EFFECT OF NATURAL KAOLIN ON THE CRACKING OF CORRUGATED PVA FIBRECEMENT SHEETS

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ABSTRACT

The replacement of asbestos fibres with cellulose fibres in corrugated fibre reinforced cement sheets by the Hatschek process resulted in edge cracking in stacked sheets. This is due to the hydrophilic nature of cellulose fibres, which increases its tendency for exchanging water with the surroundings. The drying process of corrugated sheets, in a stack, resulted in shrinkage hence edge cracking along the sheets. To reduce the magnitude of drying shrinkage and edge cracking potential, natural kaolin was proposed as a mitigation strategy.

The results of this study indicated that kaolin acted as an internal restraint for shrinkage, refining the microstructure at the interfacial transition zone thus reducing permeability of the matrix. The findings also showed that kaolin had pozzolanic properties, which resulted in enhancement of mechanical properties of sheets. The inclusion of kaolin in the fibre cement mix formulation in conjunction with control of curing conditions resulted in elimination of edge cracking

KEYWORDS

Edge cracking; kaolin; moisture; fibre cement; drying shrinkage.

INTRODUCTION

Kaolin is a mineral belonging to the group of aluminosilicates. One layer of the mineral consists of an alumina octahedral sheet and a silica tetrahedral sheet that shares a common plane of oxygen atoms, see Fig 1. The repeating layers of the mineral are hydrogen bonded together (Bear, 1965). Due to this strong attraction, these platelets are non-expanding when hydrated. Hence, kaolin is unable to absorb water in the interlayer position. As a consequence of its high molecular stability, it has a low cation exchange capability (Mitchell, 1993). Due to its well packed structure, kaolin particles are not easily broken down and the layers not easily separated. Hence, most sorption activity occurs along the edges and surfaces of the structure (Frost, 1998).

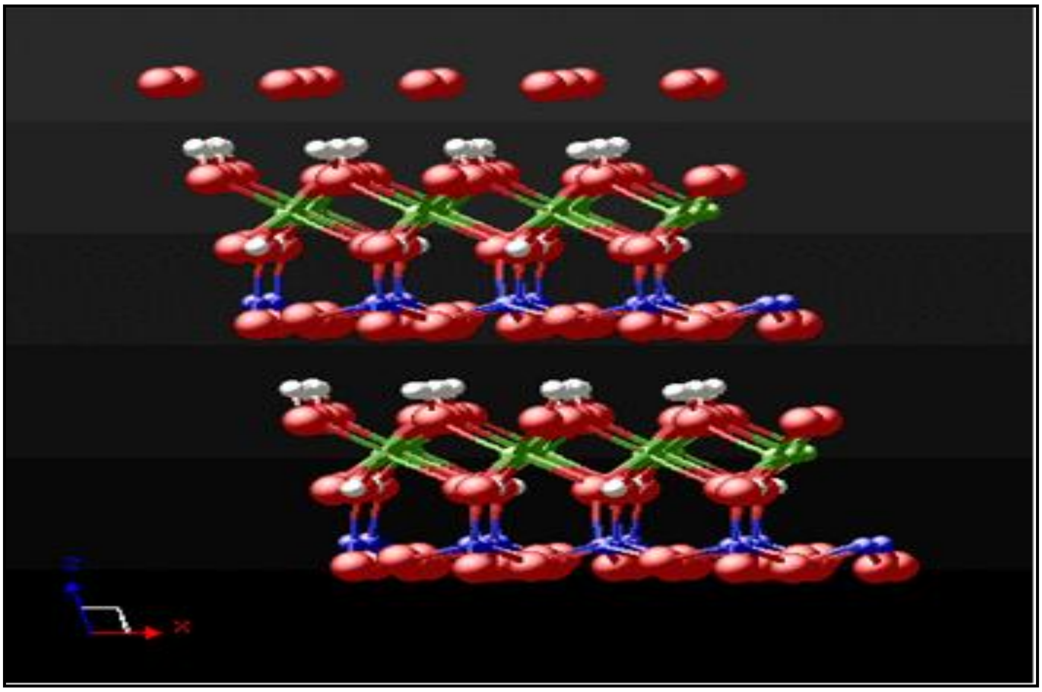

Figure 1: Kaolin structure showing the octahedral and tetrahedral sheets. (The white colour represents hydrogen atoms, red colour for oxygen atoms, green colour for aluminium atoms and blue for silicon atoms).

The chemical composition of kaolin was compared with ASTM C618 for suitability as a pozzolan. The content of silica, ferric oxide and aluminium oxide satisfied the standard for class “N” pozzolans, which is a high quality pozzolan category. Sabir et al. (2001) observed that portlandite (CH) reacts with added pozzolan (S) resulting in additional calcium silicate hydrates (CSH). The pozzolan reacts with calcium hydroxide (CH) liberated by the hydration of C_3S and C_2S of Portland cement expressed as below (Cohen, 1990).

Cement hydration: $2C_3S + 6H_2O \rightarrow 2CSH + 4CH$

$2C_2S + 4H_2O \rightarrow 2CSH + 2CH$

Pozzolanic reaction: $2CH + 2S \rightarrow 2CSH$

Firstly, there is a gradual decrease in the amount of free calcium hydroxide with time and secondly, there is an increase in the formation of CSH and Ca aluminosilicates that are similar to the products of hydration of Portland cement. The beneficial influence of pozzolans in cement matrix is due to a combination of physical and pozzolanic effects (Goldman and Bentur, 1989). The first is a filler effect leading to a reduction in porosity of the transition zone in the fresh concrete and providing the infrastructure needed for a strong transition zone. This potential is materialized by the formation of bonds between the densely packed particles in the transition zone through the pozzolanic reaction.

MATERIALS AND EXPERIMENTAL PROCEDURE

The cellulose unbleached Pine pulp used in this study was obtained from Sappi and had a kappa number ranging between 24 and 32, refined to freeness of 110 CSF. PVA fibres were from Mewlon in Japan, ground calcium carbonate from Syferfontein in South Africa and Condensed Silica Fume from Silicon Technologies in South Africa. For flocculation, two anionic flocculants were blended in a ratio of 60:40; one with 20 – 25 mol% charge density and the other 25 – 30 mol% charge density. Both flocculants had a molecular weight of 10 – 15M Daltons and manufactured by Buckmann Technologies in South Africa. Portland cement was sourced from Afrisam in South Africa and kaolin from Micronized in South Africa. The properties of cement and kaolin are illustrated in table 1 below.

Table 6.1: Physical and chemical properties of kaolin and cement

PROPERTIES	CEMENT	KAOLIN
SiO_2 (%)	22.08	67.5
Al_2O_3 (%)	4.4	24.1
K_2O (%)	0.46	5.38
TiO_2 (%)	0.37	0.89
MgO (%)	1.44	0.43
Na_2O (%)	0.10	0.38
Fe_2O_3 (%)	2.47	0.28
L.O.I (%)	≤ 5	5.93
Surface area (m2/g)	1.99	5 - 20
Color	Grey	Off-white

Fibrecement corrugated sheets, 6mm thick, were made on the Hatschek machine with composition of PVA fibres, refined unbleached cellulose pulp, Portland cement, condensed silica fume, ground limestone and kaolin. These sheets were taken from the machine to a steam chamber for 8 hours at 40 - 50˚C. After pre-curing, the sheets were taken off the steel form plates, stacked in a pile of 40 on wooden pallets. Thereafter, shrink-wrapped with transparent thin plastic and kept indoors for 14 days. The sheets produced without kaolin were labelled standard (STD), partial replacement of cement with 3% kaolin – sheets labelled kao 3 and 5% replacement of cement with kaolin – sheets labelled kao 5.

The sheets were cured under different conditions:

- From the steam chamber and placed outside in the stock yard.
- From the steam chamber kept indoors without wrapping.
- From the steam chamber, shrink-wrapped with plastic and kept indoors for 14 days then placed outside.
- From the steam chamber, shrink-wrapped with plastic and kept indoors for 7 days before external exposure.

- From the steam chamber, shrink-wrapped with plastic for 28 days, indoor curing.
- From the steam chamber, shrink-wrapped with plastic and kept indoors for 14 days then placed outside in the shade.
- From the steam chamber, shrink-wrapped with plastic and kept indoors for 14 days then placed outside with downturns facing the sunrise direction.
- From the steam chamber, shrink-wrapped with plastic and kept indoors for 14 days then placed outside with upturns facing the sunrise direction.

After 14 days curing, the sheets were unwrapped and tested as per ISO 9933 standard. The remaining sheets were wrapped again and tested at 28 days.

RESULTS AND DISCUSSION

Impact of kaolin addition on wet-dry movement of sheets

The finer particles of kaolin improved the particle packing of cement paste, in particular the interfacial transition zone, filled the voids between large cement particles thus reducing permeability. The more dense structure reduced the ingress and egress of moisture in the sheets thereby reducing or preventing drying shrinkage. The results of moisture movement in corrugated sheets are presented in Fig. 2. The sheets with 3% and 5% kaolin as replacement of cement resulted in the movement reduction of 17.2% and 10.5% respectively. The reduction in movement on kaolin modified sheets at 28 days was less than the standard sheets (15.5% for STD, 12.4% for kao 3 and 15% for kao 5). The optimum results were achieved with 3% kaolin mix formulation.

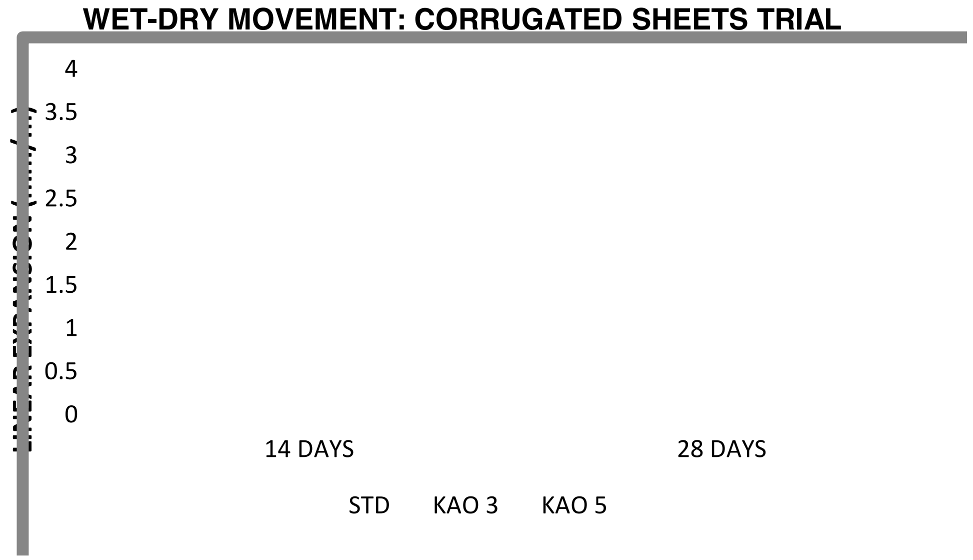

Figure 2: Wet-dry movement of corrugated sheets and the effect of incorporating kaolin as cement replacement over time.

The relationship between moisture and movement was studied in detail and the results are shown in Fig.6 below. The moisture-movement tests were conducted on sheets after 21 days of curing. The moisture content of the sheets, after removal of the plastic wrap, was between 25% and 28% as shown in Fig. 3. Fig. 3 (a) indicated that the rate of moisture loss was slower in kaolin modified sheets than the standard sheets. The refined matrix permitted slow release of water to the surrounding. Both graphs (Figs. 3b and 4) showed that the sheets with 3% kaolin exhibited the least total movement followed by the 5% kaolin inclusion then the standard. The kaolin modified sheets showed less movement than the standard sheets due to the refinement of the microstructure thus reducing permeability. Since porosity was reduced then water within the kaolin modified sheets would be available for further hydration process.

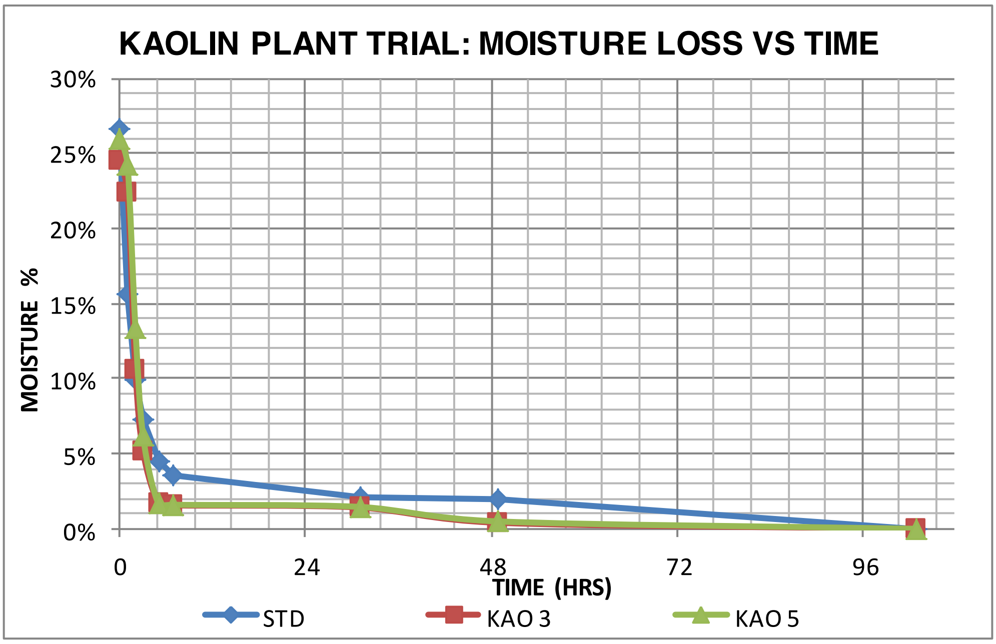

Figure 3(a): Rate of moisture loss for corrugated sheets incorporated with kaolin at various contents.

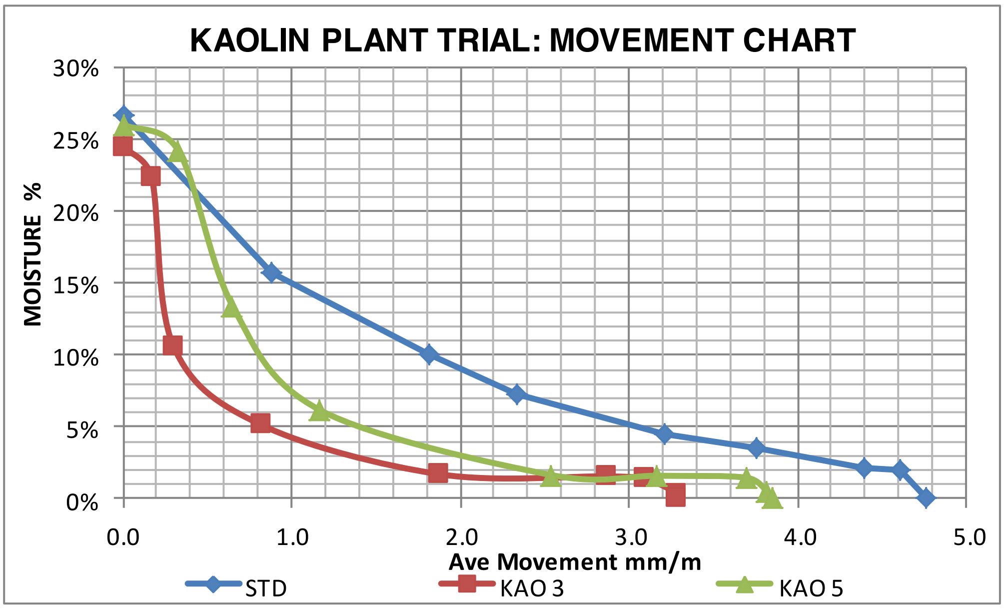

Figure 3 (b): Moisture movement in corrugated sheets incorporated with various levels of kaolin as partial replacement of cement

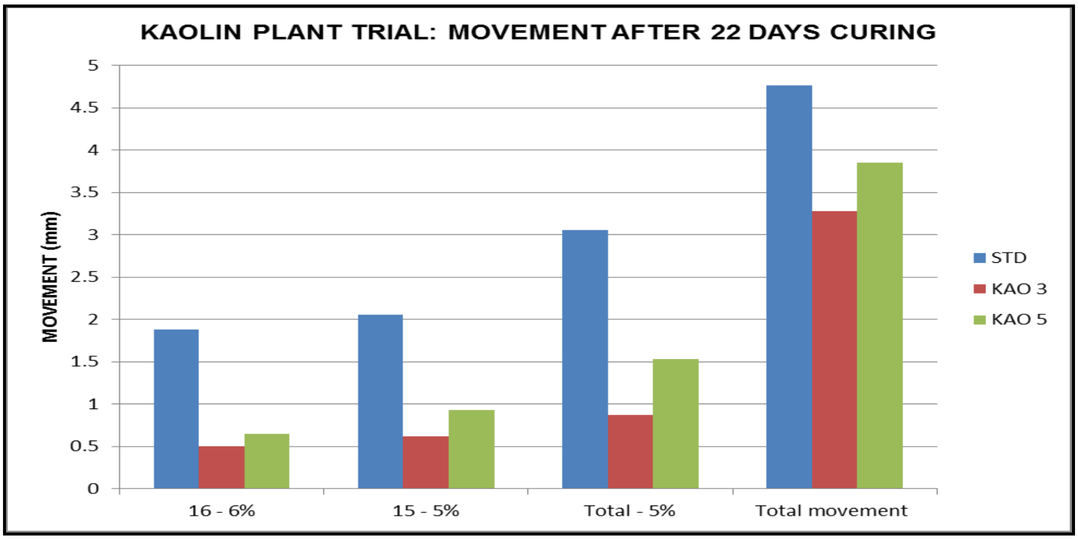

Figure 4: Movement of corrugated sheets at different ranges of moisture and the effect of various levels of kaolin to movement

The results in Fig. 4 demonstrated that the least movement for all mix formulations was attained when the sheets were dried from 16% to 6% moisture. The 3% inclusion of kaolin in the formulation reduced the total movement of sheets by 31% whereas that of 5% kaolin inclusion was only 19% than standard sheets. This implied that when sheets are unwrapped and immediately exposed outside then these sheets will move as shown by total movement. The main factor that contributed to drying shrinkage was not the high moisture content but the rate at which the water evaporated from the sheets. It is therefore important to control the curing process, as will be seen later in the following section.

At 14 days curing, efflorescence was observed on the surfaces of the standard corrugated sheets. This was due to the migration of calcium hydroxide to the surface then reacted with CO_2 in the atmosphere to form a whitish haze, see Figure 5 below. Addition of kaolin to the formulation prevented efflorescence in two ways:

- The calcium hydroxide combines chemically with kaolin and renders the lime unavailable to be leached to the surface by migrating moisture.
- The denser matrix reduces the ingress and egress of moisture in the composite mix. When moisture is prohibited from penetrating then the probability for efflorescence is eliminated.

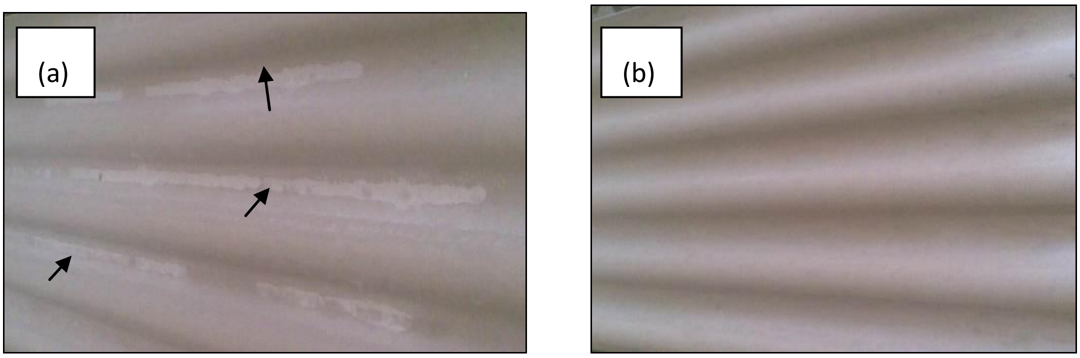

Figure 5: (a) Standard and (b) kaolin modified corrugated sheets

Effect of different curing conditions on cracking of PVA corrugated fibrecement sheets

The least development in density was observed in the sheets that were kept indoors for 7 days prior to external exposure. The results showed a significant increment in density at 28 days for the sheets that cured outside for a longer period. This was as a consequence of CO_2 penetrating the sheets followed by transformation of $Ca(OH)_2$ generating $CaCO_3$. Its formation results in the refinement of the fibre-matrix transition zone thus increasing density. This was in agreement with the findings of Kalbskopf et al. (2002).

The pictures indicated formation of small edge cracks from the sheets that were initially cured indoors with wrapping and, wider cracks were observed in the sheets that were cured outside without wrapping.

Figure 6: Corrugated sheets stored internally, with plastic wrapping, then cured outside without wrapping. Edge cracks appeared after 30 days curing period.

Figure 7: Kaolin modified corrugated sheets cured outside, without plastic wrapping, showed wide edge cracks after 30 days curing.

The moisture movement in all the sheets was measured at 22 days curing. The wrapped sheets resulted in the highest movement as a consequence of the fast drying rate observed in Fig. 8. This was due to wrapping of sheets during curing and as the plastic was removed evaporation took place resulting in the rapid loss in moisture. On the other hand, the sheets that were cured without the wrapping were already air dry and the moisture in the sheets had reached equilibrium with the moisture in the environment. Reduction in moisture from the initial moisture content of the sheet to 5% moisture resulted in movement of 3.57, 4.33 and 4.51 mm/m for indoors, outdoors and wrapped indoors sheet respectively. The sheets that were cured indoors without wrapping did not show any edge or micro cracking.

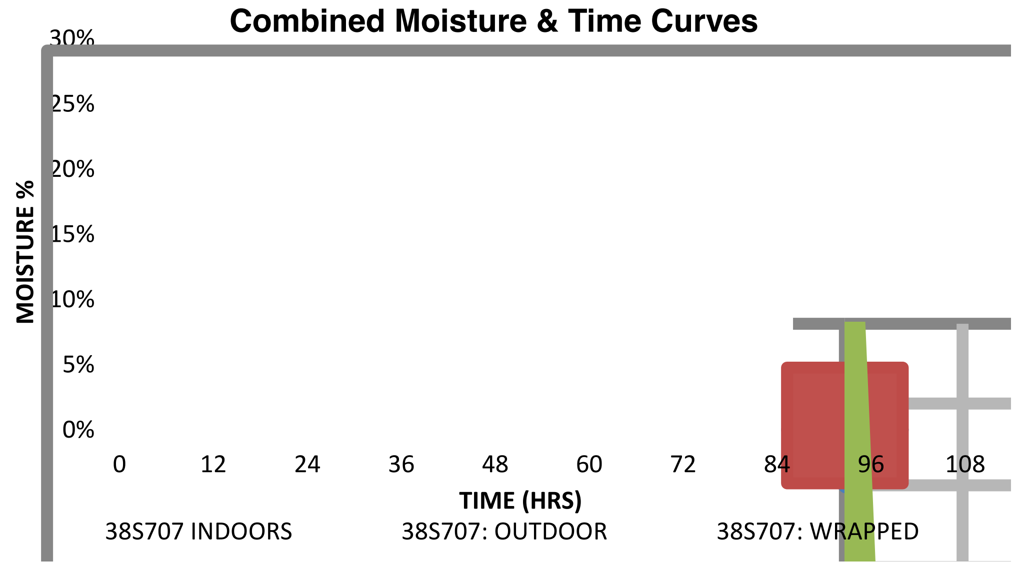

Figure 8: Evaluation of moisture loss with time in the corrugated sheets modified with 3% kaolin, as replacement of cement.

The results showed that the sheets with the upturns orientated in the direction of severe solar radiation were losing moisture at a higher rate than the sheets with downturns facing the same direction and the ones stored indoors. The total movement experienced by the indoors (IND), upturn orientated in direction of solar radiation (UPT), downturn in the direction of solar radiation (DT) and average downturn sheets (AVDT) were 4.65, 5.81, 3.98, 4.59 mm/m respectively, Fig. 9. Reduction of moisture from 16% to 6% resulted in 21%, 8%, 38% and 17% movement for UPT, DT, IND and AVDT respectively.

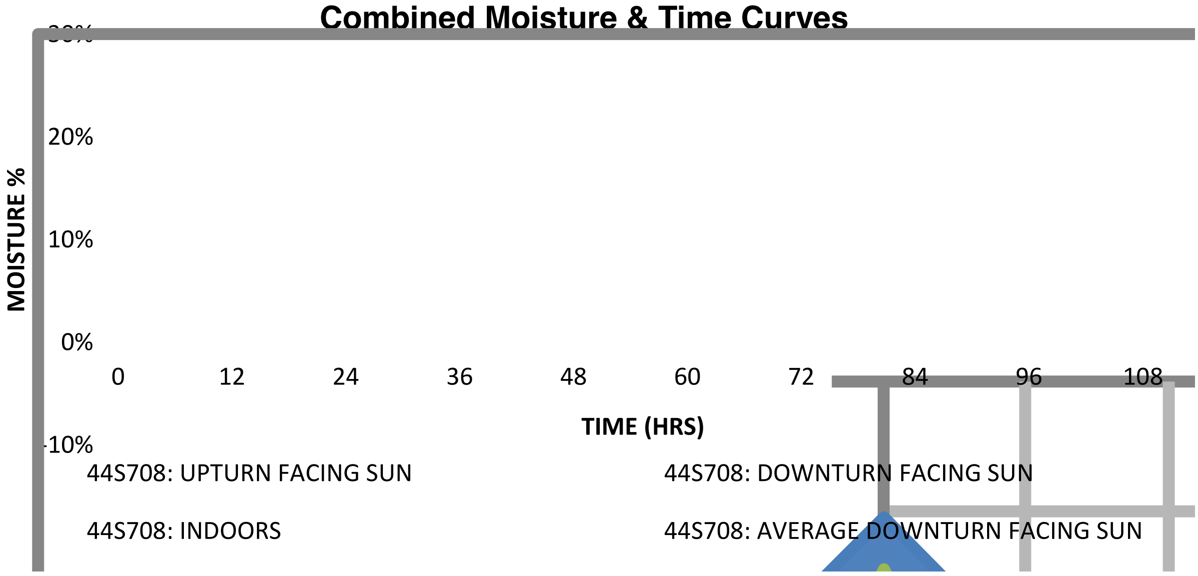

Figure 9: Evaluation of the rate of moisture loss in corrugated sheets under different curing conditions.

Moisture reduction from initial moisture, ~ 30%, to 5% resulted in movement of 74%, 13%, 59% and 28% for UPT, DT, IND and AVDT respectively. The sheets with upturns orientated in the direction of highest incidence of solar radiation exhibited the highest movement as predicted by the results in Fig. 9. The formation of cracks in these sheets can be attributed to the higher rate of evaporation of moisture at these extreme temperatures thus increasing drying shrinkage as a stress-induced edge crack. Also, the upturns exposed the composite fibre endings directly to the sunlight thus accelerated pore water evaporation. The edges dried faster than the center of the sheet in a stack thus resulting in higher moisture gradient and tensile stresses over the edge of the sheet. The least movement was attained by the sheets with downturns in the direction of intense solar radiation.

CONCLUSION

The optimum treatment for minimization of drying shrinkage in stacked corrugated fibrecement sheets was found to be the inclusion of 3% kaolin, as replacement of cement, in the standard mix formulation. These sheets had to be shrink-wrapped to accelerate the hydration process thus enhancing the effectiveness of kaolin hence reducing drying shrinkage.

Cracking of sheets also depended on the rate of moisture evaporation from the sheets. Therefore, this rate was significantly reduced by either storing the sheets in the shaded areas of the stockyard or orientating the down turns of the sheets in the direction of the high incidence of solar radiation.

The best mitigation technique for elimination of edge cracking in stacked corrugated fibrecement sheets was achieved by both modification of mix composition with 3% kaolin (microstructure) and the selection of adequate curing conditions as highlighted above.

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