# A Factorial Study Of Fibre Cement Roofing Sheet Manufacturing

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***Abstract*—Some concerns had been expressed in the past over the difficulties associated with achieving a first-pass manufacturing success which serves to obviate the efforts inherent in patching and fixing a troublesome product always. Incidentally, achievement of such a manufacturing feat requires a major shift in philosophy of product design and process technology. This study seeks to identify an omnium-gatherum of unique variables that influence quality and productivity improvement with a view to providing insight into their inter correlations so that by properly tricking on their affinities, desirable quality attributes can be achieved. A novel combination of two statistical techniques, Kendall Coefficient of Concordance and Principal Component Analysis (PCA) - was adopted. The former was used to analyze data matrix generated by thirteen Judges who were requested to rank the sixty one variables in merit order sequentiality upon which basis an index of concordance in ranking among the judges was computed as w = 0.43 and the latter further analyzed the outcomes of the questionnaires crafted with top thirty of the well ordered variables, purposively selected, using statisttiXL software. The results obtained by Kendall Coefficient of Concordance suggested that the functional role of Hatsheck processing machine is outstanding. On the other hand, the result by PCA indicates that significant parsimony was achieved in data reduction from thirty to mere eleven. Further, product series, wielding a factor loading of 0.859, appear to appeal most to customers' preferences. This study has helped to clarify thinking in the productivity of fibre cement roofing sheet and cladding manufacturing world.**

***Keywords—Fibre cement sheet, Foam lamella, omnium-gatherum, Principal Component Analysis, Product integrity.***

## I. INTRODUCTION

Seemly application of innovation and inclusion of Nigeria Local Content policy in the production of fibre cement roofing sheet has remained a daunting challenge in building material sourcing. Introducing indigenous innovation through local content policy compliance will contribute towards reducing production cost and help to nudge the Nigeria economy towards national economic transformation. Four indigenous fibre cement roofing sheet manufacturing firms exist in Nigeria. These firms' import substitution practices appear very unsatisfactory to say the least. This study identified an omnium-gatherum of factors that hamper or enhance productivity in fibre cement roofing sheet production with a view to examining these and bring about improvement in manufacturing process and hence, achieve quality of output as well as material sourcing. The approach of the current study is therefore systematic and knowledge-based.

A body of past studies has addressed roofing sheet manufacturing processes. For instance, Georgian [1]. Studied competitive strategies for securing foothold in the opportunities offered by the fibre cement roofing and cladding material manufacturing in Europe. The result shows that there exists ample opportunity for the company to improve performance in the Bulgarian roofing market. The current study has similar economic interest and therefore would like to identify with their success factor. Also, the potential of using hard wood short fibre as an alternative to the conventional soft wood fibre pulp and synthetic fibre in reinforcing cement based materials has been evaluated. The result revealed that the use of hard wood short fibre brought an improvement in the mechanical strength of the product and also reduced cost of production with respect to energy saving during pulp refining [2]. Moreover, a new methodology for selection of flocculant and dosage administration for optimum performance of the machine and good quality product. With the application of Artificial Neural Networks (ANNs) for the analysis of flocculation data, and the mechanical properties of the final composite, a relationship was established between the mechanical properties of the fibre cement composites and the flocculation process [3].

Furthermore, to improve the strength of the Modules of Rupture (MOR) of fibre cement used two different techniques namely, cause and effect matrix, and failure mode and effect analysis to reduce the number of factors was studied further. The final result showed a process capability index (PCI) improvement. Whereas the study used cause and effect matrix and failure mode and effect analysis to achieve factor reduction, the present study applied Kendall Coefficient of Concordance to rank the factors in merit order sequentiality which enables the selection of top 30 factors out of 61 to be made, thereby achieving factor reductions subject to further analysis [15]. Furthermore, experimental studies on non destructive testing of moisture in cellulose fibre cement sheets in Poland, the result was found useful for determining the moisture content in cellulose fibre cement sheet and detecting defects in them. The result serves as a guide to the regulation of moisture content in fibre cement roofing sheet [4]. Again, Van Der Heyden [5].carried out studies to determine the required specification of raw materials that is best suitable for fibre cement sheet. He found out that raw material producers do not orient their production process towards the fibre cement firms but rather for the larger market that patronizes them. The study was targeted towards two commonly used matrix raw materials namely: cement and condensed silica fume. The result shows that specific requirement of raw material should be satisfied as much as possible in order to assure high quality fibre cement products. It has also been shown that product formation can substantially influence fiber dispersion, quality of performance and cost of production in fiber cement sheet production industries [6]. The research work is relevant to the current study in several ways. Recent studies on fibre cement roofing manufacture include: Fibre Cement Recycling from the Grave back to the Cradle [7]. Coir Fibre Reinforcement and Application in Polymers Composite [8]. An Experimental Study on the Flexural Performance of Agro-waste Cement Composite Boards [9]. Effects of Eucalyptus Pulp Refining and Durability of Fibre Cement Composites [14]. Light-Weight Fibre Cement Cladding Elements, [13]. Others include: A Review of High Volume Low Lime Fly Ash Concrete [10]. Transformation to Fibre Cement from Asbestos Cement [11]. and Exposure Hazard Analysis in Cement Fibre Sheet Manufacturing Industry [12].

It is evidence from the foregoing sample review, that the balance of literature is deficient in the use of gamut of factors to analyze roofing sheets manufacturing dysfunction. A major advantage of PCA approach adopted is that it provides a correlation matrix that relativizes the interplay among the identified factors. More importantly, the statistiXL software employed varimax rotation to achieve factor reduction, and in this context, it reduces the thirty variables to mere eleven variables. Previous to this, the Kendall coefficient of concordance ranked sixty one factors in merit order sequentially on the basis upon which thirty top factors are selected purposively for further analysis. Furthermore, the PCA model adopted shows that product dimensioning in terms of family fibre series proved to be an important concept in fibre cement roofing sheet manufacture. Thus, the aim of this study is to identify a gamut of factors that militate against or promote the production of fibre cement roofing sheet production with a view to understanding the inter correlation among the identified variables in order that the fibre cement roofing sheet manufacturing products in Nigeria can be readily optimized. A sub aim of the study is to introduce innovative practices into the production process with due regard to compliance with Nigeria substitution import strategy (Local content policy).

## II. METHODOLOGY

The research design underpinning this study entails administration of questionnaires crafted with the scale items identified through a wide literature survey. The scale items were administered to thirteen selected judges who ranked them in descending order of importance. The measure of agreement among the judges who ranked the scale items was computed. This measure of agreement is called the Kendall Coefficient of Concordance (W). It represents the degree of concordance, among the selected judges, in ranking the variables in descending order of importance. In other words, it reveals whether the judges were consistent in ranking or not. A test statistics $\chi^2$ called Chi-square was used to validate the index of agreement among the judges. The Chi-square test, moored on a null hypothesis ($H_0$) proposes that the ranking by the 13 judges are discordant while the alternate hypothesis ($H_1$) proposes that the 13 judges were consistent. The null hypothesis was rejected at p-value of 0.05. The respondents' scores were collated into data matrix having a dimension of 143 by 30.

The matrix dimension (143×30) is tall and slim as required. Though the statistiXL software churned out correlation matrix, in theory it was determined as follows. Let X and Y represent a pair of column vector of respondents' scores in a correlation matrix of the 30 fibre cement roofing sheet production. The correlation matrix $r_{jk}$ is given by:

$$r_{jk} = \frac{\Sigma xy}{\sqrt{(\Sigma x^2)(\Sigma y^2)}}$$

(1)

Where, $x = X_{ij} - \overline{X}_{\cdot j}$

$y = Y_{ij} - \overline{Y}_{\cdot j}$

$$\overline{X}_{\cdot j} = \frac{\sum_{i=1}^{N} X_{ij}}{N},$$

$$\overline{Y}_{\cdot j} = \frac{\sum_{i=1}^{N} Y_{ij}}{N},$$

$$N = n_j = I = i_{max}$$

$$J = j_{max}$$

It is instructive to state that the total number of entries in the correlation matrix is, ab initio, determined by:

$$^{n}C_2 = \frac{n!}{(n-2)!2!}$$

$$^{n}C_2 = \frac{30!}{28!2!} = \frac{29 \times 30}{2} = 435$$

The matrix was fed into statistiXL software that generated many outcomes namely: descriptive Statistic, correlation matrix, eigenvalues, eigenvector, unrotated factor loading, case-wise factor scores, varimax rotated factor loadings, explained variance and factor plot, among others. On the basis of this statistiXL output, factor matrix interpretation was rendered and results discussed.

## III. RESULT AND DISCUSSION

### *A. Result of Kendall Coefficient of concordance.*

The result of analysis of data matrix concerning the rating of 13 judges who ranked the 61 variables relating to fibre cement roofing sheet production showed that the index of consistency in ranking is W = 0.43. The $\chi^2$ test statistic used to test the adequacy of W made us reject the null hypothesis of discordance among the judges at a p-value of 0.05. This suggests that if the experiment was replicated 100 times, it is only in less than five occasions shall the result obtained differ.

Kendall coefficient of concordance is given by:

$$W = \frac{S}{\frac{1}{12}K^2(N^3 - N)} \quad (2)$$

$$S = \sum\left(R_j - \frac{\sum R_j}{N}\right)^2 \quad (3)$$

$R_j$ = Colum sum of ranks

N = 61

S = Variance

K = Number of Judges = 13

From factor Ranking Matrix

$\sum R_j = 24449$

$\frac{\sum R_j}{N} = \frac{24449}{61} = 400.80$

$S = \sum\left(R_j - \frac{\sum R_j}{N}\right)^2 = 1373095.64$

Therefore S= 1373095.64

$W = \frac{1373095.64}{\frac{1}{12}13^2(61^3 - 61)} = 0.43$

Also

$\chi^2 = K(N-1)W = 13(61-1)0.43$

$= 335.40$

Since $\chi^2_{cal} = 335.40 > \chi^2_{tab.} = 79.082$, we fail to accept the null hypothesis ($H_0$) and therefore conclude that the judges ranking of the 61 scale items were consistent.

The result of the varimax rotated factor matrix is depicted in Table 1.

In what follows, we present the clustering of variables:

i. Product information

Table 2: Cluster 1 (Factor 1): Product formation

| Variable Number | Variable Description | Factor Loading |
|---|---|---|
| 9 | Flow on process | -0.732 |
| 20 | Sheet compressive strength | -0.700 |
| 25 | Sheet product density | -0.605 |
| 7 | Fibre cement slurry | -0.590 |
| 12 | Slurry Retainability | -0.488 |
| 21 | Cellulose Refining | -0.487 |

This is a lanky principal factor, called Product Formation, having substantial, middling or moderate factor loadings. Within the framework of product formation, getting the preparation of the six variables right may not guarantee the quality of the fibre sheet because there are other conditions and processes that must be met or satisfied. As shown in Table 2, the variables (9, 20, 25, 7, 12, and 21) do not directly lead to good products quality formation, hence their negative factor loadings.

Table 1: Varimax Rotated Factor Loadings matrix of 30 roofing sheet variable

| Variable | Factor 1 | Factor 2 | Factor 3 | Factor 4 | Factor 5 | Factor 6 | Factor 7 | Factor 8 | Factor 9 | Factor 10 | Factor 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Main Production Machine | 0.201 | -0.492 | 0.330 | -0.234 | -0.160 | 0.027 | -0.091 | 0.180 | 0.018 | -0.394 | -0.027 |
| Production Process Stage | -0.232 | -0.039 | 0.013 | -0.732 | -0.136 | -0.177 | -0.026 | -0.148 | -0.179 | -0.030 | 0.241 |
| Production Cost | -0.206 | 0.198 | -0.060 | 0.073 | -0.431 | 0.002 | 0.114 | 0.371 | 0.352 | -0.037 | 0.055 |
| Slurry density | -0.100 | -0.305 | 0.193 | 0.141 | -0.457 | 0.009 | 0.347 | 0.152 | 0.159 | 0.354 | 0.063 |
| Filtration Process | -0.175 | 0.032 | 0.115 | 0.641 | -0.234 | -0.030 | 0.041 | -0.218 | -0.245 | -0.149 | 0.265 |
| Flocculants | -0.124 | 0.028 | 0.830 | 0.034 | 0.116 | 0.063 | 0.063 | 0.048 | -0.113 | -0.058 | -0.099 |
| Fibre Cement Slurry | -0.590 | 0.095 | 0.210 | -0.065 | -0.406 | -0.114 | 0.120 | 0.012 | -0.156 | 0.218 | -0.095 |
| Anti foam | 0.020 | 0.097 | 0.494 | 0.053 | -0.088 | -0.444 | -0.160 | -0.074 | 0.209 | -0.305 | 0.235 |
| Flow on process | -0.732 | 0.051 | 0.046 | -0.101 | -0.235 | 0.046 | -0.066 | -0.060 | 0.080 | 0.012 | -0.135 |
| Thickness | 0.100 | 0.054 | 0.007 | 0.039 | 0.172 | -0.046 | 0.781 | 0.047 | -0.022 | -0.015 | 0.082 |
| Composite Concentration | -0.246 | 0.070 | -0.061 | -0.184 | -0.677 | 0.088 | -0.273 | 0.094 | -0.036 | -0.004 | 0.170 |
| Slurry Retainability | -0.488 | 0.321 | 0.195 | -0.037 | -0.354 | 0.336 | -0.183 | 0.036 | 0.149 | 0.054 | 0.044 |
| Portland Cement | 0.059 | 0.089 | 0.041 | -0.018 | -0.105 | -0.037 | 0.069 | 0.814 | 0.059 | 0.034 | 0.096 |
| Slurry Viscosity | -0.203 | 0.126 | -0.060 | 0.085 | -0.599 | -0.424 | -0.105 | 0.054 | -0.178 | -0.067 | 0.145 |
| Composite Optimization | -0.130 | -0.033 | -0.038 | 0.033 | -0.766 | -0.095 | 0.074 | 0.014 | 0.145 | 0.048 | -0.237 |
| Thickness Control | -0.013 | 0.049 | -0.051 | -0.002 | 0.018 | 0.099 | 0.077 | 0.074 | 0.042 | 0.004 | 0.844 |
| Dimensioning | -0.029 | 0.042 | 0.090 | 0.082 | 0.062 | -0.024 | 0.083 | -0.048 | 0.089 | -0.859 | 0.041 |
| Settled process $H_20$ | -0.109 | 0.694 | 0.308 | 0.106 | -0.270 | 0.076 | -0.004 | 0.166 | -0.052 | 0.122 | 0.161 |
| Cement basicity | 0.151 | 0.424 | -0.122 | -0.178 | -0.273 | 0.188 | 0.414 | -0.349 | 0.216 | -0.224 | -0.031 |
| Compressive strength | -0.700 | -0.162 | -0.147 | 0.132 | 0.082 | -0.244 | 0.030 | 0.174 | -0.044 | -0.137 | 0.123 |
| Cellulose Refining | -0.487 | -0.277 | 0.105 | -0.321 | -0.140 | -0.050 | 0.017 | -0.113 | 0.023 | -0.004 | -0.370 |
| Raw Material Yield | 0.025 | 0.626 | -0.016 | -0.063 | 0.051 | -0.059 | 0.039 | 0.116 | 0.106 | -0.159 | -0.007 |
| Waste product Recycle | 0.069 | 0.468 | -0.228 | 0.213 | 0.051 | -0.376 | 0.119 | -0.194 | 0.389 | 0.099 | 0.168 |
| $H_20$ Content | -0.188 | 0.061 | 0.002 | -0.172 | -0.124 | -0.736 | 0.107 | 0.080 | 0.084 | 0.011 | -0.107 |
| Sheet product Density | -0.605 | 0.023 | 0.078 | 0.051 | -0.444 | -0.155 | -0.097 | -0.181 | 0.176 | 0.058 | 0.033 |
| Curing | -0.126 | 0.075 | -0.074 | -0.026 | -0.050 | -0.032 | -0.006 | 0.102 | 0.801 | -0.145 | 0.014 |
| Demoulding of sheets | 0.186 | 0.337 | -0.010 | -0.101 | 0.024 | -0.229 | 0.161 | 0.150 | 0.063 | -0.274 | 0.515 |
| Production Rejects | 0.190 | -0.080 | 0.346 | 0.010 | -0.157 | -0.173 | 0.023 | -0.117 | 0.482 | 0.211 | 0.439 |
| Wet waste | -0.305 | 0.318 | 0.023 | -0.006 | -0.199 | -0.125 | 0.459 | 0.176 | 0.060 | -0.114 | 0.133 |
| Fibre cement Products | 0.341 | 0.488 | 0.064 | 0.176 | -0.150 | -0.254 | 0.294 | -0.148 | -0.166 | 0.062 | 0.195 |

Further, Flow on Process was trumped by PCA as the most important step in product formation. It wields a factor loading of -0.732. If this process is well regulated there will not be oversupply or undersupply of slurry onto the vat.

Next in importance is Sheet Compressive Strength. It represents the ability of the sheet to withstand load. This strength is determined after fibre cement sheet curing. Sheet Product Density wields a factor loading of -0.605. The forming drum presses the green sheet against the main drive roller. The strength and homogeneity of the final product is affected by this pressing.

Another important step in the product formation is Fibre Cement Slurry. It wields a factor loading of -0.590, thus indicating its relevance in the product formation process. It represents the stage after all necessary raw materials had been properly mixed. Again, another vital stage is the draining of water from the vat. It is required that only water should pass the sieve so that the integrity of the slurry is maintained. This process in product formation Slurry Retainability wields a factor loading of -0.488.

The last variable in Product Formation Factor is the Cellulose Refining. It shows a factor loading of -0.487. The process is referred to as pulping involving grinding of cellulose, sieving the ground material and then mixing with water. Finally the composition is refined by another process of grinding. The mixture at this time is transferred to a tank (refine tank). From this tank, the flow to the mixer is regulated via a valve.

All this represent the first stage of fibre sheet manufacturing process. It is instructive to note that the PCA has naturally ordered the stages of product formation.

ii. Productivity Management.

Table 3: Cluster 2 (Factor 2): Productivity Management

| Variable Number | Variable Description | Factor Loading |
|---|---|---|
| 18 | Settled process water | 0.694 |
| 22 | Raw material yield | 0.626 |
| 1 | Main production machine | -0.492 |
| 30 | Fibre Cement products | 0.488 |
| 23 | Waste product recycle | 0.468 |
| 19 | Cement Basicity | 0.424 |

The factor, creatively labeled Productivity Management, is bipolar in the sense that it is a combination of both positive and negative variables (scale items).

It should be noted that the main production machine does not in itself and by itself directly manage productivity; rather it can be well managed through regular Preventive Maintenance Policy (PMP) to achieve productivity, hence the negative factor loading.

The first scale item in the cluster is settled Process Water, which has a factor loading of 0.694. It is the highest loading in the platoon and hence the most important process. The process water contains a solution of raw material composite that can be recycled to achieve greater yield. The content of the recycled water enhances the richness of the next batch of production just as recycled steam enhances the temperature of boiler feed water thereby increasing heating efficiency.

Scale item 22 (Raw Material Yield) exerts a factor loading of 0.626 which represents substantial loading. It denotes optimization of slurry composition. If the slurry is seemly utilized, the expected product output would be high.

Again, Fibre Cement Products has nearly middling factor loading signifying that the final product quality would determine its suitability for use. Also, another middling loading is found in scale item 23, named Wet-Waste Recycle. It is akin to what is termed waste to wealth through recycling instead of throwing such away.

The last scale item is cement basicity which exercises a factor loading of 0.424. It has characteristic of binder. If it has appropriate clinker or calcium carbonate content, then the fibre sheet would have good quality and short curing time. Details are shown in Table 3.

In finality we observe that if these production variables are properly managed, productivity of production process will be high.

iii. Suppressant.

Table 4: Cluster 3 (Factor 3): Suppressant

| Variable Number | Variable Description | Factor Loading |
|---|---|---|
| 6 | Flocculants | 0.830 |
| 8 | Anti-Foam | 0.494 |

This biform agents have been creatively labelled Suppressant because, while the first (Flocculants) curtails the formation of colloidal or particulate matter in slurry, the second (antifoam) inhibits the formation of foam in slurry. This defoaming agent agglomerates entrained air bubbles and causes them to disperse by destabilizing the foam lamellas on the surface of the liquid because of its low viscosity.

To a great extent, Flocculants hold a meritorious factor loading of 0.830 which tends to justify its importance in product formation. Again, Anti foam possesses a middling factor loading of 0.494. We see, from Table 4 that the biform factor is sturdy because both have positive factor loading.

iv. Process Line Management

Table 5: Cluster 4 (Factor 4): Process Line Management

| Variable Number | Variable Description | Factor Loading |
|---|---|---|
| 2 | Production Process Stage | -0.732 |
| 5 | Filtration Process | 0.641 |

The dyad cluster deals with production line management. It is a process in fibre cement sheet production through which the products pass until they are fully processed. The first is Production Process Stage in a full gamut of processes needful to form the fibre cement sheet. It has a substantial factor loading of -0.732 as shown in Table 5. Process line management stage in the production process do not directly lead to good product outcome rather it's the management of those stages that lead to better product. Thus, indirect relationship exists between output and the process stage through which they passed. For this reason, process stages are indirectly related to good product outcome. In conclusion, it's not necessarily the various stages through which raw material are processed that lead to good outcome of product but effectiveness of these various process management that assure good outcome of products.

Again, Filtration Process has a significant factor loading of 0.641 as shown in Table 5. In this process, a hollow cylinder, covered with a sieve cloth, rotates in a vat, which is fed with slurry so that the cylinder is constantly submerged to about ¾ of its height. Due to hydrostatic pressure, the slurry tends to flow through the sieve cloth. A thin layer of fibre cement is retained on the sieve, but some water together with fine particles will flow inside the sieve. As long as the water can pass through the sieve, the thickness of sheet layers will increase.

v. Blending cost

Table 6: Cluster 5 (Factor 5): Blending Cost

| Variable Number. | Variable Description | Factor Loading |
|---|---|---|
| 15 | Composite Optimization | - 0.766 |
| 11 | Composite Concentration | -0.677 |
| 14 | Slurry Viscosity | -0.599 |
| 4 | Slurry Density | -0.457 |
| 3 | Production Cost | -0.431 |

Optimization of product mix leads to cost minimization and profit maximization. In that case optimized materials blend lead to cost minimization and hence profit maximization. Indirect relationship exists between materials mix maximization on the one hand and cost minimization on the other, hence the negative factor loading.

Composite optimization with substantial factor loading of -0.766 is important because it ensures right material mix at lower cost. The (PCA) model employed placed it top on the scale because it's the key to achieving productivity. On the other hand, composite concentration shows a factor loading of -0.677 which determines the quantity of each composite in the mix.

Further, slurry viscosity and slurry density are important parameters that contribute significantly to good outcomes. They possess factor loading of -0.599 and -0.457 respectively as shown in Table 6. While slurry viscosity relates to thickness of the slurry and its flow readiness, the slurry density refers to the spatial property of compactness. Again, Production Cost needs to be minimized without compromising quality of outcomes. A trade off or balance therefore needs to be struct between achieving desirable materials blend and cost of production.

vi. Good Finish

Table 7: Cluster 6 (Factor 6): Good Finish

| Variable Number. | Variable Description | Factor Loading |
|---|---|---|
| 24 | Water Content | - 0.736 |

This variable, Water Content, in the final product has to be at lowest level in order to achieve a good finish of the fibre cement sheet. The variable, as shown in Table 7, has a factor loading of – 0.736. It should be noted that the higher the moisture content of the product, the lower the goodness of the finish. There is therefore a kind of inverse relationship, and hence the negative factor loading

vii. Sizing

Table 8: Cluster 7 (Factor7): Sizing

| Variable Number | Variable Description | Factor Loading |
|---|---|---|
| 10 | Thickness | 0.781 |
| 29 | Wet waste | 0.459 |

The dual factors have two variables called Thickness and wet waste. Thickness has a factor loading of 0.78 while wet waste has 0.459 as shown in Table 8. Sizing is an important process in the process line

viii. Binder

Table 9: Cluster 8 (Factor 8): Binder

| Variable Number | Variable Description | Factor Loading |
|---|---|---|
| 13 | Portland Cement | 0.814 |

In the production of fibre cement sheet, the quality of cementitious binder used is crucial to the quality of the final product as well as the cost. The PCA model employed has ranked Portland cement as a meritorious variable with a factor loading of 0.814 as shown in Table 9. This goes to emphasize that manufacturers of fibre cement sheet should pay greater attention to the quality of cement being used for production.

viii. Product Integrity

Table 10: Cluster 9 (Factor 9): Product Integrity

| Variable Number | Variable Description | Factor Loading |
|---|---|---|
| 26 | Curing | 0.801 |
| 28 | Production Rejects | 0.482 |

This cluster, Product Intensity, refers to the state of wholeness, soundness, or flawlessness of the fibre cement sheet. It contains two variables namely Curing and Product Rejects shown in Table 10. The former wield a factor loading of 0.801, illustrating its importance in overall product integrity. Actually, curing has to take place under salubrious condition in order that cracks resulting from staying too long under curing chamber would be obviated. Delaminating is also another cause of defects in the finish product. All this can lead to product rejects which possess a factor loading of 0.482. In effect product integrity is a positive manifestation of good fibre cement sheet quality. It is indeed a quality index.

ix. Product Attributes.

Table 11: Cluster 10 (Factor 10): Product Attributes

| Variable Number | Variable Description | Factor Loading |
|---|---|---|
| 17 | Dimension | - 0.859 |

Dimension has to do with product integrality. It involves predetermination of product sizing done in series. By series it is meant grouping objects to relate linearly by varying successive differences in dimension, form or configuration. This wields a factor loading of – 0.859 as shown in Table 11. The PCA model trumps it as the most important operation of all. Its purpose is to meet customers' specifications. It therefore guides order placement and production planning.

Fibre cement sheets exist in a spectrum of discrete family series from which customers select. The attribute selected by one differs from that of another depending upon taste. Taste therefore depends on individuals and not necessary upon set standards of the product. This illustrates the fact that the particular dimension or sizing does not directly relate to product attributes, rather, it depends on customer specification. Satisfaction is relative to individual customers. It therefore bears no positive correlation to product attributes.

x. Attribute Control

Table 12: Cluster 11(Factor 11): Attribute Control

| Variable Number | Variable Description | Factor Loading |
|---|---|---|
| 16 | Thickness control | 0.844 |
| 27 | Demoulding of sheets | 0.515 |

Attribute Control is a neologism applied to the control of product attributes. The attribute, shown in Table 12, in this context refers to:

(i) Product desirable thickness, and
(ii) Sheet surface roughness homogeneity.

Controlled demoulding ensures smoothness of sheet surface. Thickness control wields a meritorious factor loading of 0.844 showing its importance in product quality control. Overall attribute control is essential in product quality regulation.

## IV. CONCLUSION

The PCA model adopted was successful in achieving parsimony in factor reduction from 30 variables to 11 variables. A substantial parsimony has been achieved in terms of data summarization. The results show that 3 principal factor, namely clusters:1, 2, 3 creatively labeled: Production Formation, Productivity Management and Blending Cost represent the principal factors, and as such represent as essential aspect of Quality Control (QC) that will make the fibre cement roofing sheets meet customers specifications. Thus the PCA model adopted has reshaped worldview and clarified thinking in fibre cement roofing sheet and cladding manufacturing world. This study has been successful in identifying an omnium gatherium of variables that influence fibre cement roofing sheet production and, in addition, provided insight into their merit order sequentiality and the way the variables interplay. This perception is thus know-how, a technology. It can guide manufacturers on the physics of inclusion of local content to roofing sheet production.

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