# Effect of Flame-Retardant Treatment on the Mechanical Properties of Some Tropical Timbers

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**SYNOPSIS**

Potassium aluminum sulphate, hereafter referred to as alum, was used as a flame-retardant for some African timbers. It was observed that this treatment did not drastically reduce the strength of these timbers. Reasons are adduced to explain this result.

## INTRODUCTION

Since the dawn of civilization, timber has been widely used both structurally and as a decorative material in buildings. Unlike some other traditional building materials, such as concrete and steel, timber will burn if exposed to an igniting source under favourable conditions. It is hardly surprising, therefore, that some considerable energy has been expended in finding the right flame-retardant (FR) formulations for wood and other cellulosics.[1-4]

In a recent paper, we have shown[5] that alum functions as a FR for some tropical timbers. It has also been reported[6] that in certain circumstances treatment with flame-suppressant formulations can reduce the strength of some species of solid timber.

In this article, some tropical timbers were impregnated with alum and the effect of this on the mechanical properties was examined. The same timbers,[5] viz., *Chlorophora excelsa, Nuclea diderichii, Ceiba pentandra,* and *Terminalia superba,* subsequently to be called by their trade names of iroko, opepe, ceiba, and afara, respectively, were used.

## EXPERIMENTAL

### Materials

The four timbers, obtained from a local sawmill, have the characteristics shown in Table I. The alum was procured from the Federal Superphosphate Fertilizer plant at Kaduna, Nigeria, and assays as: $Al_2O_3$ (25.5%), Fe (0.0025%), insoluble matter (0.084%), and moisture content (18.47%).

### Method

1. Flame-retardant treatment: The method used is the same as outlined in ref. (5).
2. Moisture regain: Oven-dry treated and untreated wood splints were kept in a constant humidity (71%) chamber at 25°C for 40 d. Moisture regain was calculated as:

$$\text{Moisture regain (\%)} = \frac{\text{Wt after exposure} - \text{Wt of oven-dry sample}}{\text{Wt of oven-dry sample}} \times \frac{100}{1}.$$

3. Measurement of mechanical properties: The INSTRON Table Model 1026, at crosshead speed of 100 mm $min^{-1}$ and chart speed of 200 mm $min^{-1}$, was used to measure the tensional breaking load. Gauge length was 5 cm. Sample width and thickness of about 1.5 and 0.15 cm, respectively, were maintained. In the case of bending load, the Dennison Machine Model No. T4 282, M/C No. 23313, was employed. The sample was held horizontally between two iron bars (gauge length still 5 cm). By means of a metal rod projecting from the machine head, pressure was gradually applied to the centre of the sample until break.

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**Table I**

| Characteristics | Iroko | Opepe | Afara | Ceiba |
|---|---|---|---|---|
| Specific gravity | 0.56 | 0.23 | 0.45 | 0.18 |
| Moisture content (%) | 27.80 | 33.70 | 35.70 | 37.30 |
| Porosity index (% water imbibition) | 36.60 | 49.0 | 29.40 | 68.80 |

## RESULTS AND DISCUSSION

In Figure 1 it is evident that the quantity of alum absorbed by the wood samples depends on the liquor concentration. In the type of system, i.e., polymer solution, the manner of chemisorption is well represented by the Fick's Laws. The first law is:

$$J = D\frac{(\partial C)}{(\partial x)},$$

where $J$ = rate of accumulation of the reagent per unit area of the reference plane oriented normal to the $X$-axis, $D$ = diffusion coefficient, and $C$ = local reagent concentration at a point distance $X$ from the origin of coordinates. A second differential of the first law expression with respect to time is the Fick's second law:

$$\frac{\partial J}{\partial t} = D\frac{\partial^2 C}{\partial x^2},$$

which implies that the rate of accumulation of the reagent of the surface, and hence its penetration into the wood matrix, would essentially be linked to the bath concentration. On the basis of this argument, the observations highlighted in Figure 1 are in accord with theoretical considerations. It is also observed that lighter timbers imbibe more alum than heavier ones. This is hardly surprising as more porous materials, as shown in Table I, are expected to accommodate more of the salt.

For the four timbers, it can be seen from Figure 2 that there are some moderate decreases in the bending load as the quantity of alum in the sample increases, i.e., the sample becomes more embrittled. This effect, however, does not seem to depend directly on the relative amounts of alum; for example, ceiba, which absorbs the highest quantity, is not the most deleteriously affected. It is therefore likely that bending strength losses as a result of alum treatment has to do with the timber species. All that is definite at present is that the greater the density of these timbers the higher the bending strength. In fact, ceiba and opepe, whose oven-dry densities are similar, have very close bending strengths at all alum concentrations.

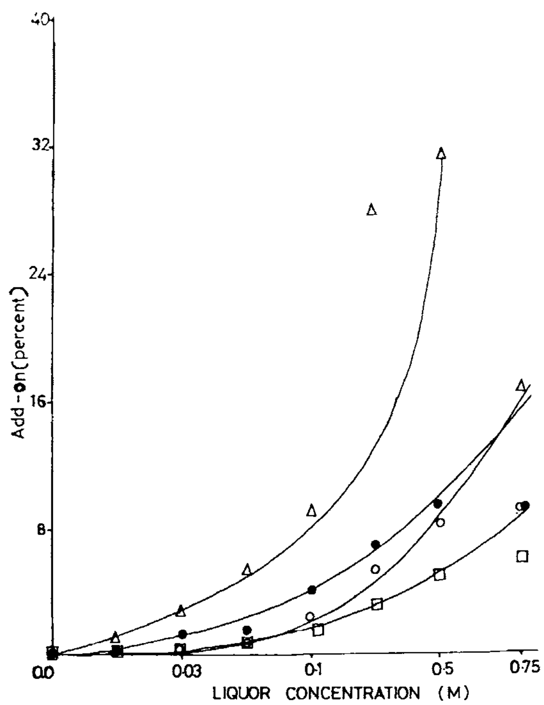


**Figure 1** Effect of liquor concentration on add-on (%) iroko (⊖—⊖—⊖), afara (⊟—⊟—⊟), ceiba (△—△—△), and opepe (●—●—●).

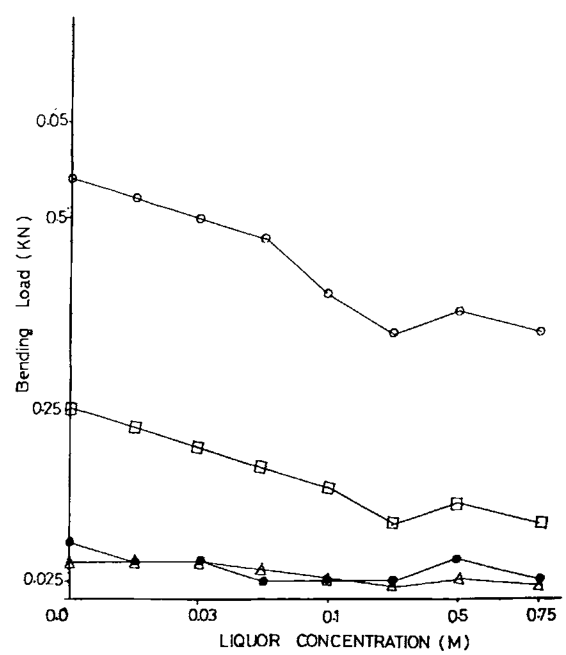


**Figure 2** Effect of FR imbibition on maximum bending load of iroko (⊖—⊖—⊖), afara (⊟—⊟—⊟), ceiba (△—△—△), and opepe (●—●—●).

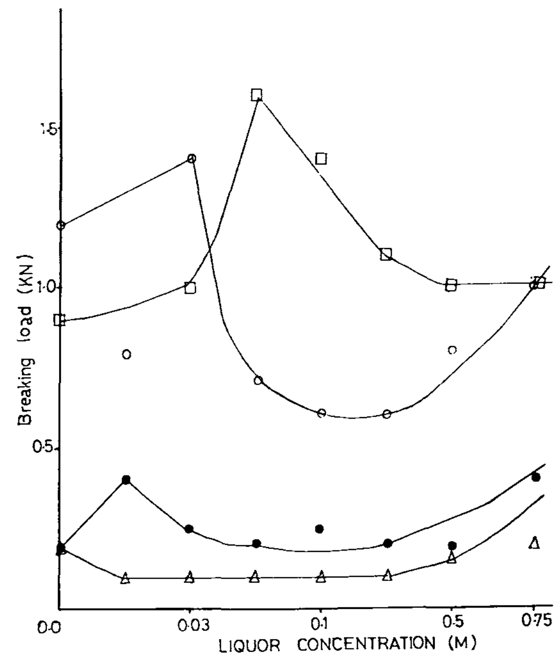


**Figure 3** Effect of FR imbibition on load at break of iroko (⊖—⊖—⊖), afara (⊟—⊟—⊟), ceiba (A—A—A), and opepe (●—●—●).

A rather complex picture is presented in Figure 3. The effectiveness of untreated wood in resisting an applied force is a function of the total cell wall and extractive materials, manifested in the sample density. This perhaps explains the trend in the tensile strengths of the untreated timbers (Fig. 3). Below the fibre saturation point, the strength and elastic characteristics of cellulosics, including wood, vary inversely as the moisture content. This is attributable to the well-explored plasticization phenomenon. Alum is a deliquescent double-salt and is therefore expected to increase the natural moisture absorptivity of wood (Fig. 4), thereby contributing to strength reduction.

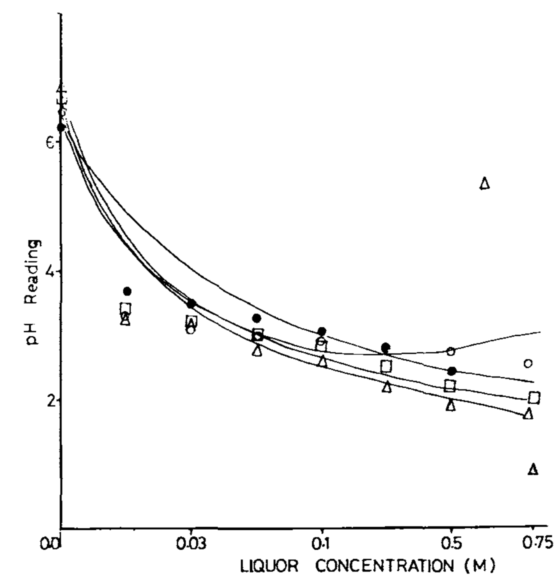


**Figure 4** Effect of FR imbibition on moisture regain of iroko (⊖—⊖—⊖), afara (⊟—⊟—⊟), ceiba (A—A—A), and opepe (●—●—●).

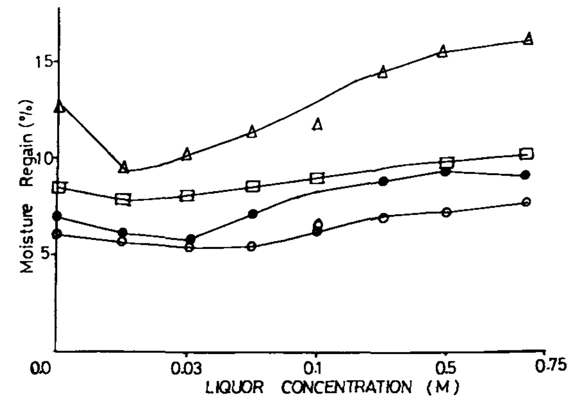


**Figure 5** Effect of concentration on pH of liquor of iroko (⊖—⊖—⊖), afara (⊟—⊟—⊟), ceiba (A—A—A), and opepe (●—●—●).

Other possible contributors to strength losses as a result of innoculating wood with alum could be acid attack and the physical pulling apart (rupture of H-bonds, etc.) of the wood grains. In fact, Figure 5 shows that the pH of the padding liquor decreases as the concentration increases. Also at the cure stage, some quantity of alum decomposes according to the equation:

$$Al_2(SO_4)_3 \cdot K_2SO_4 \cdot 24H_2O = Al_2O_3 + K_2O + 4SO_3 + 24H_2O,$$

thereby yielding the strongly acidic gas, $SO_3$. The observations depicted in Figure 3 indicate that despite all these possibilities the FR treatment of the timbers with alum results in but little losses in tensile strength.

Wood is naturally hygroscopic. Alum is deliquescent. Incorporation of alum into wood is therefore expected to enhance moisture absorption. This is borne out by the results in Figure 4. The sorption of small molecules, including water, by polymers, has been extensively discussed in the literature[7–10] and is now believed to take place by a number of interdependent mechanisms, such as the formation of solid-sorbate solution, dissolution of sorbate in a series of flexible polymer chains (the Florry–Huggins law), attachment of the sorbate onto active centres on the polymer (the Hill–Rowen postulate), and the Brunaur–Emmet–Teller mechanism, whereby there is a polynuclear adsorption on pore walls. It is felt that the trend observed in Figure 5 is due to the water molecules being attached to the cellulose macromolecules by some or all of the mechanisms above, as well as attraction by the alum within the wood interfibre or matrix spaces.

## CONCLUSION

The following conclusions can be drawn from this work:

1. The use of alum as a FR material for these tropical timbers does not drastically reduce the strength of the timbers.
2. On the other hand, moisture regain is appreciably enhanced.

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