Correlation between the thermal performance and the microstructure of the material used in medium and high voltage transformer terminals

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Abstract. In Colombia, energy companies neglect the distribution that represents the main and most valuable process, presenting shortcomings in prevention and forecasting programs, using contractors who perform corrective maintenance of the components without guaranteeing the quality and performance of the materials. Within the process, the terminals determine the effective connection between the voltage line and the transformer, which have faults that are evidenced by the thermal deterioration of the material. In this work, a diagnosis of the thermal performance of these components was carried out and it was correlated with the microstructure, observing variations of the working temperature, with a thermography camera, for three types of terminals, which were classified by X-ray fluorescence in brass Z20, Z40 and Z60, and for two types of connection, copper and aluminium. The microstructure results showed that copper is the conductor that degrades the terminals faster, evidencing cracking of the material; on the other hand, the Z40 brass was the most stable with the lowest temperature variation regardless of the conductor diameter; however, in all cases the behaviour of higher temperature to lower calibre is satisfied.

1. Introduction
The secondary output terminals are electrical devices of distribution transformers, responsible for connecting the transformer to user connections, these terminals suffer wear by meteorological agents that affect their integrity and compromise their operation [1-3], causing power interruptions, generating economic losses for the company [4-5], who must take urgent intervention and compensation measures, on the other hand, there is discomfort in users because it affects daily lives, the food rots or because the services offered remain inoperative [6-7].

The physicochemical deterioration of terminals affects transformer performance, reduction of effective conduction area and increase in resistance due to the oxides formation, common anomalies that cannot be completely stopped, for that reason, to extend the lifetime of these devices and to develop effective strategies to reduce their impact, are problems that the scientific community strives to solve [8-12].

The thermal monitoring of electrical substations is a routine and effective exercise to quickly perform measurements, evaluating the operation of different electrical parts, easily identified by the relative increase of temperature that they present before failure, this increase of temperature accelerates the
processes of degradation that affect in a unlike way to the connections, because they are manufactured in different materials [13-15].

In this paper, the correlation between the deterioration presented in secondary output terminals of distribution transformers for Energy Company from Boyacá, is determined by means of a thermal, of composition and microstructure study.

2. Methodology
Analysis of terminals started with measurement of work temperatures, they were obtained in peak hours, performing 4 replicates using a thermographic camera, collecting the samples showing higher temperature, to which they were made: firstly, composition analysis by X-Ray Fluorescence (XRF) and secondly, analysis of microstructure, on the parts of smaller diameter that suffer greater wear by Joule effect, carefully following the methodologies described in Table 1.

Table 1. Ratio of ASTM standards used in microstructural analysis.

| Analysis                           | Standards ASTM | Analysis | Standards ASTM |
|------------------------------------|----------------|----------|----------------|
| Metallographic preparation         | E 03–01        | Micrographs | E 407–99       |
| Grain size                         | E 112–96       | Inclusions | E 45–97        |

The experimental matrix was constructed based on three factors (Table 2). (a) type of connection, copper base and aluminium base; (b) manufacturing material of terminals, brasses Z20, Z40 and Z60 and (c) calibre of the connectors, thicknesses: 1/0, 2/0 and 4/0.

Table 2. Experimental matrix.

| Connection     | Material of terminals | Connection     | Material of terminals |
|----------------|-----------------------|----------------|-----------------------|
| Copper         | Brass Z20             | Aluminium      | Brass Z40             |
|                | Brass Z40             |                | Brass Z40             |
|                | Brass Z60             |                | Brass Z60             |

3. Results and discussion
The series of terminals used (Figure 1) in physical appearance are of varied materials, to establish the composition of each of them, metallographic and microstructure tests were carried out, including the grain size.

Figure 1. Brass terminals (a) Z20 Al, (b) Z20 Cu (c) Z40 AM (d) Z40 Cu (e) Z60 Al (f) Z60 Cu.

3.1. Composition analysis using FRX
The composition of the samples (Table 3) in the polished inner section (core) was typical of a muntz brass (60-40) and a bearing brass (80-20) with few traces of iron inherent in the manufacturing process. The external section of the unpolished samples, they had chlorine contamination, which affects the integrity of the material, as it forms cuprous and cupric chlorides, generating an unstable blue-green patina, corroding the piece, these salts reacts with the environment to produce hydrochloric acid, modifying the corrosion rate of the base material.
Table 3. Percentage composition of the terminals, obtained by FRX.

| Sample | Section | Composition (%) |
|--------|---------|-----------------|
|        |         | Fe   | Cu | Zn | Cl |
| Z40    | Core    | 0.38 | 59.2 | 40.4 | - |
| Z20    | Core    | 0.68 | 79.6 | 20.0 | - |
| Z20    | External| 0.50 | 39.2 | 56.3 | 4.10 |
| Z60    | External| 0.78 | 0.6  | 0.10 | 98.5 |

3.2. Counting inclusions
The micrographs of Figure 2, show that material of analysed pieces is homogeneous, with no evidence of inclusions. During scanning, cracks were observed in the Z60-Cu and Z60-Al, (Figure 3(a)) samples, possibly due to residual stresses confined within material generated by sudden temperature changes, a pore is also observed (Figure 3(b)), as a result from process of solidification, which is common in melt-formed pieces.

![Figure 2](image)

Figure 2. Micrographs (a) Z20 Al, (b) Z20 Cu (c) Z40 AM (d) Z40 Cu (e) Z60 Al (f) Z60 Cu.

![Figure 3](image)

Figure 3. (a) cracks present in sample Z60 (b) pore present in sample Z60-Copper.

3.3. Determination of grain size
Figure 4(a) shows the typical microstructure of a brass moulded in sand, where it is observed a single-phase present due to the Zn content, the black spots correspond to small pores and fissures due to stresses created in the process of cooling. Figure 4(b) shows a change in the grain elongation, which is like obtained in a brass 60-40 of phase β, that when they cooled initiates precipitation of α phase, which has higher concentration of copper. Figure 4(c) presents the regular grain of a brass with low Zn content, its granulometry is 4 sizes, when compared to template. Figure 4(d) shows a microstructure similar to that presented in a Brass 60-40 after being initially subjected to heating to 600°C and then to an abrupt cooling, for this reason, α phase is precipitated and the excess copper is retained, the microstructure also has an elongation of grain which hinders determine its size. Figure 4(e) and (f) show a clear grain growth, such as that found in muntz brass after being subjected to heating to 800°C and later cooled abruptly, this thermal modification favours that the grains evolve to more equiaxial and great forms.

![Figure 4](image)

Figure 4. Grain size–100X. At top of the image the comparison template is displayed (a) Z60–Al, (b) Z40–Al, (c) Z20–Al, (d) Z60–Cu, (e) Z40–Cu y (f) Z20–Cu.
3.4. Operating temperature

As a result of operating temperature averages (Figure 5) it was found that the fact of making copper connections to any terminal always has higher operating temperature when compared with aluminium, also it was established that in the two connections the manufacturing material with the highest operating temperatures is the Z60 brass, this fact is more evident in copper connection, as far as the conductor calibre, which is inversely proportional, compared to the operating temperature.

![Figure 5. Average operating temperatures for terminals connected to copper and aluminium.](image)

4. Conclusions

The reduction of the calibre increases the working temperature, which is higher in the copper connections, degrading the material of the terminals more quickly.

The high operating temperature in terminals, such as the one presented in sample Z60, accelerate the degradation processes, increasing the number and size of the cracks, as evidenced in the micrographs taken to this material.

The Z40 brass presented high operating temperatures, however, no significant degradation was found in obtained micrographs, showing that its composition presents a greater thermal stability.

Most terminals that are continuously exposed to sudden changes in temperature since their manufacture, show a weakening in their granulated structure, thus facilitating their deformation continuous and subsequent failure.

References

[1] Salas B Schorr M Carrillo M Zlatev R Stoycheva M Lopez G Vargas L Terrazas G Ocampo G 2012 Air Quality - New Perspective ed G Lopez Badilla, B Valdez and M Schorr, (Croatia: InTech) chapter 13
[2] Cárdenas E García S Fernández F Dzul A 2012 Rev. Fac. Ing. Univ. Antioquia 64 57
[3] Cárdenas C Pardo O Barajas E Santos A 2016 Tecviencia 11(20) 27-33
[4] Davis J 2000 The Effects and Economic Impact of Corrosion Corrosion: Understanding the basics ed Davis & Associates (Ohio: ASTM International) chapter 1 pp 1-17
[5] Cortés E 2013 Andamios 10(21) 345-369
[6] Navas D Ramírez H Echeverry I 2013 Revista Esc. Ing. Antioq. 19 23-31
[7] Gomez V Peña R Hernández C 2012 Inf. y Tec. 23(2) 109-116
[8] Murugan R Ramasamy R 2015 Eng. Fail. Anal 55 182-192
[9] Kusumadevi G Gurumurthy G 2015 J. Elec. Sys. Inf. Tech. 2(2) 172-177
[10] Shayan T Jan T Afzal R Khan A 2015 International Conference Data Mining, Civil and Mechanical Engineering (Balı) (Indonesia: International Institute of Engineers) (http://iieng.org/allproceedings.php/29) pp 49-52
[11] Martin Y Corvo F Castaleda A Valdés González Pérez J Portilla C 2007 Cenic Ciencias Quimicas 38(1) 219-225
[12] Song J Wang L Zibart A Koch C 2012 Metals. 2 450-477
[13] Nazmul A Taib S 2013 App. Therm. Eng. 61(2) 220-227
[14] Mora E, Venegas E 2011 Rev. Met. UTO 30 57-64
[15] Adbin Z Kumar A 2014 Int. J. Elec. Power. Energ. Syst. 3 753-59