

# Investigation of the Thermal Conductivity of Ceramic Tiles Processed from Steel Slag (SS).

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## ABSTRACT

This work examined the thermal conductivity of Steel Slag Tiles (SST). Six samples were investigated with SS compositions ranging from 0-100wt%. Thermal conductivity test was conducted following standard procedure. The steady-state heating approach was adopted in conducting the test. It was observed that the thermal conductivity of SST decreased as the composition of SS increased. Sample containing zero wt % SS, recorded the highest thermal conductivity value of  $11.30\text{Wm}^{-1}\text{C}^{-1}$ . It could therefore be concluded that incorporation of SS into ceramic bodies bring about decrease in the thermal conductivity, by extension increasing further the insulation properties of the material.

(Keywords: thermal conductivity, insulation, steady-state, slags)

## INTRODUCTION

Thermal response of materials when exposed to elevated or sub-ambient temperature changes or thermal gradients are very important element in material selection processes. Ordinarily, thermal property is the response of a material to the application of heat [1]. When a solid absorbs energy in the form of heat, its temperature rises and its dimensions increase. The energy may be transported to cooler regions of the specimen if temperature gradient exists, and consequently, the specimen may melt. For practical utilization of solids, heat capacity, thermal expansion and thermal conductivity are critical properties that must be carefully handled. Steel-making industries generate a wide variety of solid waste, that are predominantly composed of slag, powdery materials, scraps and sludges. Most of these wastes are not easily recycled and

constitute a great challenge to the industry [6]. Recently, a good number of research work has been dedicated to slag utilization and the suitability of such products processed using steel-making industry wastes [2,6,8].

Blast furnace slag can be said to have received so much attention and a lot of work abound on its utilization in tile processing [6,8]. SS may be said to be slags produced at steel melting shop during pig iron and steel production [7]. The incorporation of SS into ceramic tile production is not too popular as a result of factors like high iron content of the waste. However study [7] reported that iron content is the major basic difference between blast furnace slag and steel slag. In blast furnace slag, FeO is around 0.5%, whereas, in case of SS, total iron content is much higher. Study [2] blended steel slag with kaolinite clay to produce value added ceramic tiles that could be used as floor and wall tiles. This present study is focused on the examination of the thermal conductivity of ceramic tile bodies processed from this industrial waste considering its high iron composition, since non-metallic materials like tiles are good thermal insulators.

## THERMAL CONDUCTIVITY

Studies [1,3-4] suggested different thermal conductivity mechanisms which include thermal phonon conductivity ( $K_c$ ), radiation conductivity ( $K_r$ ) and electronic conductivity ( $K_e$ ) as shown in equations (1-2).

$Q = -K_{eff} \left( \frac{dT}{dx} \right) \dots (1)$ , where Q=heat flux,  $K_{eff}$  =effective thermal conductivity,  $dT/dx$ =temperature gradient.

$K_{eff} = K_c + K_r \dots (2)$  Study [1] reported that heat is transported in solid materials by both

lattice vibration waves (phonon) and free electrons. Thermal conductivity is associated with each of these mechanisms and the total conductivity is the sum of the two combinations as shown in equation (3).

$K = K_l + K_e \dots (3)$ , where  $K$ =thermal conductivity,  $K_l$ =lattice vibration thermal conductivity,  $K_e$ =electronic thermal conductivity. Both studies [1,3], agreed that usually, one or the other of these mechanisms predominate. Study [4], listed three methods of measuring thermal conductivity as follows (i) two-linear parallel probe method (ii) plane heat source method (iii) hot guarded plate method. He further classified these techniques as steady-state method, non-steady state method and indirect method for the determination of  $K_r$ . The steady state methods usually yield total thermal conductivity ( $K_{eff}$ ) values shown in equations(2-3) and non-steady state approach usually produces thermal diffusivity ( $a_{eff}$ ) values, which can be converted to thermal conductivity using equation (4);  $k = a \cdot c_p \cdot \rho \dots (4)$ .

## MATERIALS AND METHOD

Steel slag tiles (SST) used in study was produced in accordance with the procedure set out in [2]. The chemical composition of the samples as determine in [2] is presented in Tables 1 and 3. Six samples of SST were used with SS variations ranging from 0 -100 wt % as shown in Table 2.

### Thermal Conductivity Experiment

A steady state heating approach was adopted. Figure 1 shows the overall experimental set up used in this work [5]. The Heater was connected in parallel with a voltmeter and in series with the ammeter, and a rheostat. A 12 volts battery was used as the power supply. The final temperature difference obtained after 8hours of steady heating was used in determining the thermal conductivity ( $K$ ) as shown in equation (5)  $K = \frac{VId}{A(T_1 - T_2)} \dots (5)$ , where  $V$ =voltage(volts),  $I$ =current (ampere),  $d$ =thickness of sample(m),  $A$ =cross-sectional area of sample(m<sup>2</sup>),  $T$ =temperature(°C).

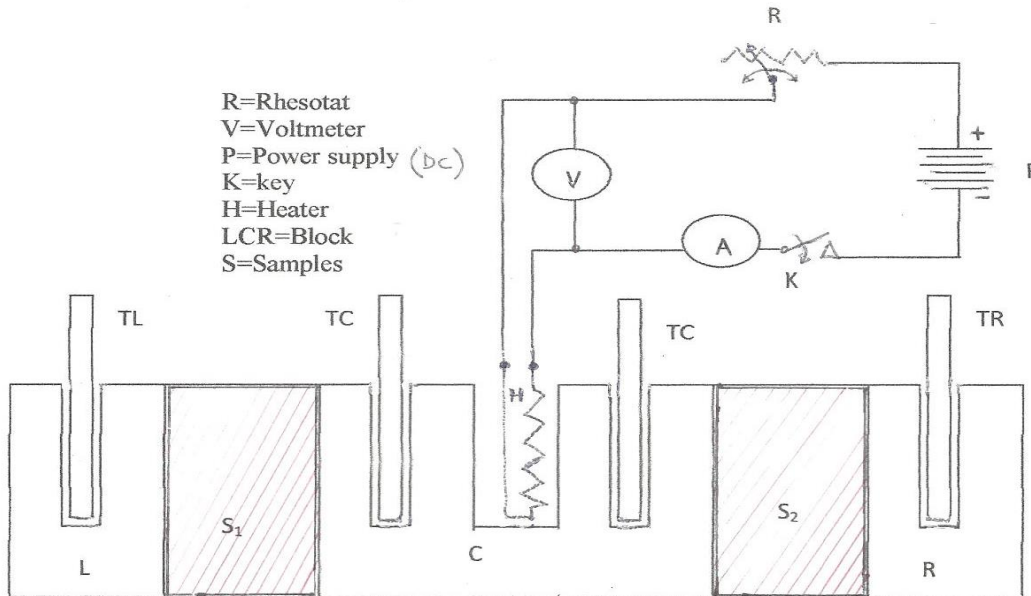


Figure 1: Thermal Conductivity Test Procedure.

## RESULTS AND DISCUSSION

**Table 1:** Chemical Analysis of SS and Clay (wt %)

Oxides	Steel slag	Kaolinite clay
SiO <sub>2</sub>	40.80	48.01
Al <sub>2</sub> O <sub>3</sub>	10.46	31.32
Fe <sub>2</sub> O <sub>3</sub>	2.56	4.78
CaO	31.30	1.21
MgO	12.30	1.45
Na <sub>2</sub> O	0.58	0.98
K <sub>2</sub> O	0.70	0.81
TiO <sub>2</sub>	0.20	0.63
H <sub>2</sub> O (LOI)	1.09	10.82

**Table 2:** Batch Composition (wt %)

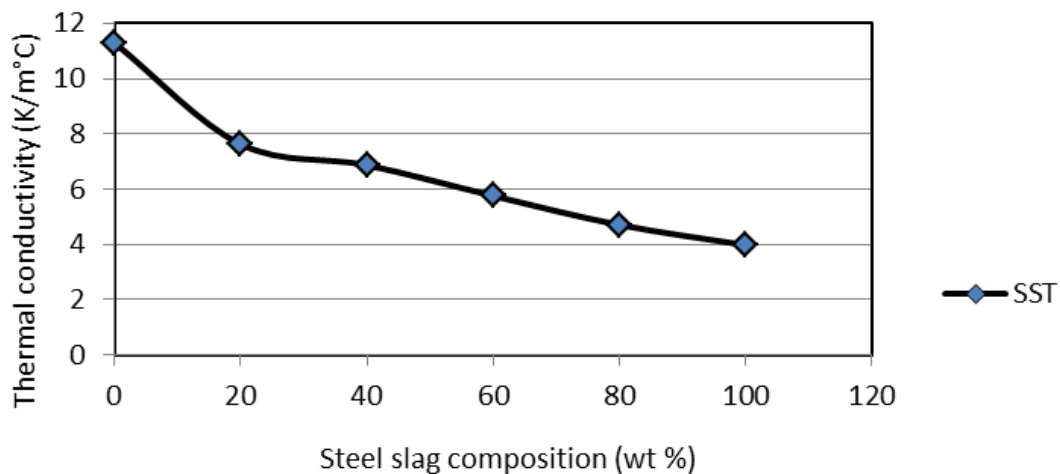
	Sample number					
	1	2	3	4	5	6
Kaolinite	100	80	60	40	20	0
Steel slag	0	20	40	60	80	100

**Table 3:** Calculated Chemical Composition of SS and Clay Mixtures

Oxides	Sample Number					
	1	2	3	4	5	6
SiO <sub>2</sub>	52.81	51.62	49.63	48.05	46.46	44.88
Al <sub>2</sub> O <sub>3</sub>	34.45	29.86	25.27	20.68	16.09	11.50
Fe <sub>2</sub> O <sub>3</sub>	5.25	4.76	4.28	3.79	3.30	2.81
CaO	1.33	7.95	14.57	21.19	27.81	34.43
MgO	1.59	3.98	6.36	8.75	11.19	13.53
Na <sub>2</sub> O	1.07	0.90	0.90	0.81	0.72	0.63
K <sub>2</sub> O	0.89	0.86	0.84	0.82	0.79	0.77
TiO <sub>2</sub>	0.69	0.59	0.50	0.40	0.31	0.22

**Table 4:** Thermal Conductivity (K) of Tested Samples

SS Composition (wt%)	Temperature difference(°C)	K(Wm <sup>-1</sup> °C <sup>-1</sup> )
0	12.5	11.30
20	18.5	7.63
40	20.5	6.87
60	24.5	5.76
80	30.0	4.71
100	35.5	3.98



**Figure 2:** Influence of SS Composition on the Thermal Conductivity of Ceramic Tile.

Table 4 shows the results of the thermal conductivity of SST for the different batch compositions shown in Tables 2 and 3. Table 4 and Figure 2 revealed a progressive decrease in the thermal conductivity as SS compositions increases from 0-100wt %. Sample with zero wt% SS recorded high thermal conductivity of  $11.30 \text{ Wm}^{-1} \text{ }^{\circ}\text{C}^{-1}$ . As the conventional ceramics raw materials are replaced with steel slag (20-100wt%), a decrease in the thermal conductivity was observed.

The reduction in the thermal conductivity could be attributed to the presence of SS in the samples. This is in line with the findings of [3] who reported that thermal conductivity of liquid slags tends to increase with increasing  $\text{SiO}_2$  content. From Table 3, it was observed that as SS replaces the conventional ceramic raw material, a progressive decrease in  $\text{SiO}_2$ ,  $\text{Fe}_2\text{O}_3$ , composition in all the samples investigated was observed. Based on earlier studies [3-4], it is found that thermal conductivity is equally affected by the nature of cations with  $\text{KLi}_2\text{O} > \text{KNa}_2\text{O} > \text{KK}_2\text{O}$ .

Study [3] also observed that transport of phonons is much more difficult for chain-to-chain movement. Thermal conductivity of slag involves the movement of phonons. As a non-metallic material, SS/SST, lack large number of free electrons. Consequently, phonons are primarily responsible for thermal conductivity recorded by the samples investigated. Incidentally, phonons are not very efficient as free electrons in the transport of heat energy as a result of phonon scattering by lattice imperfections [1], thus justifying the thermal conductivity values recorded in this work. However, the thermal conductivity values recorded by the sample investigated, are within the range (2-50W/m-K) suggested by [1].

## CONCLUSION

Simple experiments like the one conducted in this work provided us with a valuable insights into the factors upon which thermal conductivity of SST depend. Thermal conductivity of SST is not very much dependent upon the chemical composition of the slag; since the high iron content of the SS did not negatively affect the insulation potentials of the sample.

From the results obtained in this work, it could be concluded that the incorporation of steel slag into

ceramic tile bodies decreased thermal conductivity.

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