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SUITABILITY OF ELECTRIC ARC FURNACE (EAF) SLAG AS PARTIAL REPLACEMENT FOR CEMENT IN SANDCRETE BLOCKS

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ABSTRACT

The use of Electric Arc Furnace (EAF) Slag which is a by-product solid waste in Steel Production was investigated for use as a partial replacement for cement in sandcrete blocks. The tests carried out on cement and finely ground slag to determine their compositions and physico-chemical properties as well as the evaluation of the results are presented. It was found that the compressive strength of sandcrete blocks ranged from 1.4 - 4.0 N/mm^2 for 50% - 20% replacement of cement with EAF slag respectively whilst that of standard cement block was 4.5 N/mm^2. The result of the study shows the possibility of replacing up to 20% of cement with EAF slag in sandcrete blocks without sacrificing the strength significantly. It is therefore believed that the use of the slag in the construction industry shall bring about some economic benefit and as well mitigate the negative impact of this waste on the environment.

KEY WORDS: EAF Slag, Cement, Block Making, Compressive Strength, Curing times.

INTRODUCTION

Slags are by- product wastes generated in the course of production of steel typically in the ratio of about 1 tonne of slag to 5 tonnes of steel. As shown in Table 1, their types and composition are varied and depend on the method of steel production used. Thus we have Blast Furnace (BF) slag, EAF slag and Cupola slag etc. Finding appropriate application for slag not only offers an economic incentive but also an opportunity to dispose of this high tonnage difficult - to - handle solid waste in line with the concept of steel production and environmental best practice for sustainable development (IISI, 2005).

Table 1: Chemical Compositions of Slags in Steel Production

Compounds	BF Slag$^+$, %	Cupola Slag^{++}, %	EAF Slag *, %
Lime, CaO	36-43	7.6	34.02
Silica, SiO_2	28-36	50.2	19.25
Alumina, Al_2O_3	12-22	24.30	6.40
Iron Oxide, Fe_2O_3	0.31-1.7	15.50	18.69
Magnesia, MgO	4-11	2.14	13.55
Manganese Oxide, MnO	-	-	2.18
Loss on Ignition, LOI	-	-	-
Total Sulphur	1-2	-	-
Others (SO_3, Na_2O,K_2O etc)	-	0.78	5.91

*this work; $^+$Lee (1974); $^{++}$Aderibigbe et al (1982)

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Earlier studies (BSP, 1977; Matyas, 1978) have led to the use of BF slag as bases in road construction and for maintenance and surfacing of the roads. This practice is widespread in Europe and India with large scale BF production. Report from Germany indicates the adoption of basic Oxygen Furnace (BOF) slags for road, track laying and construction of canal (Rellermeyer, 1975). Furthermore BF slag has been successfully employed in the manufacture of cement and glass (Lee, 1974).

Cupola slag was also reported to have partially replaced cement in mortar mix preparation (Aderibigbe et al, 1982. As the technology of producing steel by Electric Arc Furnace method is itself relatively new, work in the area of possible commercial application of EAF slag has not yet been extensive.

However investigation carried out so far has shown a good promise for the use of EAF slag in the building industry. Studying the strength properties of EAF slag, Edoro (1986), found that using coarse EAF slag aggregate in place of river gravel in identical water/cement concrete mixes a higher strength of up to 1.2-1.6 N/mm^2 was obtained in favour of the slag aggregates. Pellingrino (2009), investigated the mechanical and durability characteristics of concrete containing EAF slag aggregate and found that they were satisfactory.

Concerning the workability of the concrete mixes from OPC and EAF slag, the results of earlier studies, (Okpala et al, 1987; Diagbonya, 1987), are shown in Tables 2 and 3. There was a noticeable increase in both the slump and compacting factor values. This was due to the presence of the granulated slag in OPC concrete. The increase noticed is as the result of the presence of fairly high percentage of ferrous oxide (FeO) in the slag. This compound in essence does not absorb much water, thus makes available more mixing water than when cement alone is used. The water non-absorbent nature creates free mixing water that permits higher slump and compacting factor.

Table 2: Mix Proportions for the Designed Strengths of 30N/mm^2 & 40N/mm^2

CURING AGE IN DAYS	DESIGNED STRENGTHS							
	30N/mm^2				40N/mm^2			
	MIX PROPORTION			WATER CEMENT RATIO	MIX PROPORTION			WATER CEMENT RATIO
	Cement	Sand	Coarse Aggregate		Cement	Sand	Coarse Aggregate	
7	1.00	1.76	2.40	0.43	1.00	1.23	1.67	0.33
14	1.00	1.80	2.45	0.45	1.00	1.98	1.67	0.43
21	1.00	1.98	2.76	0.50	1.00	1.76	2.68	0.45
28	1.00	2.49	3.38	0.57	1.00	1.98	2.68	0.46
90	1.00	4.36	5.93	0.66	1.00	2.59	3.51	0.55

Furthermore, the slag used has coarser nature than the fine grained cement. It is presumed that this must have reduced absorption capacity when compared with cement, since absorption rate increases with surface area which in turn increases with fineness of particles. Reduced absorption, for a given quantity attracts increased slump and compacting factor.

From the study, the increase in slump and compacting factor is however minimal and is of the order of 7 to 14 mm for slump values and 2.5 to 4.5% for the compacting factor values. This minimal increase indicates that the rate of absorption of the mixing water by the cement may be slightly higher than that of granulated slag.

Table 3: Comparison of Density and Compressive Strength of Mortar Mixes from EAF Slag and River Sand

Curing Period in Days	SLAG MORTAR		RIVER SAND MORTAR	
	Density Kg/m^3 (x10^3)	Cube Strength N/mm^2	Density Kg/m^3 (x10^3)	Density Kg/m^3 (x10^3)
3	2.090	14.05	2.065	12.05
7	2.094	26.20	2.065	21.65
14	2.095	30.50	2.065	28.25
28	2.100	37.80	2.068	35.60
90	2.103	38.50	2.070	36.10

The object of this paper therefore is to investigate the suitability of EAF slag as a partial replacement for cement in sandcrete blocks which can be of a great economic advantage to the building and construction industry and as well mitigate the adverse effect of dumping the slag in the environmental.

METHODOLOGY

The EAF slag used in this work was ground to fine powder after pieces of metals and refractory materials were removed. The physical and chemical characteristics of the ground slag, sand and Portland cement were determined. Test cubes of size 100 x 100 x 100mm were cast first using cement /sand gravimetric ratio of 1:8 as control. Further, 5 other test cubes with gradual replacement of cement with slag content varying between 10% - 50% were prepared. For each test cube a set of 5 samples was prepared and subjected to varying curing ages ranging from 7 to 56 days. The compressive strengths of the test cubes were determined with Universal Cold Crushing Machine model Netzsch.

Although the normal curing age of concrete is 28 days, the extension in time of 56 days and 90 days (3 months approximately) allowed more observation on further increase in strength of the sample with increasing curing age.

In the similar vein, test cubes were prepared using a volumetric ratio of cementitious materials to sand of 1:6 (equivalent of 1:12 gravimetric ratio). Curing was carried out for this group of test cubes for between 7 and 90 days. Some 2000 blocks were moulded using 30 percent replacement (by volume) as a means of validation of the result of the study.

RESULTS AND DISCUSSION

The physical properties of cement, slag and sand are shown in Tables 4 and 5. Similarly the results of chemical analysis of cement and slag are given in Table 6.

Table 4: Physical Properties of Cement, Slag and Sand

Properties	Cement	Slag	Sand
Bulk Density (g/cc)	1.41	1.65	2.69
Moisture Content (%)	0.16	0.66	0.15

Table 5: Particle Size Distribution for Cement, Slag and Sand

Particle Size (Less than), mm	Cumulative %		
	Cement	Slag	Sand
1.000	100	100	99.55
0.800	100	100	99.05
0.630	99.94	99.93	98.60
0.400	99.94	99.93	97.60
0.315	98.53	99.89	84.25
0.250	72.10	99.89	65.42
0.160	32.43	99.85	37.2
0.125	17.89	93.83	5.8
0.100	10.85	62.03	1.4

From the physical properties of cement, slag and sand as shown in Tables 4 and 5 it is clear that by virtue of higher bulk density of 1.65 g/cc, slag is heavier than cement with the bulk density of 1.41gm/cc. Also it is seen from the grain size distribution, that slag used is finer than cement since for example 62.03 percent of slag passed through 0.100mm sieve size as against 10.85 percent cement which passed through the same sieve size.

Table 6: Chemical Constituents of Cement and Slag

Compound	Weight, %	
	Normal Portland Cement	Slag
Lime	64.01	34.02
Silica	19.63	19.25
Iron Oxide	5.23	18.69
Alumina	2.14	6.40
Magnesia	1.40	13.55
Manganese Oxide	0.50	2.18
LOI	3.17	-
Others (SO_3, Na_2O, K_2O etc)	4.37	5.91

Taking a critical look at the chemical compositions of both the EAF slag and cement as given in Table 6, one observes that they contain the same basic chemical compounds though in different proportions. This probably explains the pozzolanic property of slag when the fine aggregate is exposed to the atmosphere.

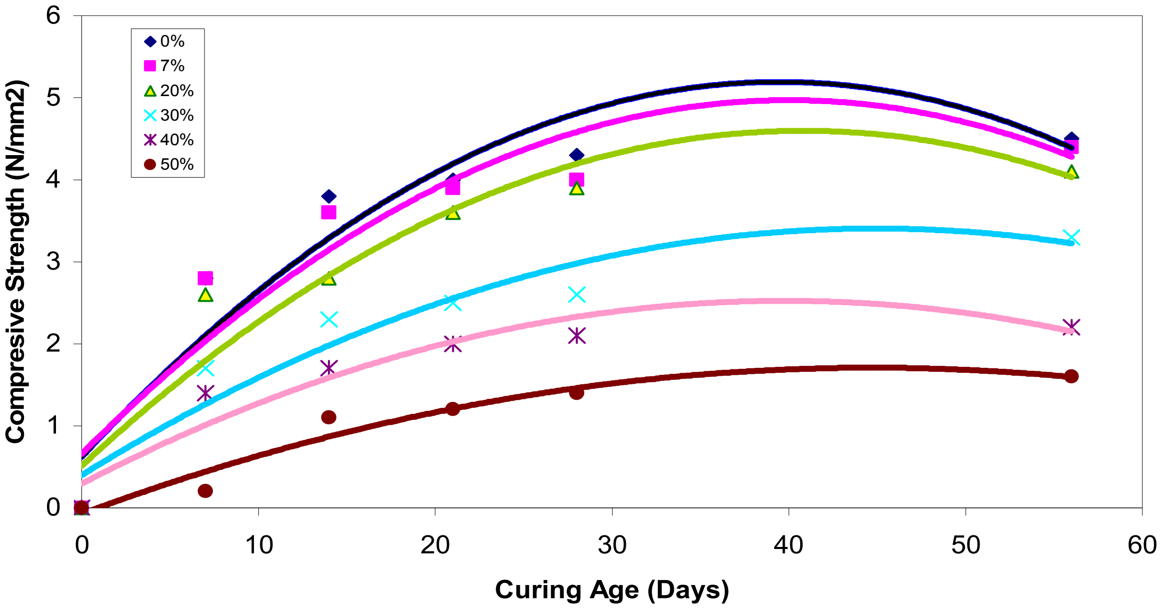

Figure 1: Variation of Compressive Strengths with Curing Ages (Gravimetric Ratio 1:8)

The compressive strengths of various cement/slag/sand blends are illustrated in Figures 1 to 4. The results indicate that the strength of each cast increases with curing age.

As up to 20 percent cement was replaced with slag in the test cubes, there appeared to be some 12 percent loss in strength compared with the control cube (100 percent cement).The decrease in the compressive strength continued with increasing slag content in the specimen. It was however observed that the decrease in the strength of the test cubes with increasing slag content reduced with increasing curing period. This was illustrated by comparing the compressive strengths for 0 percent slag replacement (control) to that for 50 percent slag replacement, obtained by finding their ratio. For example from the curves in Figure 1, based on the mix by weight of cementitious materials/sand, the ratios were 9.08; 3.66; 3.65; 2.84 and 2.78 for 7; 14; 21; 28 and 56 days curing periods respectively. Similarly based on the

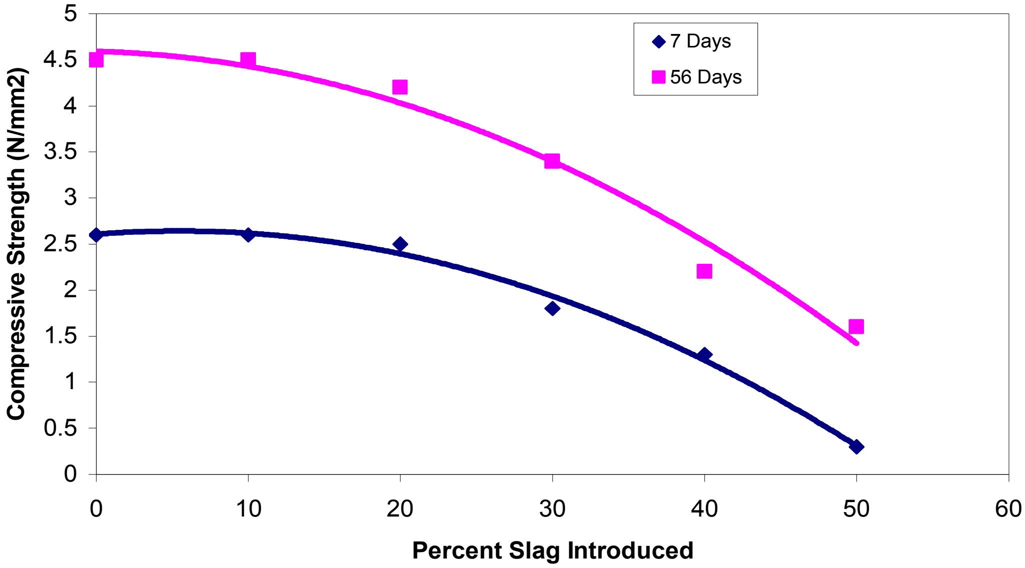

Figure 2: Variation of Compressive Strengths with Increasing Slag Content (Gravimetric Ratio 1:8)

curves for the cementitious materials/sand mix volume (1:6) having equivalent of 1:12 gravimetric ratio shown in Figure 3, the ratios of compressive strength for zero percent (0%) slag replacement (control) to that for fifty percent (50%) slag replacement were found as 4.50; 3.67 and2.78 for 7; 28 and 90 days respectively.

The plots in Figure 3, show a strong relationship between the curing period and the compressive strength for the twenty percent (20%) and thirty percent (30%) replacement of cement with EAF slag. There is a marked increase in strength of about 1-1.5 N/mm^2 as the curing period increased from thirty (30) days to ninety (90) days. However for zero (0%) percent and ten (10%) percent slag replacement appreciable compressive strengths of above 1.6N/mm^2 are achieved within thirty (30) days curing period and only a little increase of about 0.2 N/mm^2 in strength as the period increases to ninety (90) days. For forty percent

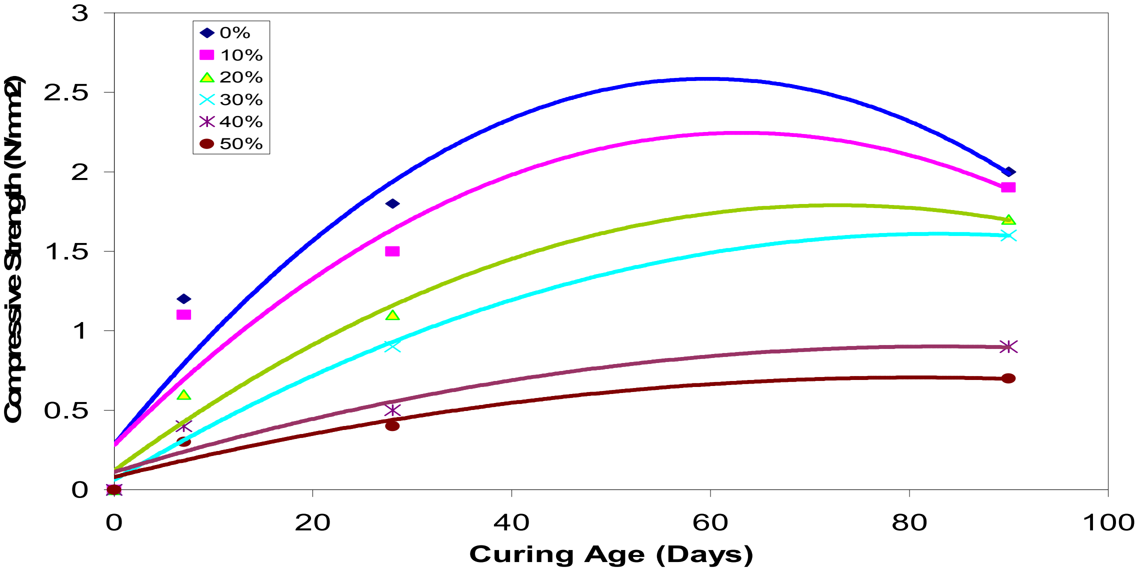

Figure 3: Variation of Compressive Strengths with Curing Ages (Volumetric Ratio 1:6; Equivalent Gravimetric Ratio 1:12)

(40%) and fifty percent (50%) slag replacement the compressive strengths were low at below 0.5N/mm^2 which marginally increased by less 0.2 N/mm^2 as the curing age increased from thirty (30) days to ninety (90) days.

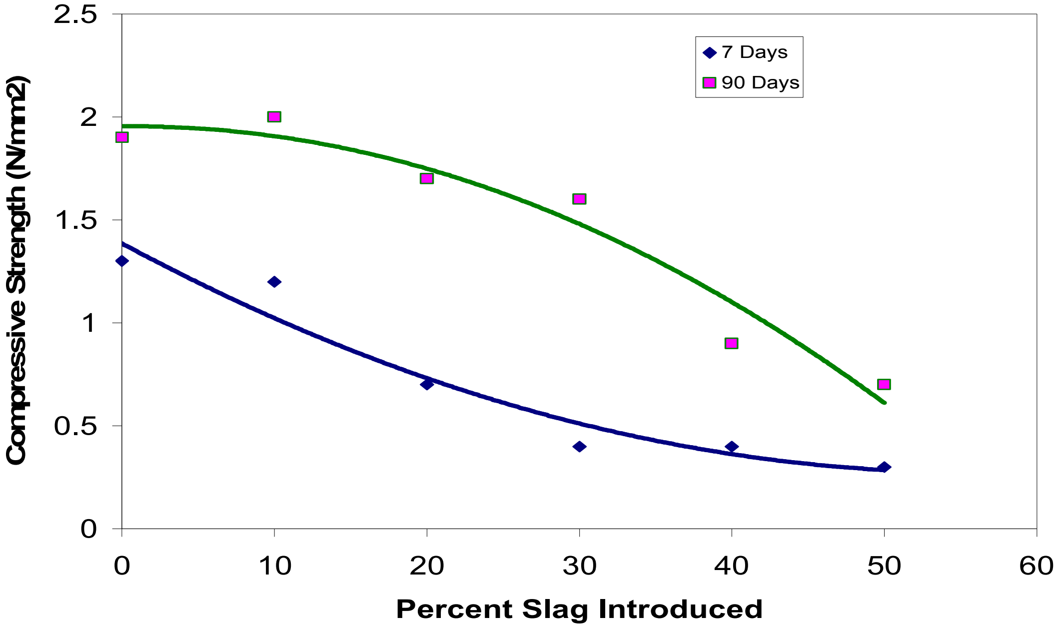

Figure 4: Variation of Compressive Strengths with Increasing Slag Content (Volumetric Ratio 1:6; Equivalent Gravimetric Ratio 1:12)

The above results therefore suggest that for the range of twenty percent (20%) and thirty percent (30%) EAF slag replacement in cement, a slow and long process of curing is necessary to fully develop the strength of block. The necessity of a curing period for EAF slag applied in engineering and construction to stabilise has emerged very strongly from literature. This involves allowing the slag to sufficiently expand on account of hydration its free lime content (Matyas, 1978; Manso et al, 2004).

The slow strength development in the cement/slag/sand block test cubes at the initial stages of curing may be due to the same reason reported (Lee, 1974) for Portland cement/slag concrete where it was believed that at the initial stages, slag acted as an inert filler when the hydration of free lime is yet to commence fully. As the cement hydrates, lime ($Ca(OH)_2$) is produced, the alkali soluble silica and alumina available in the slag react to form calcium silicate and aluminate hydrates which expand and reduce the porosity of the concrete. The reduction in the porosity leads to increase in the strength of the concrete.

It is interesting to note that the loss in the compressive strength experienced when cement was replaced to the tune of 20 percent slag was not appreciable. This has some implications in Nigeria where the cost of cement is very high and is increasing almost everyday and slag disposal is becoming a serious environmental problem.

The results where about 20 and 30 percent EAF slag replaced cement in block making for field tests, showed that the losses in compressive strength compared with control blocks were about 10 percent and 40 percent in respect of the former and the latter respectively. In the light of these results we may recommend that for building purposes, blocks produced with about 20 percent EAF slag replacement may find application in areas where strength requirement is critical. Correspondingly blocks with 30 percent replacement by EAF slag may be used in the non- load bearing areas such as perimeter fencing. It should be noted that a building supported on load bearing walls is of course limited to two – storey. However, the soil bearing pressure should be in the order of 100 KN/m^2 or more (Oyenuga, 2001).

Load bearing walls need not be provided with additional structural elements like columns and beams except where end bearings are inadequate. When such end bearings cannot be guaranteed, the columns are usually introduced with pad footings. Non – load bearing walls would not carry over bearing loads other than their self weights (Reynolds et al., 1981). Hence, the use of EAF of slag / cement blocks will not pose danger or threat to structural stability. However if the blocks are to be used in building construction, it can well perform as partition walls. This proposal is in line with the observations made by other workers who studied the properties of EAF slags and concluded that they can find use in unconfined applications such as open fills and road bases and shoulders (Matyas, 1978); masonry mortars and paving mixes for rural roads with low levels of traffic (Manso et al, 2005).

CONCLUSION

In this work, the results of the use of EAF slag as partial replacement for cement in sandcrete blockmaking have been presented. On the basis of the results the following conclusions may be adduced:

- Cement can be replaced partially by 20 percent of EAF slag in blockmaking without sacrificing the strength appreciably.
- The compressive strength of the blocks decreased with an increase in slag content.
- There is the need to allow for curing of the slag for the strength of the block to develop.
- Correspondingly it was found that the compressive strengths generally improved significantly as the curing period increased up to 90 days.

REFERENCES

Aderibigbe, D. A and Ojobo, A. E. 1982. Properties of Cupola Slag as a Pozzolana and its Effect on Partial Replacement of Cement in a Mortar. Conservation and Recycling. 5, (4):.

Diagbonya, V. O., 1987. Strength Properties of Electric Arc Furnace Slag Concrete. M.Eng Thesis. University of Benin, Benin City.

Edoro, A. E., October, 1986. Investigation into Some Possible Uses of EAF Basic Slag Produced in Delta Steel Company. Research and Development Report.

International Iron and Steel Institute., 2005. Steel: The Foundation of Sustainable Future. Sustainable Report of the World Steel Industry, Brussels.

Lee, A. R., 1974. Blast Furnace and Steel Slag Production, Properties and Use. John Wiley, New York.

Matyas, A. G., August 1978. “Utilization of Steel Making Slag”. Iron and Steel Engineer. 29 – 30.

Manso, J., Gonzalez, J. J and Polanco, J. A., 2004. “Production of Concrete (with good properties) using EAF Slag as Fine and Coarse Aggregate.”. J Material in Civil Engineering, 16, (6): 639- 545.

Manso, J. M., Losanez, M., Polanco, J. A and Gonzalez, J. J., 2005. “Ladle Slag in Construction”. J Material in Civil Engineering, 17, (5): 513-518.

Okpala, D. C and Diagbonya, V. O., 1987. Use of EAF slag as a fine aggregate in mortar and as partial replacement of cement in concrete 1st UNIBEN Conference on Engineering and Technological Development.

Oyenuga, V. O., 2001. Simplified Reinforced Concrete Design. Asros Ltd, Surulere, Lagos.

Pellegrino, C., 2009. “Mechanical and Durability Characteristics of Concrete Containing EAF Slag as Aggregate”. www.sciencedirect.com.

Personal Communication., 1977. – Bhilai Steel Plant (BSP) In - Plant Training.

Rellermeyer, H. M and Mass, H. G., 1975. Utilization of BOS Slags at August Thyssen Hute AG. Annual Open Hearth Steelmaking Conference 131-137. Toronto.

Reynolds, C. E., et al. 1981. Reinforced Concrete Designer’s Handbook. 9th Edition. View Point Publication.