated | 3-3.5 microns |

### 3.3 Plasticizers (CPW and DOP)

DOP (di-2-ethylhexyl phthalate) with a molecular formula $C_6H_4[COOCH_2CH(C_2H_5(CH_2)_3CH_3]_2$ prevailed as the preferred general-purpose plasticizer for PVC until the late 1970s. In 1968, more than 550 different materials were listed as commercial plasticizers, available from over 75 suppliers in the USA [17]. The cost is also low. Also, DOP used here is DOP C8 with specific gravity value of 0.9. Chlorinated Paraffin Wax (CPW) is as an optional secondary plasticizer. Here the CPW used was of type Grade II CP 52 which contains about 52 % of Chlorine.

### 3.4 Stabilizers

Stabilizers are necessary to provide the additional effects to the PVC mixture that base materials cannot provide. Additives for the photo stabilization, bleed resistance, gelation degree, foam expansion, tear strength, thermal stability, aging effect, electrical resistance, pigmentation, coloration, flexibility, humidity diffusion etc are also used to give the desired outcome [9-14]. All of the samples contain 2-3% of Stabilizers with the composition as shown:

**Table3:** Composition of Stabilizers

| Stabilizers Used | Approximate Percentage |
|---|---|
| Stearic Acid | 8-14 |
| PE Wax | 9-13 |
| $TiO_2$ | 6-10 |
| TBLS | 15-20 |
| CS | 10-12 |
| ESO | 22-30 |
| Colorants + Others | 18-24 |

## 4. EXPERIMENTATION

The experimentation included the preparation of the mixture and the samples. After which the Ultimate Tensile Strength was recorded for each of the sample.

### 4.1 Preparation of the Mixture

Different blends of PVC were prepared with the help of Batch mixture Machine with the help of extrusion process. Fixed composition of 45% of PVC Resin was used in each case. The batch mixtures were produced having total weight percentage of the plasticizer from 32% to 42%. Three different heating zones were provided for heating up the PVC mixture. The temperatures of the heat zones recorded were 133°C, 146°C and 169°C respectively. The screw speed was set to 30 rpm. The water bath was used to cool the extruded PVC. Fig-1 shows the three heating zones of the extrusion machine

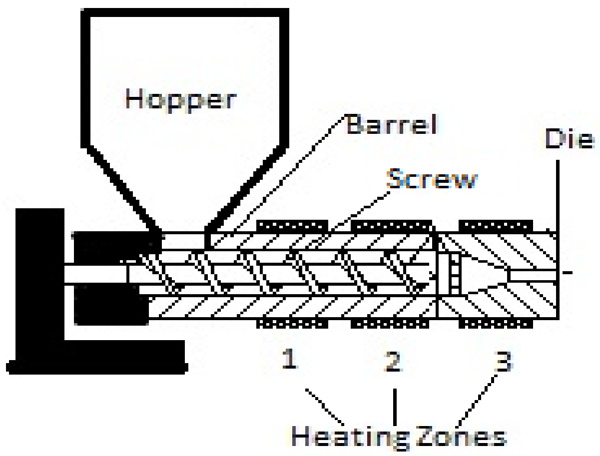


**Fig -1**: Three heating zones in Extrusion process

Different compositions were prepared based on the varying compositions of the plasticizers and calcium carbonate. The representation of the lower and upper limits of the mixture is given in the Table-4.

**Table-4:** Upper and lower limits of the mixture components

| Name | Lower Limit | Upper Limit |
|---|---|---|
| CaCO3 | 23.50 | 29.09 |
| CPW | 8.70 | 13.04 |
| DOP | 10.0 | 15.04 |

A total of nine mixtures were made with varying composition of DOP, CPW and $CaCO_3$. The mixture was allowed to cool down in the room temperature.

### 4.2 Ultimate Tensile Testing

Nine samples were made from each of the mixture and they were made according to IS: 10810 (Part 7) with a diameter at 3 mm and the marker lines were set to 2 mm. The testing was done on Universal Tensile Strength Machine (Kamal Metal Industries). The Ultimate Tensile Strength for each of the material was found out.

**Fig -2**: Tensile Testing Machine

On the basis of the tests done on the Tensile testing Machine, the following data was collected. Table-5 shows the percentage of each component with the respective Ultimate Tensile Strength.

**Table-5:** Values of UTS for the mixtures

| Mixture | $CaCO_3$% | CPW % | DOP % | UTS $N/mm^2$ |
|---|---|---|---|---|
| X1 | 23.50 | 10.71 | 15.04 | 12.00 |
| X2 | 27.42 | 10.42 | 12.80 | 11.40 |
| X3 | 27.27 | 11.83 | 10.00 | 11.03 |
| X4 | 26.15 | 12.10 | 11.00 | 10.60 |
| X5 | 27.27 | 10.91 | 12.73 | 12.20 |
| X6 | 28.26 | 8.70 | 10.86 | 10.40 |
| X7 | 23.78 | 13.04 | 14.44 | 10.86 |
| X8 | 23.95 | 10.92 | 13.41 | 13.00 |
| X9 | 29.09 | 9.09 | 10.92 | 11.30 |

## 5. RESULTS AND DISCUSSIONS

The Design of Experiment approach was followed to know the effect of the interactions between the constituents of the PVC. Illustrations were done statistically with the help of MINITAB 16.

### 5.1 Contour Plot

CPW and DOP, both of the constituents were taken as plasticizers. The combined effect of CPW and DOP with Calcium carbonate interaction showed an asymmetric variation of Tensile Strength as seen on Fig-3, where we can see that Plasticizers are helping in increasing the tensile strength of PVC but only up till a certain limit. The maximum tensile strength is obtained when the composition of Plasticizers is in between 23.34% and 24.94%, and in case of $CaCO_3$, composition is less than 24.5%.

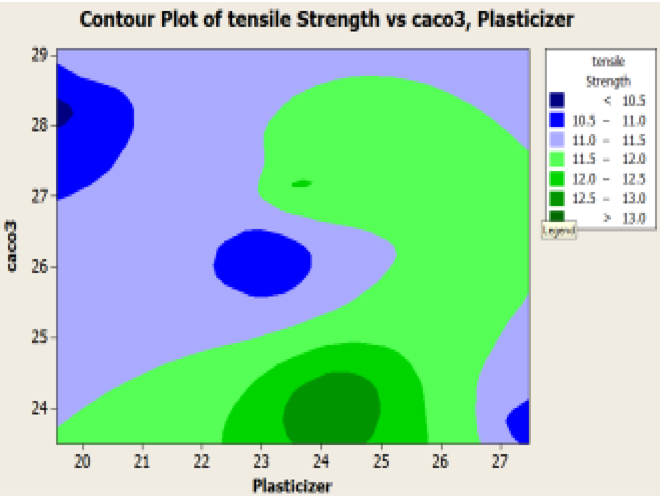


**Fig -3**: Contour Graph of Tensile Strength v/s $CaCO_3$ and Plasticizers

Similarly in Fig-4, the relations between the constituent plasticizers were analyzed. The composition of CPW between 10.62%-11.32% and DOP having composition between 13.06%-13.91% gave the area having the highest value of tensile strength.

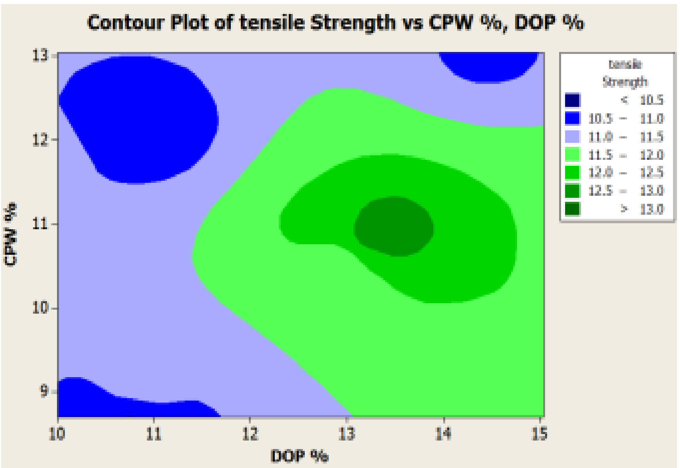


**Fig -4**: Contour Graph of Tensile Strength v/s CPW and DOP

### 5.2 Scatterplot Graphs

Scatterplot Graph between DOP and Tensile Strength, as seen in Fig-5, showed that, with increase in the composition of DOP there will be increase in Tensile Strength of PVC. The scatterplot of CPW and Tensile Strength did not have any considerable impact on the UTS so, the graph is not shown. Plasticizers usually soften the materials and weaken the intermolecular attraction thus decreases the tensile strength but increasing the elongation. But for some specific composition of DOP, the molecular bonding has turned better. Good tensile strength can be noticed as the composition of DOP elevates from 13% to 15%.

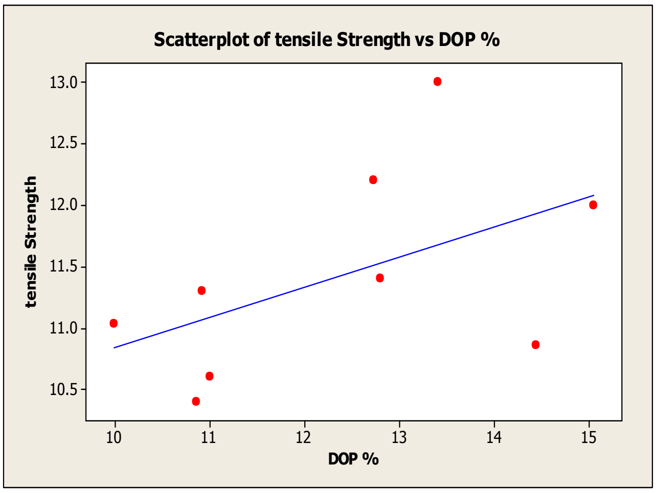


**Fig -5**: Scatterplot of Tensile Strength v/s DOP%

Fig-6 represents the variation of Tensile Strength with the composition of Calcium Carbonate. It can be clearly seen that with the increase in the composition of Calcium Carbonate, the Tensile Strength is decreasing. For the composition less than 24% of $CaCO_3$, the tensile strength is good. It is evident that the tensile strength will decrease with increase in the percentage of $CaCO_3$ having particle size of 3-3.5 microns. Coated $CaCO_3$ could have resulted in inertness from the effect of the plasticizers on it. As the amount of $CaCO_3$ increases, due to the poor adhesion between the particles of $CaCO_3$ and the matrix, the tensile strength is decreasing.

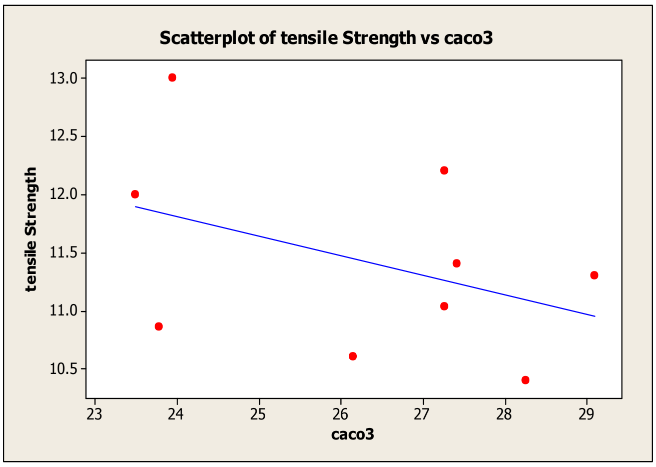


**Fig -6**: Scatterplot of Tensile Strength v/s $CaCO_3$%

### 5.3 Response Optimization

Response optimizer was used to find out the optimum composition setting for the mixture. The model was made with the purpose of obtaining the target value of Ultimate Tensile Strength based on IS: 5831 – 1984, according to which the UTS should be 12.5 $N/mm^2$.

The Target value was set to 12.5, lower and upper limits were 12 and 13 respectively. Value of importance was kept to 2. The optimal values were noticed which are as seen on Table-6.

## 6. CONCLUSION

The highest values of Ultimate Tensile Strength can be obtained by keeping the composition of Plasticizers (CPW and DOP) between 23.34% and 24.94% and by using less than 24.5% $CaCO_3$. The composition of CPW between 10.62%-11.32% and DOP having composition between 13.06%-13.91% gives the highest value of Ultimate Tensile Strength. For the range of 10% to 15% of DOP, the Tensile Strength of PVC will increase with increase in its composition. With increase in the amount of Calcium Carbonate, the Tensile Strength of PVC will decrease. There is a very negligible variation in UTS when the composition of CPW is changed from 8.7% to 13%. Therefore, DOP is a primary and CPW is a secondary plasticizer. The optimum composition obtained for UTS from Response Optimizer is shown in the table shown below.

**Table-6:** Optimum percentage of components for UTS

| Ingredient | PVC Resin | $CaCO_3$ | CPW | DOP | Stabilizer |
|---|---|---|---|---|---|
| Percentage | 45.0 | 23.52 | 13.0 | 14.75 | 3.69 |

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