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IMPROVING THE THERMOPLASTIC EXTRUSION PROCESS IN CABLE MANUFACTURING

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ABSTRACT

Cable manufacturing in a developing country like Nigeria today is faced with a number of problems that affect the quality of cables produced from extrusion to insulation of conductors. The main cause of the problems is the low and variable output rate from extruder causing non-uniform conductor diameter which results in insulation surface appearance defects. These defects manifest in form of pimples, dimples, cracking, air cavity, voids and porosity within the plastics which are insulation.

The conductor insulation normally used is the Polyvinyl chloride (PVC) which is normally sourced locally or imported. The locally produced PVC is cheaper in cost than the imported one but at the expense of quality due to inconsistency in the percentage combination of plasticizers, fillers, stabilizers, lubricants, and other additives required for producing quality PVC resin for cable applications. If the local manufacturers of PVC are not patronized, it will lead to employees losing their jobs and most likely their family income with other attending societal ills.

The work in this paper takes a close to look at what should be done to improve the quality of locally produced PVC at little or no increase in cost. It has been discussed while working with one of the manufacturers that the required additives to produce an acceptable level of quality PVC resins for cable application are not optimally combined proportionately. In order to improve the quality of local plastics, optimum proportion of the required additives for quality cable insulation were experimentally determined at a comparable cost and better additive material consumption.

The ratio of weight per charge (Kg/charge) of additives especially plasticizer and chalk gave a good output comparable in quality to the imported ones. The test results obtained from the analysis of the local plastics with optimum proportion of additives are comparable to the imported one. The analysis is based on insulation test, cost savings, material consumption/wastages, viscosity, melt temperature, flows and pressure requirements associated with extrusion process of thermoplastic.

KEYWORDS: Extrusion, Output Rate, PVC Resin, Additives, Weight per Charge, Material/Cost Analysis

INTRODUCTION

The basic materials required for cable production are copper (Cu) or Aluminum (Al) and plastics. There are a variety of extruded power cables but the most commonly used are polymer for low voltage (< 1000V) cable-insulation or the outer jacket application are usually Polyvinyl Chlorides (PVC). Cable consists of a low resistance conductor to carry current and an insulator (PVC) to confine the current flow into the conductor.

The quality required for a good insulator includes high flexibility at low temperature, high D.C voltage strength, low dielectric constant, low dielectric loss, high insulation resistance cut-through and high dielectric strength. The quality of cable depends more on the quality of the insulating material. The greatest threat to the quality of a cable, especially to end users, is that of insulation breakdown which invariably leads to short circuit.

The insulator (PVC) which is plastic is a blend of polymers and additives. Thus,

Plastic = Polymer + Additives (hit the additives)

Additives, such as chalk, plasticizer, lead stabilizer (particularly tribasic acid lead sulphate because of its good non-conducting electrical properties), fatty acid, paraffin wax and ethylene – octene co-polymers, are added to PVC resin for cable applications to bring the insulation to the required standard [1].

The formulations of flexible PVC require a large number of formulations that include other additives in addition to the polymer resin. PVC formulations are designed considering the quantity of components compared with 100 parts of resin, that is in phr (*part per hundred resin*, by weight) [2]

A typical rigid PVC compound can have total additives of 8 to 37 parts per hundred resins (phr). In addition, flexible PVC compounds can contain 25 to 80 Phr 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.

Flexible PVC, in compounds characterized by high loading of plasticizers, is used in variety of applications including film and sheath for packaging, coated fabrics for upholstery, floor coverings and wire and cable insulation [3].[4]. Vinyl wire insulation provides the electrical and physical properties necessary to meet most building wiring requirements.

There are several hundred vinyl compounds designed especially for insulating and jacketing application. Flexible vinyl is the major material used in wire and cable insulation and sheathing for telephone systems, electronic equipment electrical apparatus and cords, power distribution lines, and automotive components. Vinyl offers many important properties such as dielectric behavior, elongation and resistance to cutting/crushing, resistance to oil exposure, resistance to embrittlement and resistance to UV light degradation [5].

This study is focused on experimental determination of optimum combination of plasticizers, fillers and other additive, and the chemical nature of PVC resin itself, which is susceptible to thermal degradation at elevated temperature to produce a good quality PVC resin which when extruded can be used to produce a good flexible and quality cable. Additives are selected to be compatible with the material and the process conditions for shaping the material. The improvement of specific property of a material by the addition of an additive is usually at the expense of some other property [6]. Many of the problems experienced with vinyl extrusions are also applicable to other thermoplastics.

The structure of the rest of this paper is presented as follows: Section 2 gives the theoretical background of thermoplastic (PVC) behaviour and extrusion process while section 3 is dedicated to quality evaluation of local PVC material in terms of its physical, chemical, thermal, mechanical and electrical properties in addition to its specific density and consumption rate evaluation.

The mixing of the percentage composition of certain additives to generate new plasticized PVC grade and the analysis, on cost implication and consumption rate is carried out in section 4 for comparisons, and section 5 draws the conclusion and recommendation of the study.

1. BASIC PRINCIPLE OF EXTRUSION

A plastic extrusion is a high volume manufacturing process in which raw PVC material is melted and formed into a continuous profile [7]. Fundamentally, the process of extrusion consists of converting a suitable raw material into a product of specific cross-section by forcing the material through an orifice or die under controlled conditions. In order that this simple conception can have practical value, however, there are certain requirements which must be satisfied with as regards the equipment and the PVC.

The equipment must be capable of providing sufficient pressure continuously and uniformly on the material so that it will flow under pressure and solidify when these conditions are removed. Extrusion of thermoplastic material (PVC) takes place in the screw extrusion machine.

1.1 Screw Extrusion

Extrusion of thermoplastics is a process in which the material is melted by external heat / frictional heat and conveyed forward by a screw to the opening of the die, which gives the shape of the required product. A screw extruder is a machine consists of a screw of special form rotating in a heated barrel or cylinder in which a feed opening is placed radially or tangentially at one end and an orifice or die axially at the other.

The screw extrusion machine comprise of Hopper, Barrel/Screw and Dies. A restriction in the form of a breaker plate and screen is sometimes placed between the ends of the screw and the extruding die in order to assist the build-up of a pressure gradient along the screw. The screw is usually bored throughout, or for some part of its length, so that it may be fluid cooled or heated, according to the requirements of the feed material [8].

The rotating screw takes the material which is usually in the form of free-flowing cold chips, powders or cubes-from the feed opening, through the heated barrel zones, and compact it against the breaker plate or other restriction, so that a pressure is built up. During this period the material is forced into intimate and substantially sliding contact with the hot barrel walls and is also sheared and worked so that frictional effects are produced.

The combined effects of the hot barrel and the heat due to internal friction in the material cause the thermoplastic to soften so that it may be forced through the restriction to the extrusion die, where it is given the required form. The extruder, however, is mainly a “melting mixing, and a conveying machine” to deliver a homogeneous plastic melt to a die at a specified uniform temperature and pressure. Unfortunately, even when all the operational parameters in an extrusion process such as pressure, temperature, screw rotation rate and so on appear to be under controlled, the end product may still show inconsistencies. Thus, the extrusion process does not improve the quality of resin fed into the extruder [9].

2. ANALYSIS OF PVC MATERIAL

About 10mm strip were cut for sample test from each of the various local PVC suppliers like Patpalst, Italopalst, Romaplast and Marple plastics and also from overseas PVC like France GM22 and APivin are tested using the following parameters in accordance with NIS 153 specification standard (IEC 60227) [10]:

Table 1: Average Measured Values of Tested Parameters Compare with Standard

PVC MATERIAL SUPPLIERS	ELONGATION (%)		FORCE, F_{max} (N)		TENSILE STR. T.S (N/mm^2)		INS. RESIST. AT 70^{o}C (MΩ)		MOISTURE ABSORPTION (Kg)		HIGH VOLT. 0.6/1(kV)		CRACKING AT 150^{o}C	OTHER OBSERV-ATION	REMARKS
	TEST	REQD	TEST	REQD	TEST	REQD	TEST	REQD	TEST	REQD	TEST	REQD			
MARPLE PLASTIC (LOCAL)	201	≥125	148.3	≥120	11.5	≥12.5	0.516	≥0.01	0	≤0.002	3	3	NONE	Pores and rough surface	T.S not okay. Low ins.
ROMA PVC (LOCAL)	247	≥125	122.7	≥120	12.2	≥12.5	0.713	≥0.01	0	≤0.002	3	3	NONE	NONE	Low T.S relatively,
PATPLAST (LOCAL)	153	≥125	130	≥120	11	≥12.5	0.535	≥0.01	0.001	≤0.002	3	3	CRACKED	Hard to peel and	Low T.S ; Lower than
ITALO-PLAST (LOCAL)	175	≥125	135.3	≥120	11.5	≥12.5	0.59	≥0.01	0	≤0.002	3	3	CRACKED	Hard to peel and rough	Low T.S ; Lower than desired
FRANCE GM22 (IMPORTED)	251	≥125	125.3	≥120	17.2	≥12.5	0.713	≥0.01	0	≤0.002	3	3	NONE	NONE	PASSED
APIVIN OVERSEA (IMPORTED)	250	≥125	125	≥120	16.9	≥12.5	0.705	≥0.01	0	≤0.002	3	3	NONE	NONE	PASSED

- Elongation (%)
- Maximum Breaking Force (F_{Max})
- Tensile Strenght (T_{Max})
- Insulation Resistance at 70^{o}C
- Moisture Absorption (%); some PVC material are very hygroscopic
- High voltage test
- Cracking at 150^{o}C / 2hrs
- Other physical observations; such as hardness to peel, roughness, pimples, dimples, cavity

The results of the tested parameters as compared with the standard are represented in Table 1.

2.1 Specific Density of PVC Material

The specific gravity (SG) of PVC material is a standard determinants of its material rating. Thus it is desired that the chosen value should be less than the required value to reduce insultion weight, material consumption and hence production cost. In the course of the experiment, it was found that the SG of PVC materials from local suppliers is higher and there is variation in SG of different PVC batches from the same local supplier. Table 2 shows the measured SG of PVC from various suppliers-local/imported.

Table 2: Measured Values of SG of PVC from Local and Overseas Suppliers Compared with the Desired Value

S/No	PVC Material Suppliers	Insulation Reqd. ≤ 1.36 (g/cm^3)	Remarks	Sheath Reqd.≤ 1.4 (g/cm^3)	Remarks
1	Patplast (local)	1.368	+0.6%; above the maximum require value	1.415	+0.35% above the max. value
2	Romaplast (local)	1.38	+1.47%; above the maximum require value	1.42	+0.7% above the max. value

Table 2: Contd.,

3	Marple Plastic (local)	1.45	+6.6%; above the maximum require value	1.45	+2.6% above the max. value
4	Italoplast (local)	1.38	+1.47%; above the max. value	1.42	+0.7% above the max. value
5	France (Imported)	1.327	-2.43%; below the max require value.(economical)	1.327	-5.9% below the max. (very economical)
6	Apivin (imported)	1.268	-6.76%; below the max. require value (Very economical)	1.37	-2.8% below the max. require value (economical)

From Table 1 and 2, it was established that local suppliers manufactured low qaulity grade of plasticised PVC materials for cable applications coupled with high SG and hence high consumption rate. Details are as revealed in Table 9 on application to different cable sizes.

2.2 Platicised PVC Materials

Plasticised PVC is a compounded or fluxed mixture of the polymer, plasticizer, heat and light stabilizers and lubricants. It may also contain pigments and fillers. The ease of extrusion depends, to a large extent, on the formulation and adequacy of mixing and fluxing during the compounding operation [11].

Table 3 shows the local manufacturer's existing designed formulation of plasticised PVC materials.

Table 3: General % Composition of Plasticised PVC Compounded Mixture from Local Supply (Patplast and Romaplast Nigeria Limited)

Design	Content kg/Charge	Content (%)	Remarks
Resin PV Powder (Ethyne-octene copolymer.)	100	23.7	Plastic compound before additives
Chalk	275	65.3	Additives
Plasticizer	25	5.9	
Stabilizer (Primary)	5.3	1.3	
Stabilizer (Secondary)	2.0	0.5	
Lubricant (Internal)	1.6	0.38	
Lubricant (External)	1.0	0.24	
Filler	11.25	2.68	
Total	**421.15**		

3. DESIGN OF EXPERIMENTS (DOE) FOR MIX 1 TO MIX 7

One of the general approaches to formulating flexible vinyl materials involves a novel untried concept for which the technical requirements of the product are unknown and a set of tentative needs is "guesstimated". Trial formulations, whose properties bracket the tentative needs, are developed and parts or items submitted to field trials. The process is iterated until a satisfactory product is developed [12].

Material for extrusion are often supplied in the form of specially fomulated compounds. These materials contain heat and light stabilizers, lubricants, Chalks, plasticisers, and other additives in addition to the basic resin which either improve its extrusion properties or give it the characteristics required for the particular end product.

New fomulation of certain additives ingredients were determined based on heuristics knowledge and design. The compounding operation of the PVC is carried out by a continuous process in the extrusion machine. Depending on the requirements of the basic resin, the compounding process consists broadly of carefully dispensing of the various ingredients by means of suitable mixing equipment and then fluxing the mix so that it becomes an homogeneous mass. The fluxing is carried out in extrusion machine and the PVC extrusion compund is optimised for the requirements, including flow of material into an homogeneous melt, correct proportion of lubricant used, compound adequately stabilised against heat and light and the moisture content.

A typical flexible PVC compound for cable insulation can have total additives of between 20% and 80% proportion of plasticizer. Also correct choice of plasticizer and correct degree of internal lubrication required in order to achieve an homogeneous flow of melted material without hard, unmixed, or imperfectly mixed particles. The material must also show no undue tendency to adhere to the heated metal parts of the extrusion machine. By taking these factors into cosideration, the percentage composition of the main ingredients of plasticised PVC (chalk, plasticizer, stabilizers and lubricants) were altered in such a way that when one or two are altered the rest are kept constant until an extruable PVC with good quality insulation cable output is obtained.

The mixing was done one after the other and the outcome result from every stage of mixing is analysed based on the parameters in accordance with NIS 153 specification standard (IEC 60227) in addition to other surface appearance defects before moving to the next stage. An On-line Rheometer that was interfaced directly with the extrusion 'Trial Run' process to monitore the real time melt flow or viscosity. The quality control, results and other physical observations led to the prediction of the percentage composition of the next variable(s) to be altered or kept constant. In this way, seven different mixing results were obtained and the summary of the recorded results are as presented in table 4. Mix 6 and mix 7 gave a good result in terms of high tensile strenght, standard elongation and maximum breaking force, smooth surface without pores, cracks or pimples; flexible, easy to peel insulation which behave almost like natural rubber when extruded.

The results show that mix 6 and mix 7 are acceptable quality plasticised PVC materials which will extrude acceptably and will produce insulation or sheathing with the desired properties.

Table 4: Percentage Composition of Differnet Mixing of Additives

Number of Mixing	Additives				Tested Parameter						Remarks
	Resin	Chalk	Plasticiser	Stabiliser	Tensile Strength	Elongation	Max. Force	Ins.Res	H.VTest	Cracking	
	(%)	(%)	(%)	(%)	≥12.5 (N/mm)	≥125 (%)	≥120 (N)	≥0.01 (mΩ)	≥ 3.5 (kV)	at 150°	
Mix 1	30.5	61	7.6	0.9	11.5	196	148	0.516	Passed	None	Low tensile strenght. Hard to peel with poor surface quality.
Mix 2	29.6	59	10.4	0.8	16.2	200	150	0.516	Passed	None	Tensile strenght improved. Surface with pimples and very hard
Mix 3	31	56.1	11.8	0.9	16.5	245	138	0.713	Passed	None	Poor physical properties; rough and hard surface
Mix 4	31.06	52.5	15.53	0.62	17	250	135	0.716	Passed	None	Formation of air bubbles, not flexible but a bit smooth without pores.
Mix 5	29.6	50.4	19.3	0.8	17.5	240	125	0.715	Passed	None	Material is flexible; tensile strenght close to the minimum desired value. Fairly okay
Mix 6	31.5	47.2	20.5	0.8	17.8	255	130	0.713	Passed	None	High tensile strenght and elongation, flexible without pores. Good for cable production.
Mix 7	32	41.7	25.6	0.7	17.8	255	140	0.713	Passed	None	Tensile, elongation and braking force measured above desired. Flexible with smooth and shinning surface. Good for cable application.

3.1 Cost and Material Analysis of the Acceptable Mix 6 and Mix 7

In table 4, mix 6 and mix 7 have been accepted based on the set criterial. There is a necessity to verify the effect of the specific gravity (SG), material rating and cost implication between the new formulations, imported and local PVC for further confimation of the acceptability.

3.1.1 Cost Analysis

The actual cost price, which is taken as the sum of production cost price and other expenses, is evaluated for local PVC, mix 6, and mix 7 based on the percentage composition of additives such as chalk, plasticzer, stabilizer, lubricants and fillers contianed in each of the PVC type. However, the landing cost of GM 22 from France is $2.5 per Kg. Table 5 shows the cost price of local, mix 6 and mix 7 comparison based on the quality of additives in the mix.

Table 5: Price Comparision Base on the Quanity of Additives in the Mixture

PVC TYPE	ADDITIVES										Other Expenses e.g profit,labour etc ($)	Actual Production Cost/kg ($)	Cost per 10tons ($)	Variation from Import PVC ($22,000/10tons)
	Chalk		Plastizicer		Stablizer		Lubricant		Filler					
	Qty. (%)	$/Qty	Qty. (%)	$/Qty	Qty. (%)	$/Qty	Qty. (%)	$/Qty	Qty. (%)	$/Qty				
Local	65.3	0.73	5.9	0.217	1.8	0.012	0.62	0.007	2.68	0.08	0.423	1.4	14000	- 8000
Mix 6	47.2	0.4	20.5	0.563	0.8	0.01	1.23	0.015	-	-	0.423	1.4112	14112	- 7888
Mix 7	41.7	0.347	25.6	0.693	0.7	0.01	1.23	0.015	-	-	0.423	1.49	14900	- 7100

3.1.2 Analysis of Material Consumption

Material consumption for France (imported), Patpalst (Local), Mix 6 and Mix 7 PVC was investigated on application for the production of smaller, medium and bigger size non-armoured cables such as 1kV PVC/PVC NCYY 4 x 16mm^2, 4 x 150mm^2 and 4 x 185mm^2 respectively. The manufacturing process results obtained and other measured values like insulation thickness, sheath thickness and overall diameter of the cable are shown in tables 6, 7 and 8 respectively to determine the waste or excess materials used as compared to standard material rating. The percent variation of excess material in each PVC type used to produce the above cable types is presented in table 9 for material consumption economical implication.

Table 6: Application on !kV PVC/PVC NCYY 4x16mm^2 Cable

			ACTUAL FOR IMPORT PVC				ACTUAL FOR LOCAL PVC				ACTUAL FOR MIX 6 PVC				ACTUAL FOR MIX 7 PVC			
S/NO	PROCESS PARAMETERS	DESIRED	BLACK CORE	BLUE CORE	YELLOW CORE	RED CORE	BLACK CORE	BLUE CORE	YELLOW CORE	RED CORE	BLACK CORE	BLUE CORE	YELLOW CORE	RED CORE	BLACK CORE	BLUE CORE	YELLOW CORE	RED CORE
1	**CONDUCTOR**																	
1.1	COND. DESIGN (NO X MM)	**7 x 1.70**	7 x 1.70	7 x 1.70	7 x 1.70	7 x 1.70	7 x 1.70	7 x 1.70	7 x 1.70	7 x 1.70	7 x 1.70	7 x 1.70	7 x 1.70	7 x 1.70	7 x 1.70	7 x 1.70	7 x 1.70	7 x 1.70
1.2	MATERIAL	copper	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu
1.3	DIAM. OVER SINGLE WIRE (MM)	**1.70**	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70
2	**INSULATION**																	
2.1	MATERIAL	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC
2.2	THICKNESS (MM)	**1.0**	1.0	1.05	1.0	1.0	1.25	1.18	1.15	1.12	1.12	1.1	1.05	1.05	1.1	1.1	1.0	1.1
2.3	DIAM. OVER (MM)	**7.10**	7.10	7.15	7.10	7.10	7.45	7.20	7.30	7.15	7.15	7.15	7.15	7.15	7.15	7.15	7.10	7.10
3	**CORE STRANDING**																	
3.1	DIAM.OVER STRANDING (MM)	**17.10**		17.10				17.50				17.28				17.22		
4	**OUTER SHEATH**																	
4.1	MATERIAL	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC
4.2	THICKNESS (MM)	**1.80**		1.80				2.55				2.0				1.80		
4.3	DIAM. OVER (MM)	**20.70**		20.86				22.60				21.28				20.82		

Table 7: Application on 1kV PVC/PVC NCYY 4x150mm^2 Cable

			ACTUAL FOR IMPORT PVC				ACTUAL FOR LOCAL PVC				ACTUAL FOR MIX 6 PVC				ACTUAL FOR MIX 7 PVC			
S/NO	PROCESS PARAMETERS	DESIRED	BLACK CORE	BLUE CORE	YELLOW CORE	RED CORE	BLACK CORE	BLUE CORE	YELLOW CORE	RED CORE	BLACK CORE	BLUE CORE	YELLOW CORE	RED CORE	BLACK CORE	BLUE CORE	YELLOW CORE	RED CORE
1	CONDUCTOR																	
1.1	COND. DESIGN (NO X MM)	**37 x 2.28**	37 x 2.28	37 x 2.28	37 x 2.28	37 x 2.28	37 x 2.28	37 x 2.28	37 x 2.28	37 x 2.28	37 x 2.28	37 x 2.28	37 x 2.28	37 x 2.28	37 x 2.28	37 x 2.28	37 x 2.28	37 x 2.28
1.2	MATERIAL	copper	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu
1.3	DIAM. OVER SINGLE WIRE (MM)	**2.28**	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28
2	**INSULATION**																	
2.1	MATERIAL	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC
2.2	THICKNESS (MM)	**1.8**	1.85	1.9	1.8	1.8	2.2	2.3	2.0	2.3	1.9	1.85	1.9	1.9	1.9	1.8	1.85	1.85
2.3	DIAM. OVER (MM)	**17.90**	17.95	18	17.90	18.30	18.70	18.10	18.10	18.40	18	17.95	18	18	18	17.90	17.95	17.95
3	**CORE STRANDING**																	
3.1	DIAM.OVER STRANDING (MM)	**37.20**		37.80				39.60				38.50				38.20		
4	**OUTER SHEATH**																	
4.1	MATERIAL	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC
4.2	THICKNESS (MM)	**2.2**		2.2				2.3				2.2				2.2		
4.3	DIAM. OVER (MM)	**41.60**		42.20				44.20				42.90				42.60		

4. OBSERVATIONS AND DISCUSSIONS

From the results of tables 6, 7 and 8, it was observed that the diameter over core stranding (after assembling the 4 cores) is slightly above desired with France PVC (imported) and design PVC (Mix 6 and Mix 7) but very high with Patplast (local). This is because with the use of Patplast, insulation thickness is higher than desired and this effect is more pronounced on applications to bigger cables like NCYY 4x150 mm^2 and 4x185mm^2. The increase in the insulating thickness with the use of Patplast especially on bigger cables was partly due to the inconsistency in specific gravity (SG) and also tiny particles (pimples) noticed on the surface of the cable during extrusion. This effect was not noticed during extrusion process of France (imported) and the design of mix 6 and mix 7.

Table 8: Application on 1kV PVC/PVC NCYY 4x 185mm^2 Cable

			ACTUAL FOR IMPORT PVC				ACTUAL FOR LOCAL PVC				ACTUAL FOR MIX 6 PVC				ACTUAL FOR MIX 7 PVC			
S/NO	PROCESS PARAMETERS	DESIRED	BLACK CORE	BLUE CORE	YELLOW CORE	RED CORE	BLACK CORE	BLUE CORE	YELLOW CORE	RED CORE	BLACK CORE	BLUE CORE	YELLOW CORE	RED CORE	BLACK CORE	BLUE CORE	YELLOW CORE	RED CORE
1	**CONDUCTOR**																	
1.1	COND. DESIGN (NO X MM)	**37 x 2.57**	37 x 2.57	37 x 2.57	37 x 2.57	37 x 2.57	37 x 2.57	37 x 2.57	37 x 2.57	37 x 2.57	37 x 2.57	37 x 2.57	37 x 2.57	37 x 2.57	37 x 2.57	37 x 2.57	37 x 2.57	37 x 2.57
1.2	MATERIAL	copper	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu	cu
1.3	DIAM. OVER SINGLE WIRE (MM)	**2.57**	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57
2	**INSULATION**																	
2.1	MATERIAL	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC
2.2	THICKNESS (MM)	**2.0**	2.0	2.0	2.0	2.09	2.09	2.2	2.1	2.15	2.05	2.09	2.0	2.1	2.09		2.0	2.1
2.3	DIAM. OVER (MM)	**19.60**	19.60	19.60	19.80	19.78	19.78	20.00	19.80	19.80	1970	19.78	19.60	19.80	19.78	19.60	19.60	19.80
3	**CORE STRANDING**																	
3.1	DIAM.OVER STRANDING (MM)	**41.60**		41.60				43.00				41.80				41.80		
4	**OUTER SHEATH**																	
4.1	MATERIAL	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC
4.2	THICKNESS (MM)	**2.2**		2.6				2.8				2.6				2.6		
4.3	DIAM. OVER (MM)	**46.00**		46.80				48.60				47.00				47.00		

Although the local PVC is relatively cheaper than other PVC types considered, but with inconsistency specific gravity (SG), and suface quality, leading to excessive material usage as revealed in table 9. These incosistencies result in overall effect of increaesed production cost. From table 5, the landing cost of France PVC is extremely high ($22,000/10tons) which explains why the local manufacturers prefer the use of local PVC with poor quality. Even though France PVC saves more material than other PVC types but the cost price is on the higher side. Mix 6 is very close to Patplast local PVC in term of cost per kg but it has advantage of saving more material than Patplast. Cost price of 10tons difference between Patplast (local PVC) and Mix 6 is just $112 per 10tons while the cost of material saved over Patplast local PVC when Mix 6 is used to produced 4 x 16mm^2 cable is $1015. Therefore mix 6 is more economical.

Mix 7, when compared with mix 6, shows significant effect in material saving but with cost price disadvantage. From the results of table 9, it is obvious that Mix 6 is also economical in material consuption although Mix 7 saves more material than Mix 6 but higher in production cost price.

Table 9: Excess PVC Material Consumption

PVC TYPE	CABLE TYPE & SIZE					
	NCYY 4 x 16mm^2; Desired = 361.77kg/km		NCYY 4 x 150mm^2; Desired = 920.73kg/km		NCYY 4 x 185mm^2; Desired = 1177.66kg/km	
	Actual (kg/km)	Variation (%)	Actual (kg/km)	Variation (%)	Actual (kg/km)	Variation (%)
France (Import)	377.6	4.38	966.9	5.01	1222.9	3.84
Patplast (Local)	440.6	21.8	1054	14.5	1343.5	14.1
Mix 6	404.5	11.8	996.9	8.3	1263.7	7.31
Mix 7	387.75	7.1	977.4	6.2	1237.8	5.1

4.1 Other Process Problem Associated with the Extrudate

Other problem areas which give defects in the extruded product especially the variation in insulation wall thickness are variations in extrusion process parameters such as melt temperature, melt pressure, viscosity, extruder screw speed and die output geometry. All these changes affect the ouput stability of the extruder which accounts for the variation in wall thickness diameters.

This study can further be extended for more optimal quantitative of the consistuent components like resin, chalk, placticizer and stabilizer by vaying the four additives simutaneously using multi-dimensional approach where facilities equipment are available.

5.0 CONCLUSIONS AND RECOMMENDATIONS

To select the appropriate percentage proportion of plasticizer and other additives that must be added to resin PVC powders (ethylene – ethane co-polymer) to meet up with cable insulation application standard, it has to be borne in mind that the total additives of between 20% - 65% must be added to 100 parts of base resin (phr) and also that a typical flexible PVC compounds is characterized by a high loading of plasticizers.

The results of PVC formation of Mix 6 and Mix 7 found to be good for cable production but because of price advantage and economic material consumption, Mix 6 with chalk formulation and plasticizer of 150kg (47.2%) and 65kg (20.5%) respectively is therefore deduced from the results and analyses to be a better option.

The paper has presented alternative quality PVC formulation for cable insulation in Nigeria with price advantage that is lower than imported PVC and comparable to local PVC which is always with inconsistent quality and excessive material consumption.

From the PVC formulation of Mix 6, comprising

- Resin PVC powder = 100kg/charge (31.5%);
- Chalk content = 150kg/charge (47.2%);
- Plasticizer content = 65kg (20.5%);
- Stabilizer content = 2.5kg (0.8%);

The quality of cable is greatly improved, price is also moderate and material consumption is less than local PVC.

It is therefore recommended as the optimal mix (i.e Mix 6) to PVC suppliers and cable manufacturers in Nigeria and other developing countries for low cost price, economic material consumption and high return on investment.

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