DEEP-DRAWING PERFORMANCE AND STRUCTURE-PROPERTY RELATIONS OF NIGERIA MILD STEEL

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ABSTRACT

Most inland rolling mills in Nigeria depend on Delta Steel Company (DSC), Aladja, Nigeria for their billets while the wire drawing companies depend on the rolling mills for their rods. The drawn products therefore owe their final properties to the production history of the billets and the drawing operations. Difficulties encountered by wire drawing companies using locally produced rods in deep drawing operations necessitated metallurgical characterisation on the rods. Investigation has revealed that a significant difference exists in the compositional characteristics of the locally produced mild steel rods compared to standard specifications of mild steels for wire drawing applications. The carbon content of the DSC steel is found to be higher than the standard requirements. The ductility was found to be within an acceptable range for mild steel but microstructural analysis revealed decarburization and grain growth during process annealing. Softening of products (wires and nails) was also observed and Brinell hardness number (BHN) was about 56.9% of the standard specification for 0.30% mild steel.

Keywords: Mild Steel, deep-drawing, failure, carbon content, annealing.

INTRODUCTION

Wire drawing industries in Nigeria have experienced increased demand on their products as a result of the difficulty in importing finished wire products under the present poor economic conditions in Nigeria. Wire rods form the raw materials for the wire industries and can either be sourced locally from the inland steel rolling mills or imported. Importation is made difficult by the huge foreign exchange requirements and also by government legislation. The situation encourages the use of the locally available rods produced by the inland steel rolling mills using billets from DSC, Aladja, Nigeria.

Most wire drawing companies in Nigeria utilizing locally produced rods experience premature failure during the drawing operations. Bending of nails produced locally are also experienced while in use. Experience by the companies shows that imported rods exhibit less tendency to such failure given the same process treatment[1]. The source of premature failure can generally be traced to the kind and quality of the raw material (rod), the efficiency of the drawing operations and the process technology.

Physical defects in the rod will either cause failure in the drawing operation or remain as more minute defects in the wire. Compositional consistency is essential for appropriate tooling and processing of the rod. Acceptable composition of steel for wire drawing includes low carbon SAE Number (1006, 1008, 1010, 1012, 1108 and 1110), medium low carbon SAE Number (1013 to 1022, inclusive) and medium high carbon SAE Number (1025 to 1041, inclusive)[2]. The DSC billets, which form the feed to the rolling mills, are classified as low carbon steel and should therefore satisfy process specifications for mild steel wire drawing operations. Significant differences shoudl therefore not exist between the imported and locally sourced raw materials. However, failure experienced by local wire drawers can be reduced if physical and compositional defects are minimised and appropriate wire drawing technology, human resources and facilities utilized.

It is necessary to establish the source of the breakage experienced in wire drawing and the bending experienced in nails produced from locally available rods. Investigation has been carried out to establish the characteristics of the carbon steel produced locally for use in deep drawing operations. It is hoped that the

parameters (physical and chemical) responsible for the failure can be identified and recommendation for corrections made. These will enable the local industries to maximise the utilization of locally available raw material, minimise waste, be competitive and economically viable.

EXPERIMENTAL PROCEDURE

The wire products used for the experiment were obtained from the Nigerian Wire Industries Limited (NIWIL), Ikeja, Nigeria. The wire rods analysed were produced from billets of DSC, Aladja, Nigeria. Samples were made from rods drawn to various specifications in line with stages encountered in commercial wire production operations.

The wire samples were prepared for physical and mechanical tests including tensile, hardness, and metallographic analyses. Tensile tests were carried out at the facilities of NIWIL while hardness and metallographic tests were conducted at the laboratories of the Obafemi Awolowo University, Ile-Ife, Nigeria. Hardness and tensile values were compared with standard values documented for carbon steels of similar chemical composition. Metallographic analyses were carried out to provide information on the physical characteristics of the rod as well as the heat treatment history/practices of the wire industry.

RESULTS AND DISCUSSION

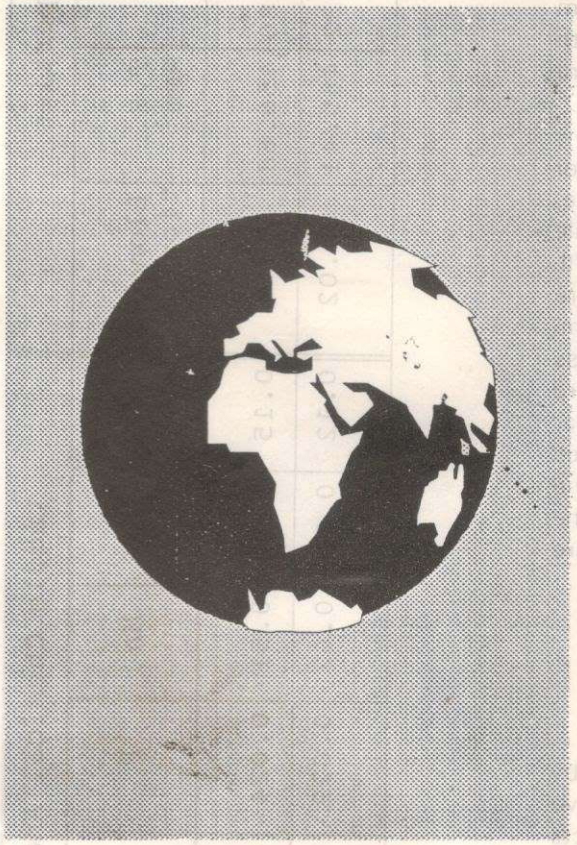
Physical Properties

The certificate of analysis supplied by DSC, Aladja, Nigeria, in respect of F 70x6 gave the following values in table 1 for rolled products ready for dispatch.

Table 1 DSC, Aladja Product Certificate of analysis for F 70x6 steel (1985)

Mechanical Properties					Laddle Chemical Analysis in %						
S/N	Heat No.	Y.S Nmm^{-2}	T.S. Nmm^{-2}	Elonga-tion %	C	Si	Mn	P	S	Cu	N_2
F 70x6	410800	319.80	456.68	36.76	0.15	0.22	0.51	0.024	0.007	0.05	0.004
F 70x6	420638	322.32	455.41	38.02	0.12	0.15	0.62	0.029	0.009	0.08	0.0039

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Reeds

Experimentally determined yield stress (Y.S.) and tensile strength (T.S.) for the 6.00mm rod (as received) were found to be 330Nmm^{-2} respectively. It is of interest to note that the measured value of the yield stress and tensile strength compare favourably with the values determined by the DSC, Aladja (see Table 1). As observed by Sisco (3), the relationship between the carbon content and mechanical properties show that for a 0.15%C mild steel, the yield stress is 220.63Nmm^{-2} and the tensile stength is 372.32Nmm^{-2}.

Figure 1 represents a plot of the increase in tensile strength of plain carbon steel with increasing amount of cold working. Curve A - B representing data collected for wire materials drawn from DSC rods is superimposed on a standard plot for different ranges of carbon content (4). It can be observed that the general shape of curve A - B agrees with the standard plot and falls within the carbon range of 0.30 - 0.60 per cent. Figure 2 also shows the effect of cold working on the ductility of plain carbon steel. Curve X-Y represents data from wire materials drawn from DSC, Aladja rods superimposed on a standard plot (2). The upper limit of the plot represents low carbon steel (% C <0.3) and the lower limit represents high carbon steel (% C >0.3). From Figure 2, the curve X-Y is displaced towards the lower limit, thus suggesting higher carbon contents than obtainable in standard mild steel. Based on the results from Figures 1 and 2, composition sensitive properties were estimated using 0.15%C and 0.3%C of the as - rolled rod. The values obtained together with the measured values are displayed in Table 2.

Table 2: Composition Sensitive Properties of as - rolled plain Carbon Steel

Properties	Measured	DSC (at 0.15% C)	Sisco (1937)	
			0.15%C	0.3%C
Y.S. Nmm^{-2}	330.0	319.80	220.6	303.4
T.S. Nmm^{-2}	466.0	456.68	372.3	496.4
R.A. %	60.8	-	68.0	52.0
BHN	91	-	136	160
Elongation %	27.4	36.76	37.0	29.0
% Pearlite	0.34	-	-	-

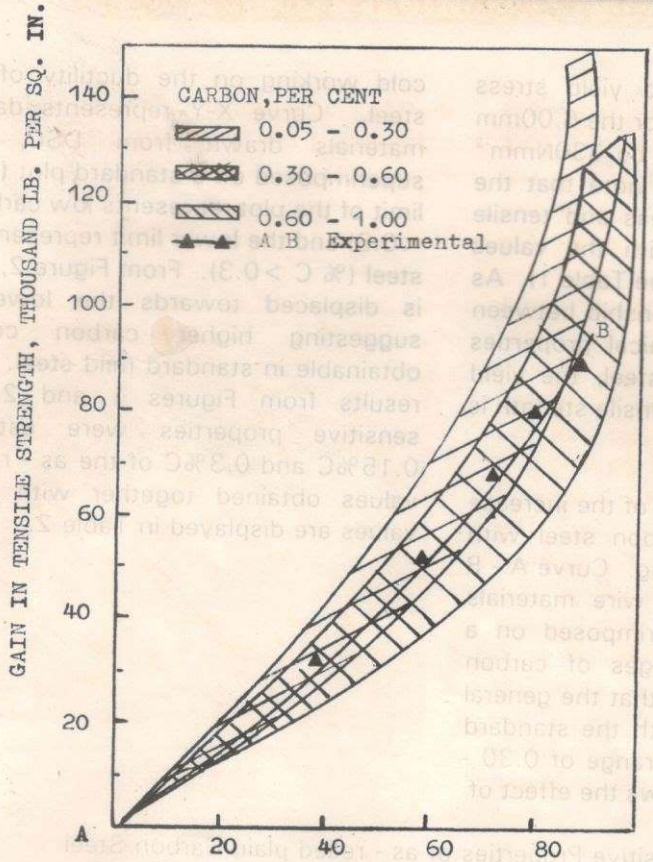


Figure 1: Increase of tensile strength of plain carbon steel with increasing amounts of cold working (From ASM 1977).

Figure 2: Effect of cold working on the ductility of plain carbon steel.

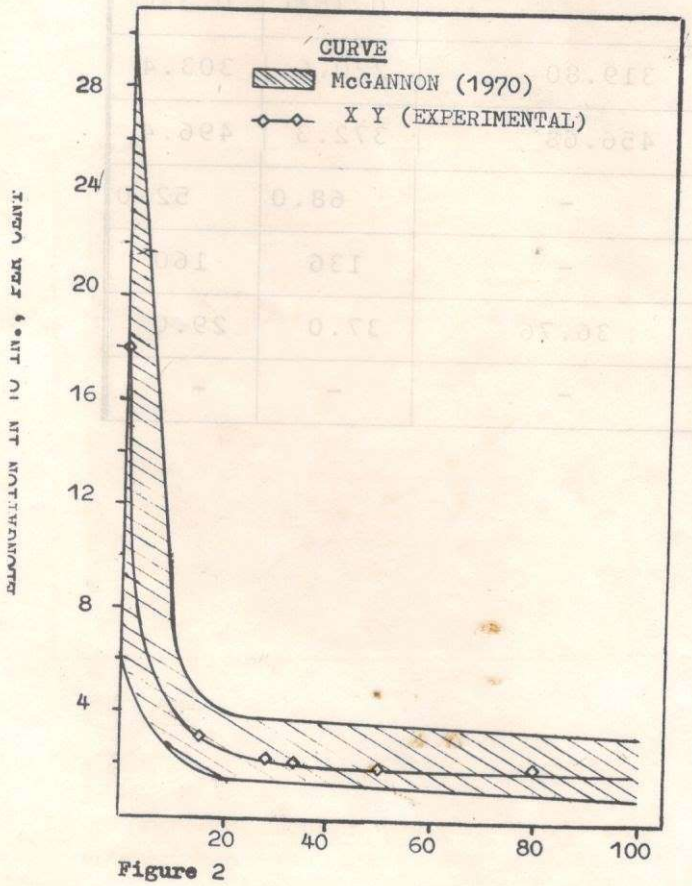


Figure 2

At 0.3%C, the values compare favrouably with the experimental values and those quoted by DSC. However, the percentage elongation given by DSC corresponds to 0.15%C data. It is therefore obvious that the carbon content of the rod produced by the inland rolling mills using DSC billet is about 0.3%C. From Table 2, it can also be observed that the measured hardness value is 56.9% of the literature value at 0.3%C.

The problems encountered by wire drawers with the use of rods obtained from DSC billet have been: (1) premature failure during drafting; (2) softening of the final products (wire or nails). It was decided to investigate the effects of reduction of area and elongation on the product diameter. Figure 3 represents a plot of the reduction of area versus the guage diameter of the drawn products. Process annealing was carried out after each draft at 700°C. Curve A shows that continous drawing from 6.05mm (as-received) rod will result in failure at about 4.2mm. This confirms the report by Ibanga (5) that producers experience failure of the wire rod in the die between 4.0mm and 5.0mm when drawn from 6.0mm gauge. Curve B is obtained by applying one hour process anneal after each draft. It is seen that failure will occur at about

2.5mm. By increasing the annealing time to 4 hours per draft, curve C was obtained. This shows that a gauge of 1.5mm could be attained before failure. Figure 4 is the plot of the percentage elongation at fracture against the gauge diameter. The right-hand portion of the curve shows decreasing elongation with reduction in gauge diameter while the left hand-side shows an increase in elongation with decreasing gauge diameter. The result indicates that at short annealing time (right hand-side) the wire becomes harder with increased drawing and becomes softer at higher annealing time (left hand side) with decrease in wire diameter. The decree in elongation could be attributed to grain refinement and work hardening while the softening occurs due to grain growth and decarburization. It is known that significant grain growth does not occur during process annealing fro 7 hours at 650°C if the carbon content of the steel is between 0.04 - 0.12%. However, large grains persist when the carbon content is above 0.2% (2). The presence of large grains was observed when 4.75mm gauge wire was annealed for 4 hours at 700°C.

MICROSTRUCTURAL PROPERTIES

The microstructure of the as - received wire rod drawn from DSC, Aladja billet is shown in Figure 5. The average grain size of the rod was found to be 23.15 microns and the pearlite volume fraction of 0.34 was obtained using linear analysis method reported by Blank and Gladman (6). The measured pearlite fraction compares with the value of 0.36 calculated at 0.3%C by using the lever rule. At 0.15%C the calculated volume fraction of pearlite is 0.17 which is very low compared to the measured value.

The effect of process annealing on the microstructure of 4.75mm hard drawn wire is shown in Figures 6 and 7. Figure 6 is the hard - drawn wire before annealing. It can be seen that significant grain refinement occurred due to the cold work. The hard - drawn specimen was annealed at 700°C for 4 hours in line with industrical practice. Figure 7 shows two interesting features compared to Figure 6: (1) the presence of extensive grain growth and (2) the near absence of pearlite regions. These results confirm the observed reduction in strength experienced with nail products of shank diameter less than 4.75mm. The near absence of pearlite region indicates decarburization problem. According to Alu (7), the wire drawers over-anneal their materials to avoid failure during the drawing operations. This practice results in softening of the final product and the associated in-use problems.

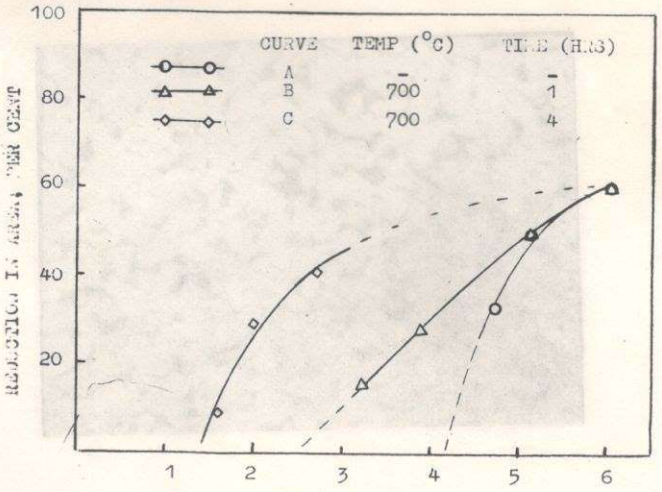


Figure 3: The effect of process annealing on the reduction in area and gauge before failure for F 70x6 steel

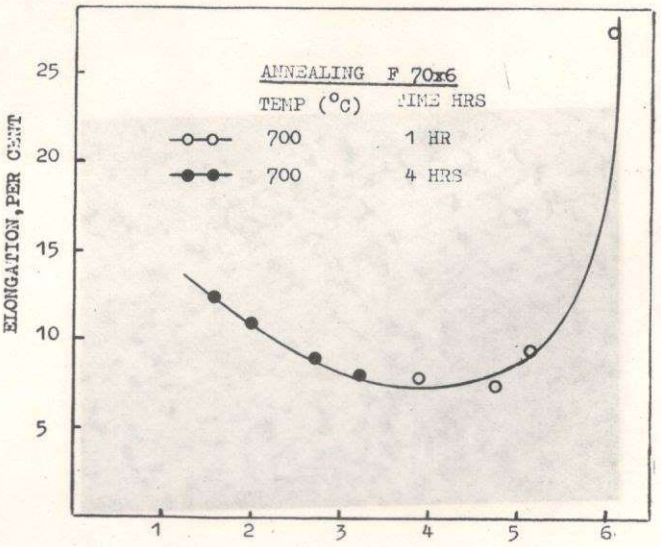


Figure 4: Effect of process annealing on the elongation and gauge diameter.

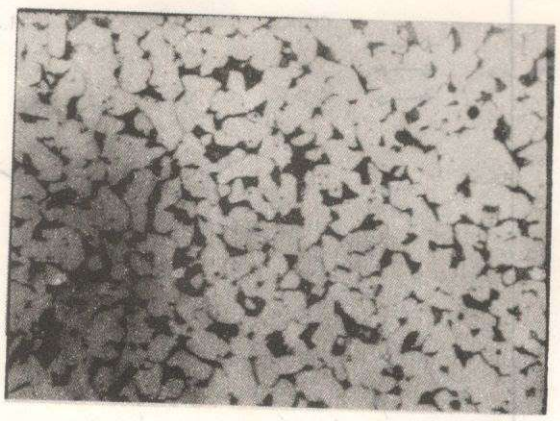


Figure 5: Photomicrograph of as-received 6.05mm diameter wire rod. Magnification: 330X.



Figure 6: Photomicrograph of hard-drawn 4.75mm diameter wire rod. Magnification: 330X.

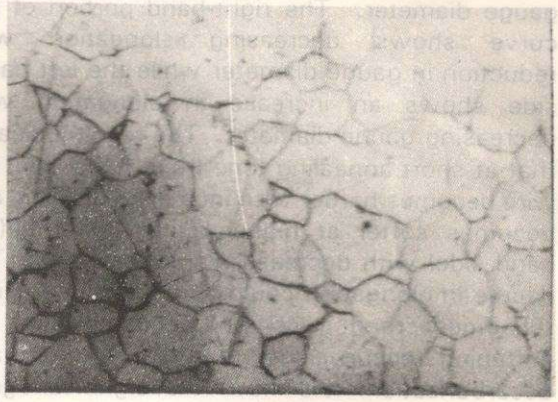


Figure 7: Photomicrograph of annealed 4.75mm diameter wire rod. Magnification: 330X.

CONCLUSIONS

The wire rods produced using DSC, Aladja billets contain about 0.3%C and have an average grain size of 23.15 microns. Using the 6mm rod, premature failure occurs on hard-drawn wires before the gauge of 4.0mm is attained. Process annealing at 700°C for 4 hours enabled the production of rods of about 1.5mm before failure. However, the annealing process gave rise to severe decarburization and grain growth which resulted in the softening of the drawn products. This softening results in the wire failure in the die and the bending of nails due to accelerated loading.

RECOMMENDATIONS

Lower annealing temperature (570-630°C) for 3 hours should be employed to rods produced from DSC, Aladja billets used in wire drawing during process annealing to relieve the stress and prevent excessive grain growth. Atmosphere control in the furnace during the annealing treatment using any of the following fases: nitrogen, coke oven gas, natural gas, propane or butane should be employed.

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methods employed to determine the number of shielding failures. Brown, G.W. [2] found that the number of shielding failures is a function only of the maximum strike distance.

$$N_o = 0.6T_d \text{ strokes/sq-km-yr} \quad [1]$$

where N_o = Number of shielding failures
T_d = Isokeraunic Level

Another method used in the early analysis was AIEE Committee Report [3] which was based on the concept that the lightning stroke current is independent of the terminating impedance which is struck. The relation between factors affecting flashover is given by:

$$I = \frac{V_k}{(1-c)^P} \quad [2]$$

where I = crest-stroke current required to cause sparkover

V = insulation flashover voltage from standard curves for 1.5 x 40 us wave at a specified reference time lag

P = potential from point struck to ground per unit stroke current

Brown [2] also gives the maximum strike distance as:

$$\gamma s \text{ max} = \frac{h + y}{2(1-Sin\theta)} \quad [3]$$

where h = height of earth wire
y = height of phase conductor
θ = shielding angle

A simplified method for estimating lightning performance of transmission lines was prepared by IEEE Working Group [4]. This method follows the following principles to:

(i) Linearise the problems on it can be solved without excessive iterative computation.

(ii) Provide a method based on classical effectts well recognised in the literature.

(iii) Provide a solution that recognises the statical nature of the problem.

(iv) Present the method in the form of a computer algorithm capable of being installed on a large variety of machines.

(v) Be able to adjust this algorithm from year to year as further research permits.

Using the above concept, the number of flashes to any line is provided by

$$N_L = 0.0041^{-1.35} (b + 4\, h^{1.09}) \quad [4]$$

where N_L = Number of lightning flashes to a line per 100Km/year

T = Isokeraunic level in the vicinity of the line (thunderstorm days/yr)

h = Average height of the shield wires, metres

b = The horizontal spacing between the shield wires, metres.

The Improved Electrogeometric Model [1] used by Erikson, adopts the following assumptions:

(i) Inception and upward-interconnecting leaders is determined when the downward lightning approaches to within the attractive radius, R_a of the structure.

(ii) The attractive radius is dependent upon structure geometry (i.e. height above earth, and mast/cylindrical configuration), as well as upon the peak amplitude of return stroke current (based in turn on the premise of a correlation between stroke amplitude and leader charge.

(iii) There is no formal relationship between structure attractive effect and ultimate lightning striking distance to ground. The latter represents a default condition implying that only the downward lightning leader has passed beyond the attractive range of the structure concerned, and is influenced thereafter only by the local topography on the ground (including the effects of trees etc. as appropriate).

(iv) Downward lightning leaders may approach a structure from various angles but once having passed beyond the attractive radius of the structure, do not travel upwards, but continue towards the earth plane.

(v) Shielding failures are more likely to occur remote from the transmission towers; i.e. in those sections of the line which are unshielded by the attractive effects of the tower itself.

(vi) The electrogeometric method of analysis is not intended as an exact emulation of the physical process of lightning strike but rather represents an analogue means whereby the possibilities of shielding failure in a particular transmission line geometry may be analysed.

(vii) Given a transmission line deisgn within which shielding failures are geometrically possible - as determined through the electromagnetic model, the incidence of shielding failures to this line is estimated probabilistically as a current dependent proportion of all the strokes attracted into the vicinity of the line.

(viii) For ease of calculation, the incidence of lightning strikes to the line is estimated using the average attractive radius expressions, but more correctly should be calculated through integration on a stroke-by-stroke basis of the individual current dependent attrative radius contours along the line route.

(ix) Tower footing resistance - Predictions of lightning flashover performance are very sensitive to the choice of tower footing resistance and unfortunately, this non-linear quantity is not often well defined. Footing resistance is usually measured with a ground resistance meter and is the observed low frequency resistance at low currents. For our calculations we will use 10 n as tower footing resistance.

The foundation for Electrogeometric Model Analysis for transmission line shielding was laid by Golde, R.H. [5]. For example, Sharma, C.[6] used the approach of the charge potential for his analysis of T&TEC lines. For the Eriksson method [1,7], the final equation used is:

$$N_s = 0.004\ T_d^{1.25}\ (b + 28H^{0.6}) \quad [5]$$

where

N_s = Lightning strikes to the lines per 100 km/yr

T_d = Isokeraunic Level

H = Structure height (Tower height)

b = Horizontal spacing between shield wires

Perfect Sheilding

In order to achieve perfect shielding, the shield wire should be located at a horizontal displacement X, given by Figure 3. From Table 3 we can see that the existing shielding angle, $_c$ is 68.76°. This shows that the existing shielding is "perfect" or "better", hence theoretically shielding failures are unlikely on this line. But in actual operational circumstances we can see from Table 4 that these are shielding failures.

Conclusion

As can be seen, the tower footing impedance used is 10 n. Using the Eriksson method the existing shielding for the line by two earth wires affords the best results. Expected outage rates for the line are 3.0 per year using Eriksson's method, 2.20 for both AIEE and IEEE methods and 1.0 using Brown's method.

Reduction of the number of outages can be acomplished by determining the tower footing resistance of each tower and making it less or equal to 10 n such that there will be passage for strike to ground easily. Also determination of the Isokeraunic level at almost every sustain will help to reduce the outages. For the perfect shielding, as can be seen from Table 3 our present tower configuration affords better performance as the existing shielding angle is 26.56°.

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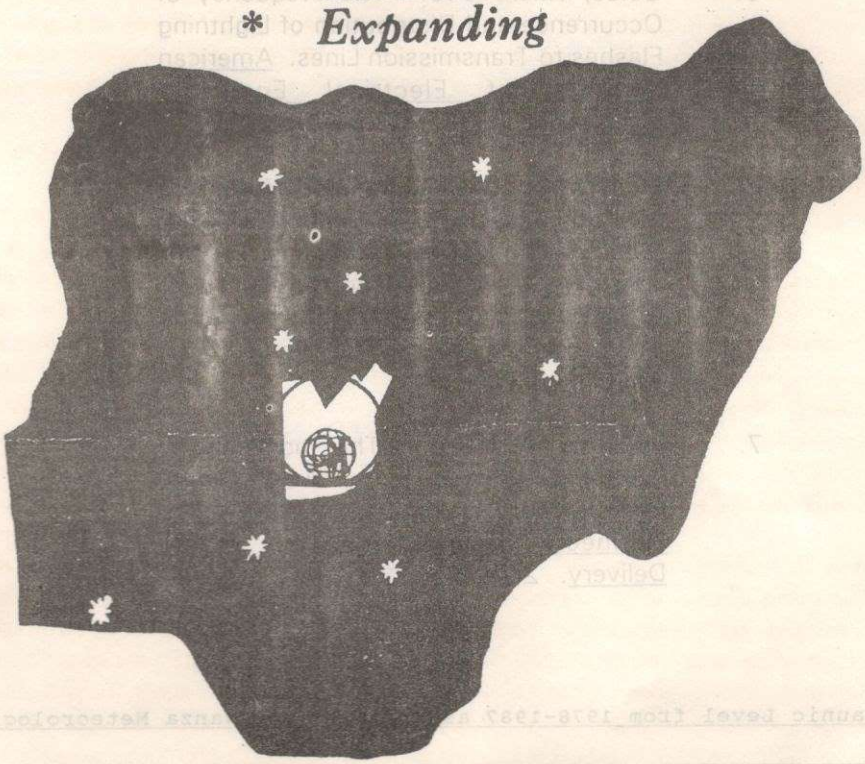
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TABLE 1

The Isokeraunic Level from 1978-1987 as Recorded at Mwanza Meteorological Station

Year	Month												Average
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1978	80	75	73	56	48	39	36	40	37	44	80	83	57.60
1979	73	85	69	50	44	40	41	45	41	47	83	77	57.92
1980	86	79	90	63	48	49	39	40	28	52	79	82	61.25
1981	77	89	81	75	42	40	36	37	39	43	78	76	59.42
1982	87	81	88	69	44	44	42	30	34	48	81	78	60.50
1983	79	83	70	68	50	43	44	38	38	50	88	86	61.42
1984	80	77	83	80	44	41	40	39	37	45	80	81	60.58
1985	81	66	79	69	39	30	46	42	29	49	69	76	56.25
1986	80	89	82	73	44	36	39	44	37	38	82	80	54.33
1987	82	79	81	69	40	44	40	39	40	46	84	77	60.10
													60.00

TABLE 2
INPUT DATA USED IN THE STUDY

PARTICULARS	TOWER VOLTAGE 132 kV
Tower Height (m)	21
Number of Insulators	9
Span (m)	270
Tower Footing Impedance (Ω)	10
Critical Flashover Voltage (kV)	1000
Earth Wire Clearance at Midspan (m)	4.8
Surge Impedance of Phase Conductor (Ω)	350
Shielding Angle (Degrees)	30

TABLE 3

COMPARISON OF EXISTING AND PERFECT SHIELDING ANGLE

Existing Shielding Angle, α_E	Perfect Shielding Angle, α_c
26.56°	68.76°

* This shows that the existing shielding is "perfect" or "better", and therefore shielding failures are unlikely on this line (i.e $I_m \leq I_c$)

TABLE 4

OUTAGE RATES USING DIFFERENT METHODS

132kV, 230km, 2 Earth Wires, Isokeraunic Level 60

METHOD	ESTIMATED OUTAGE RATE PER YEAR
Eriksson [29]	3.0
AIEE [17]	2.23
Brown [24]	1.0
IEEE [19]	2.2

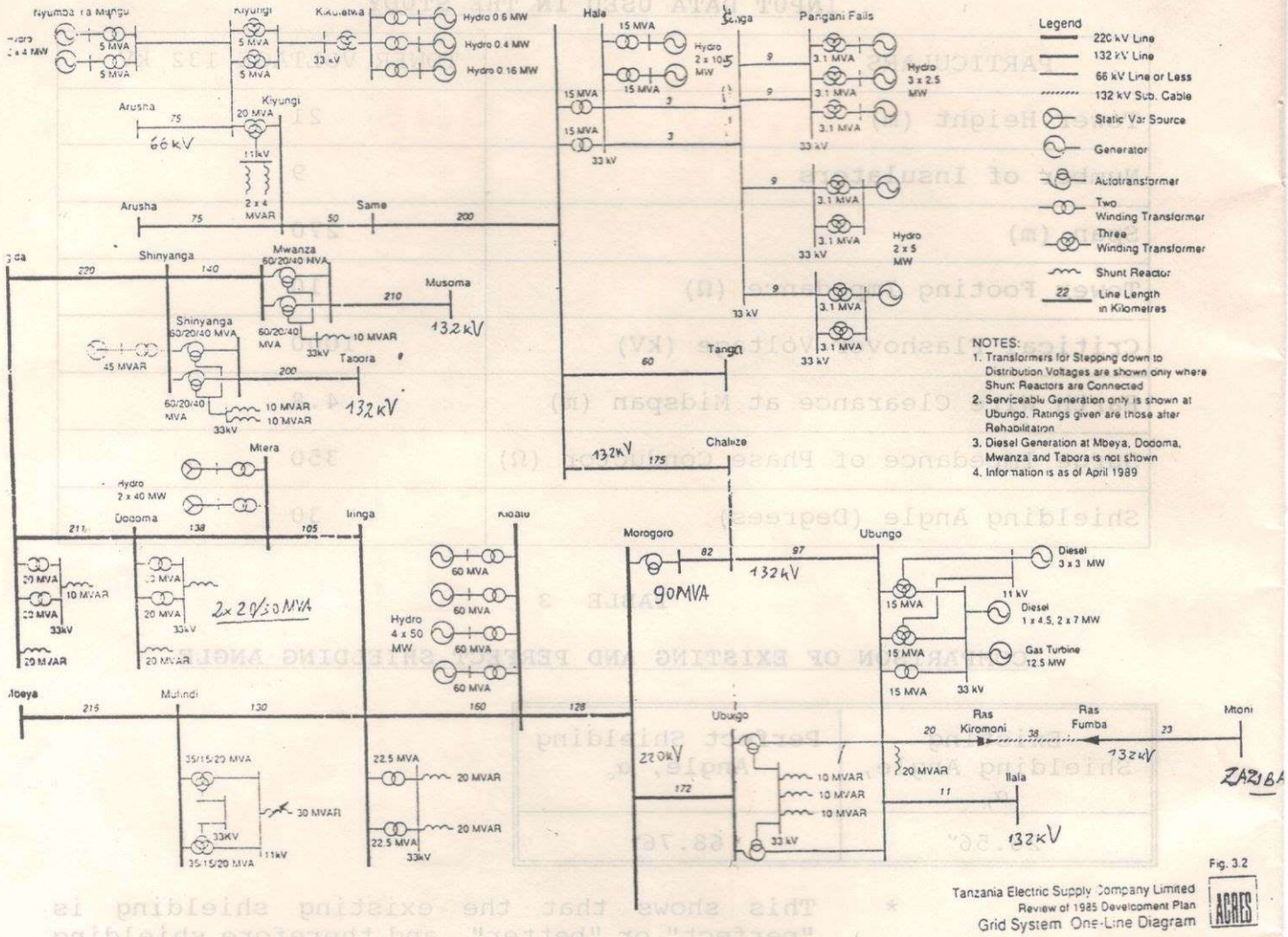


Fig. 3.2

FIGURE 1: GRID SYSTEM ONE-LINE DIAGRAM

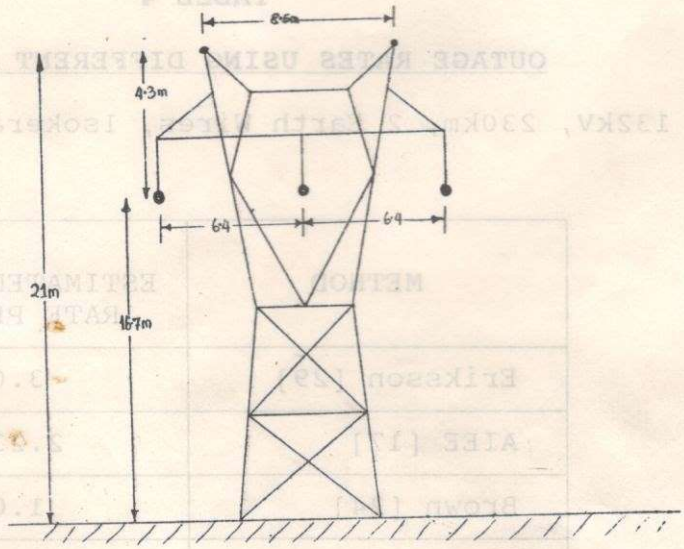


FIGURE 2: TOWER DESIGN

APPENDIX

APPLICATION OF IMPROVED ELECTROGEOMETRIC MODEL [2] FOR DETERMINATION OF INCIDENCE OF STRIKE TO LINES

Eriksson gave the new approach in determining how the strike to the power lines depends upon the tower height and also a function of isokeraunic level.

The average incidence of lightning strikes to lines is estimated by

$$N = 0.004\, T_d^{1.25} (b + 28H^{0.6})$$

where

N Lightning strikes to the lines per 100 km per year

T_d = Isokeraunic level

b = Distance between earth wires (= 0 for single earth wire)

H = Tower height

Data

Isokeraunic Level = 60

Distance between earth wires = 8.5m

Tower height = 21m

$N = 0.004\ (60)^{1.25}(8.5 + 28(21.0^{0.6})) = 1.2$ strikes/100 km/yr

For the length of 230km

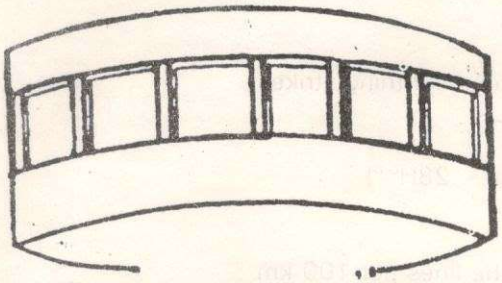
The strikes = 1.2 x 2.3 = 2.8

∴ *The strikes per year for the line* = 3

N.B. If we have a line without earth wire, the value of b = 0 is taken.

calling the Tower,

calling the Tower,"



At FCAA, we make safety of flight operations the condition for a viable and prosperous industry.

Through appropriate licencing, certification procedures as well as constant evaluation of in-flight facility performance, we assure airworthiness of air craft and competence of airmen operating in the country.

We work with aircraft manufacturers and operators to ensure aviation safety, consistent with the standards laid down by the International Civil Aviation Organisation (ICAO).

FCAA is constantly upgrading navigational aids and landing facilities around the country to enhance flight safety with minimum flight disruptions.

At FCAA, we recognise that the survival of the aviation industry depends greatly on strict compliance with laid down safety regulations.

At FCAA, we go the whole way to fulfill our corporate mission of ensuring a safe, orderly and expeditious air navigation system with a view to achieving economic regularity of air transportation within our sovereign airspace.

FCAA
FEDERAL AUTHORITY
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FEDERAL CIVIL AVIATION AUTHORITY

- we guarantee your safety always.

Murtala Muhammed Airport, P. M. B. 21038, Ikeja, Lagos.