CARBON REDUCTION WITH THE AID OF GRANULATED MILLSCALE (FeO) DURING STEEL PRODUCTION VIA THE ELECTRIC ARC FURNACE PROCESS

G. I. LAWAL AND O. I. SEKUNOWO
Department of Metallurgical and Materials Engineering
University of Lagos, Akoka Yaba, Lagos.

ABSTRACT

In Nigeria and the Third Countries generally, conventional carbon reduction mechanism using 0_2 lance during steelmaking is usually plagued with a lot of hitches which bother on irregular supply of gaseous oxygen coupled with a rather exorbitant cost regime. This has resulted in high cost of production which invariably renders steels produced in Nigeria not being competitive in the market.

The above necessitates a concerted effort geared towards finding functional alternative for 0_2 – Lance. This was achieved, as revealed by the results of the experiments using granulated iron-oxide otherwise called millscale. The scope of its application for carbon reduction during steelmaking was found to be between 0.50% and 0.90% of the initial carbon content. The optimum charging sequence of the millscale was obtained at 70kg with respect to a range of furnace liquid steel capacities from 10-20 tons per heat.

With the application of millscale, the desirable carbon reduction value was achieved within a time frame which compared favourably with that of the conventional 0_2 Lance. Other advantages of the millscale application for carbon reduction in steelmaking include:-

- consistency in production as the supply of the material (millscale) is not hampered by any constraint.
- Reduction in production cost.
- Self reliance since the material is sourced within the factory
- Improved environmental condition on the factory floor.
- Low down-time hours.

1.0 INTRODUCTION

Steel, all over the world has always been a strategic material, and, probably will continue to be so for sometime into the future. It is, therefore, fashionable to equate a Nation's potential for economic advancement through industrialization with her steel production capability and consumption.

The above, though enviable, unfortunately with the absence of scrap classification facilities, steel production in Nigeria is often plagued with excessively high carbon content thereby necessitating a rather large volume of 0_2-Lancing. However, the cost of industrial gaseous 0_2 is prohibitive and its supply usually irregular. This, as to be expected has resulted in a high cost of production which invariably renders Nigerian Steels non-competitive in the market.

This research work is an attempt to solve the problem as enunciated above by exploring the possibilities for the application of granulated iron-oxide (FeO) otherwise called Millscale, as a reducing agent during the refining stage of steel production through the Electric arc Furnace (EAF) process which employs 100% scrap.

The above objective will be achieved through experimental analyses of the results of the charging of varying quantities of millscale into the melt to effect the desirable carbon.

It is hoped that the findings of this work will be of tremendous assistance to the steel industry particularly in Nigeria and, Africa in general as the basis for the application of millscale in steel production would have been laid.

2.0 EXPERIMENTAL WORK

2.1 THE MATERIAL AND ITS SOURCE

Granulated Millscale is an oxide of iron (FeO) which is formed as a result of decarburization process taking place on the preheated billets in the reheating oven at the rolling mill. Oxidation of the billets in the reheating oven is usually substantial resulting in a lot of scale formation. The scales are normally discharged beneath the Roll-Stands during rolling operations.

The Oxygen atom in the compound (FeO) when ignited burns and produces such heat intensity which compares favourably with that of gaseous oxygen. Moreover, the compound is constituted readily reacts with the furnace contents effecting the oxidation of excess carbon in the melt.

A large quantity of granulated millscale is available on the premises of all the Rolling Mills in Nigeria. The photograph of a sample of some quantity of millscale is shown in Fig. 1.

2.2 EQUIPMENT

The main equipment employed consist of an 18 Tons Electric Arc Furnace (EAF) liquid steel capacity. A Metals Analyzer Spectrometer Model ARL 3460 was also used to carry out the chemical analysis of the melt samples at varying carbon reduction level.

The EAF has a transformer rating commensurate with short arcs. This gives a power-factor of between 0.6 and 0.7 which prevents high wear rate of the furnace linings. Moreover, the EAF carries 3-Graphite Electrodes with the intent that, a tap-to-tap times of between 21/2 and 3 hours will be achieved.

2.3 EXPERIMENTAL PROCEDURES

For the purpose of this research work, the EAF of 18 Tons capacity per heat was used.

2.3.1 CHARGING

At the outset of melting, the charges are:

- Steel scrap of varying bulkiness and chemical composition and ;
- Limestone ($CaCO_3$) as flux
- The charging of the scrap was piece-metal for efficient furnace operations while the number of scrap-pot charged depended on the scrap bulkiness. Thus, for the 18 Tons capacity, the number of scrap charges per heat ranges from (3-4) to (5-7) respectively for heavy and light section scraps.

2.3.2. MELTING

As melting progresses, calcination of the limestone results in the formation of two liquid phases while the slag floats on top of the molten metal. At about the end of he "lime boil" the furnace content is considered melted though, small portions of unmelted metal and lime may still be present.

2.3.3 CHARGING OF MILLSCALE

Immediately after the charges have melted, then, the charging of millscale commenced. This continued in varying quantities until the desired carbon level was achieved which invariably signalled the end of he refining process. The quantity charged was first weighed and then charged. Subsequent millscale charges were carried out in like manner.

2.3.4 CHEMICAL ANALYSIS

At the outset of the refining stage, a representative sample of the molten steel was obtained for a septrochemical analysis to determine the elemental concentrations in terms of Carbon, Phosphorous, Sulphur, Manganese, Tin, Lead and Zinc. These elements are the most essential for the grade of steel under investigation. Particular attention, was however, focused on the carbon value of the chemical analysis results. Hence, results of those samples which indicated carbon well in excess of the required level (0.30%C) were chosen as the object of this work. It was on these categories of heat-batches that the application of millscale for carbon reduction process was administered. A total of eight heats were studied to cover the various categories of initial carbon content.

The photograph of the melt samples is shown in Fig. 2.

2.3.5 OXYGEN LANCE

For the purposes of comparison, the case of the conventional 0_2 lance in achieving carbon level during steel production was also investigated.

The volume of oxygen lanced into the melt at intervals of time was read-off directly from the flow meter installed along the flow line. A total of eight heat-batches of varying carbon content categories were studied.

3.0 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 EXPERIMENTAL RESULTS

The proportional reduction sequence in the carbon content for each of the heat-batches studied are as presented in appendixes A and B respectively for the case of millscale and 0_2 Lance applications.

The quantity of millscale charged for each category of initial carbon contents and the period of heating the melt was subjected together with the values of carbon reduction obtained are as presented in Table A (A1-A4). Table B (B1-B4) represents that for the 0_2 Lance.

For each category of initial carbon content, the reduction sequence is depicted on the time-variations carried by the chemical analysis results sheets in appendices A and B. With the use of the parameters in the results sheets, the calculations of the rates of Carbon reduction with respect to both the quantity of millscale charged (Rm/Kg) and the period of heat application (Rm/T} were obtained thus:

$$\text{Rm/Kg:} \quad \frac{\text{Reduced Value of Carbon Obtained}}{\text{Quantity of Millscale charged in kg}} \quad \text{—(1)}$$

$$\text{Rm/T:} \quad \frac{\text{Reduced Value of Carbon Obtained}}{\text{Total Heating Period on Minutes.}} \quad \text{—(2)}$$

By subjecting the Chemical analysis results to critical analysis one after the other, the following calculation ensured: Table C contains the summaries of the above calculations. It can be seen from the table.

That the overall carbon reduction rate with respect to the quality of millscale charged is 0.0025 and 0.008 per minute of period of heat application. Table D gives that for the 0_2 Lance to be 0.01 per minute and 0.005 per volume of 0_2 lanced.

The above values were used in arriving at figures presented in Table E and F from which the graphs in Figures 3 and 4 were been drawn.

Figure 3 was drawn to portray the carbon reduction sequence with varying additions of millscale. The time lapse between each successive millscale charged with respect to the carbon reduction rate is depicted in Figure 4. In addition, Figure 5 exhibits the combined effect of both the period (time) of heating and the quantity of millscale charged with respect to the actual values of carbon reduced at every instance.

3.2 DISCUSSION OF RESULTS

With regard to the analysis of experimental results, the scope of millscale applications for carbon reduction during steel refining was found to be from 0.50% to 0.90% of the initial carbon content. This is evident in both figures 4 and 5. Below this range of initial carbon content, mere application of heat for a few minutes will effect the desirable carbon reduction.

The optimum charging condition (Fig 5) for the millscale were obtained through the outcome of the analysis of the combined effects of the period of heating and the quantity of millscale charged with respect to the actual values of carbon reduced. Figure 5 shows that the highest efficiency for the millscale application would be achieved by the initial charging of approximately 70kg into the melt and thereafter, lesser quantities depending on the carbon level. Moreover, it must be noted that the initial millscale values to the left of the optimum point (fig 5.) will require less quantity of millscale by a rather low carbon reduction value will be achieved. While values to the right of the optimum point will result in more carbon reduction values but, at the expenses of a rather prolonged heating time.

This is not desirable as prolonged heating of the bath usually result in overboiling and consequently, melt spill-off.

Figure 3 shows the carbon reduction sequences as a function of the quantity of millscale charged. From the graph, it can be seen that the cumulative quantity of millscale input into the melt to achieve the desired carbon level amounted to 204kg. As it can be seen from Table C, the average carbon reduction rate is 0.0026 per kg of millscale charged. Moreover, the millscale efficiency first increases from 0.50% initial carbon level and continues up to a limit of 0.90%. There

were no further experimental basis to ascertain what happens to its efficiency after the 0.90% initial carbon level.

The carbon reduction values obtained at a given quantity of millscale charged has a direct bearing on the period of heating of the melt. This is evident in Table A (A1-A4) and Figure 4 where the period of heating administered and the resultant reduced carbon values obtained were given. With millscale application, Figure 4 shows that a maximum of 71 minutes compared with 55 minutes in the case of 0_2 -lance were spent in order to reduce the melt's carbon content from 0.90% to 0.30%. This translates to 80% efficiency at a reduction rate of 0.008 per minute (0.01 per minute for 0_2-lance) indicating a close time scale period.

Given the level of commercial gaseous oxygen requirement as presented in Table B(B1-B4) in order to effect carbon reduction from 0.90% to 0.30% the cost implications of the 0_2-Lance approach for the steel manufacturer is considered to be substantial. From Table B(B1-B4) the average volume of oxygen required to effect the necessary carbon reduction for the various initial carbon categories are: 48, 60, 93 and 102 all in cubic meters. With the current market cost of gaseous oxygen at N 250/m3, it implies that it will cost an average of N 18,937:50k per heat to effect carbon reduction using oxygen gas. However, with the application of millscale in place of oxygen this amount will translate into a saving and consequently a possible reduction in the current market price of the steel products (long bars) by an amount not less than N 1,052:09k per ton.

4.0 CONCLUSION

The application of granulated millscale approach to achieving desirable carbon level during steel production has been explored in great detail by this research work.

On the basis of the results already presented and discussed, granulated millscale is an effective carbon reduction agent. Its efficiency is more obvious as from initial carbon content of 0.50% to 0.90%. Below this range, mere application of heat for a few minutes will effect the necessary carbon reduction.

One of the advantages millscale has over 0_2-lance is its availability at virtually no cost.

This is a sharp contrast to commercial oxygen of which supply is usually irregular resulting in a spate of unsteady production regime through unduly long down-time hours. Consequently, the use of millscale will result in consistent production and hence, enhance capacity utilization.

This study has also revealed the need for a systematic charging sequence of the millscale into the melt for efficient realisation of its applicability. This was established through the analysis of the combined interplay of the melt's heating regime and the quantity of millscale charged at any instance. From these analysis, the optimum conditions for the charging sequence is put at 70kg in a furnace liquid steel capacities from 10-20 tons per heat. This will prevent localised agitation in the melt.

In time-scale comparison between millscale and oxygen application, the desirable carbon reduction value was realised within 71 minutes and 55 minutes respectively with millscale and 0_2-Lance applications. This is another indication of close oxygen substitution for millscale in steelmaking.

From the cost benefit analysis, there is a fairly substantial cost saving benefits accruable to the steel manufacturers. In fact, the millscale approach seems to be one of the most feasible ways of making Nigeria steel products competitive in the market without compromising quality. It may as will be the saving grace, now that the steel sector in Nigeria is facing an unprecedented competition due to dumping of relatively cheap steel products from Europe and Asia.

Presently, there abounds in most of he rolling mills in Nigeria, heaps of millscale which constitute an environmental nuisance on the factory floor. Moreover, substantial amount of money is being spent by the individual companies to evacuate the material to some designated dumping sites for which Government charges some amount of money for the use of such sites. With a meaningful application of millscale in the steel production process therefore, improved environmental conditions on the factory floor will be achieved and the additional cost usually incurred in the course of millscale evacuation will cease.

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REFERENCES

1. **Davies D. J and Oelman L. A.** (1983) The Structure Properties and Heat-treatment of Metals Pitman London.
2. **Higgins R. A.** (1987) Properties of Engineering Materials, Hodder and Stroughhton England.
3. Journal of Metallurgical Pant and Technology (June 1996) (MPT) International PP. 30-35
4. Standards Organisation of Nigeria (1992) NIS 117 Standard for Steel Bars for Reinforcement of Concrete (Review) Table 1 PP.9
5. Steel Times International (May 1995); Electric Arc Furnace Supplement; PP. 22
6. **Mukhlyonov I. P.** (1978) Calculations of Chemical Technological Processes, MIR Publishers Moscow.
7. **Kempster, M. H. A.** (1964) Materials for Engineers, English Univs Press London.
8. **Colin J. S., Eric. A. B.** (1978) Metals Reference Book Properties and Selection of Metals Fifth Edition, Butterworths and Co (Publishers) Ltd London.
9. **Yu. Lakhtin, D.Sc.** (1980) Engineering Physical Metallurgy and Heat-Treatment, MIR Publishers Moscow.

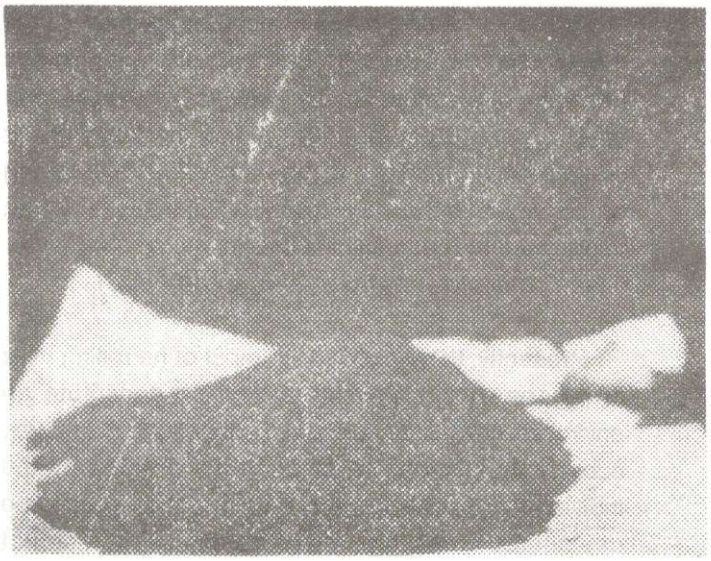


Fig. 1 Photograph of A Sample of Granulated Millscale.

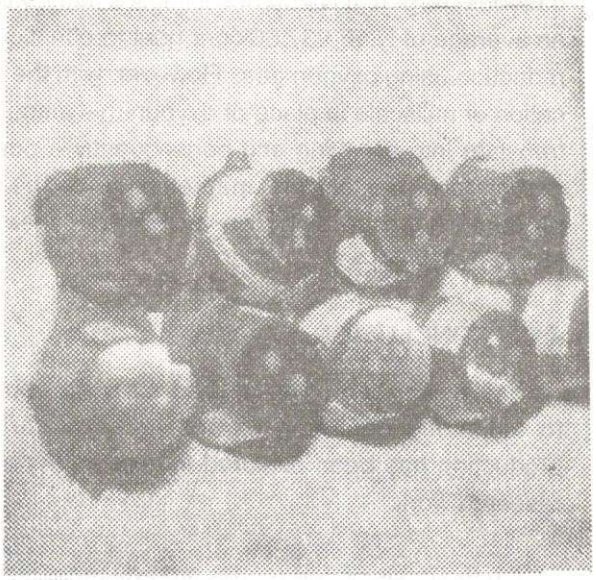
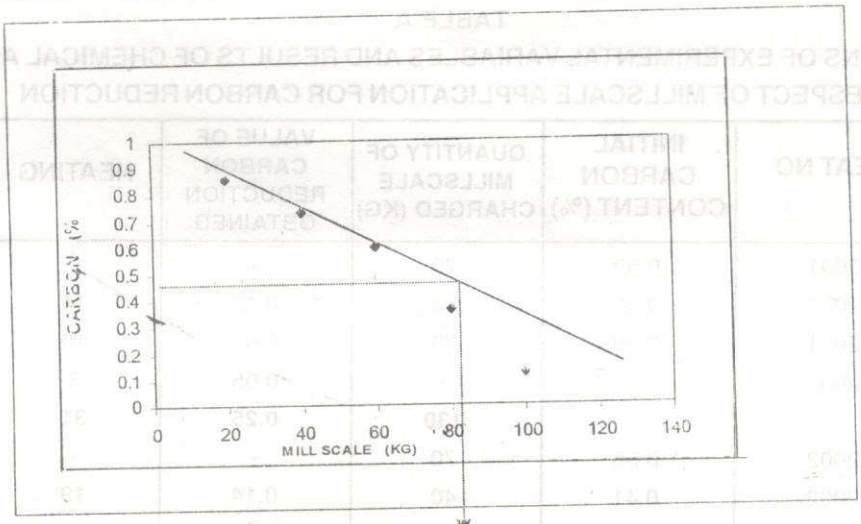
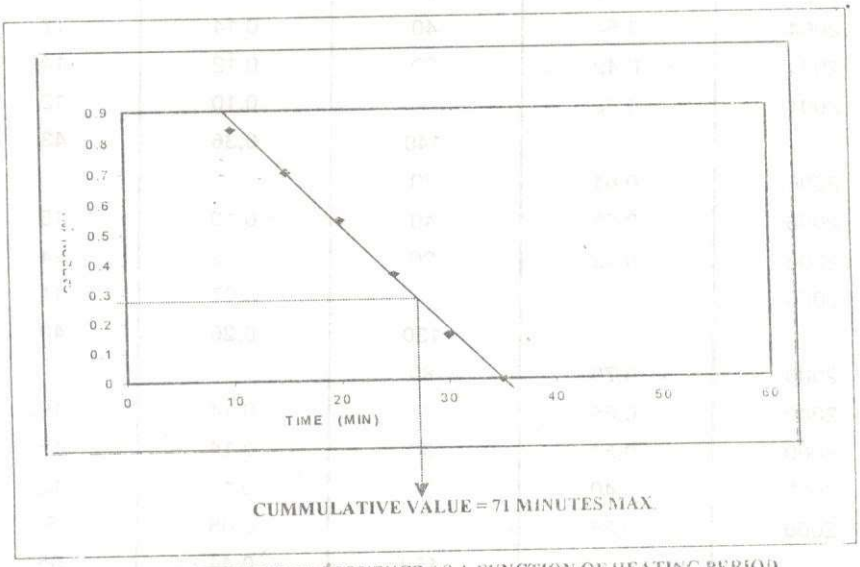


Fig. 2 Photograph of Some of the Melt-Samples Used for Spectrochemical Analysis.



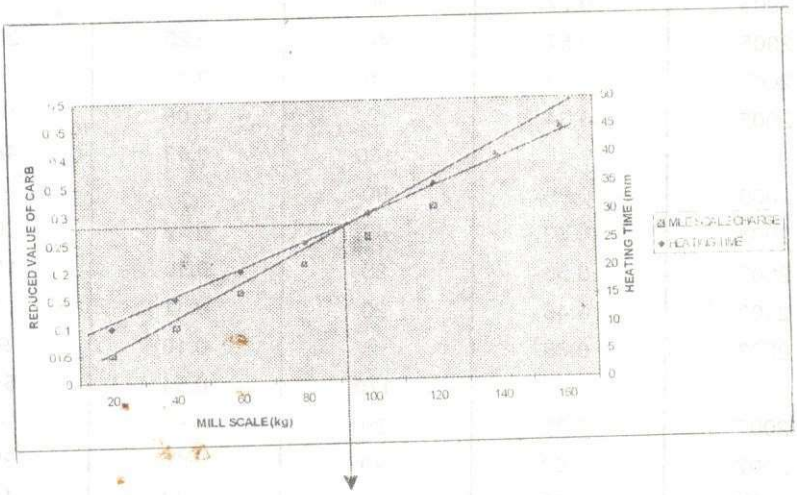
CUMMULATIVE VOLUME = 204 KG MAX. OF MILL SCALE NEEDED

FIG. 3: CARBON REDUCTION SEQUENCE AS A FUNCTION OF MILLSCALE ADDITION



CUMMULATIVE VALUE = 71 MINUTES MAX.

FIG. 4 : CARBON REDUCTION SEQUENCE AS A FUNCTION OF HEATING PERIOD



OPTIMUM CONDITIONS

FIG. 5 : CARBON REDUCTION PROGRESSION AS A FUNCTION OF THE COMBINED APPLICATION OF HEATING TIME AND QUANTITY OF MILLSCALE CHARGED.

TABLE A

PRESENTATIONS OF EXPERIMENTAL VARIABLES AND RESULTS OF CHEMICAL ANALYSIS IN RESPECT OF MILLSCALE APPLICATION FOR CARBON REDUCTION

SPECIMEN	HEAT NO	INITIAL CARBON CONTENT (%)	QUANTITY OF MILLSCALE CHARGED (KG)	VALUE OF CARBON REDUCTION OBTAINED	HEATING	REMARKS
A	2001	0.59	70	-	-	
B	2001	0.46	40	0.13	14	Rm/kg: 0.002
C	2001	0.39	20	0.07	10	Rm/T: 0.08
D	2001	0.34	-	0.05	7	
			130	**0.25**	**31**	A_1
A	2002	0.55	70	-	-	
B	2002	0.41	40	0.14	19	Rm/kg: 0.0021
C	2002	0.32	-	0.09	9	Rm/T: 0.008
			110	**0.23**	**28**	
A	2004	0.68	70	-	-	
B	2004	0.54	40	0.14	17	Rm/kg: 0.0026
C	2004	0.42	30	0.12	14	Rm/T: 0.008
D	2004	0.32	-	0.10	12	
			140	**0.36**	**43**	A_2
A	2006	0.61	70	-	-	-
B	2006	0.51	40	0.10	15	Rm/kg: 0.002
C	2006	0.42	20	0.09	14	Rm/T: 0.0065
D	2006	0.35	-	0.07	11	
			130	**0.26**	**40**	
A	2000	0.79	80	-	-	
B	2000	0.65	40	0.14	19	Rm/kg: 0.0029
C	2000	0.51	30	0.14	16	Rm/T: 0.008
D	2000	0.40	-	0.11	12	
E	2000	0.35	-	0.05	8	
			150	**0.44**	**55**	A_3
A	2005	0.77	80	-	-	
B	2005	0.57	40	0.20	22	Rm/kg: 0.0029
C	2005	0.43	30	0.14	16	Rm/T: 0.009
D	2005	0.34	-	0.09	10	
			150	**0.43**	**48**	
A	2003	0.89	80	-	-	
B	2003	0.72	40	0.17	20	
C	2003	0.56	30	0.16	19	Rm/kg: 0.0032
D	2003	0.45	20	0.11	13	Rm/T: 0.009
E	2003	0.35	-	0.10	9	
			170	**0.54**	**59**	A_4
A	2007	0.85	80	-	-	
B	2007	0.69	40	0.16	20	Rm/kg: 0.0031
C	2007	0.55	30	0.14	16	Rm/T: 0.009
D	2007	0.42	20	0.13	15	
E	2007	0.33	-	0.09	5	
			170	**0.52**	**56**	

TABLE B

PRESENTATIONS OF EXPERIMENTAL VARIABLES AND RESULTS OF CHEMICAL ANALYSIS IN RESPECT OF 0_2 - LANCE FOR CARBON REDUCTION

SPECIMEN	HEAT NO	INITIAL CARBON CONTENT (%)	QUANTITY OF 0_2-GAS CHARGED (KG)	VALUE OF CARBON REDUCTION	HEATING TIME (MIN)	REMARKS
A	1003	0.58	28	-	-	
B	1003	0.42	22	0.16	14	RO/m^3: 0.005
C	1003	0.32	-	0.10	11	RO/T: 0.01
			50	**0.26**	**26**	**B_1**
A	1007	0.52	26	-	-	
B	1007	0.36	20	0.16	13	RO/m^3: 0.0048
C	1007	0.30	-	0.06	10	RO/T: 0.096
			46	**0.22**	**23**	
A	1008	0.69	50	-	-	
B	1008	0.45	12	0.24	25	RO/M^3: 0.0056
C	1008	0.34	-	0.11	12	RO/t: 0.0095
			62	**0.35**	**37**	**B_2**
A	1005	0.62	32	-	-	
B	1005	0.45	26	0.17	16	Ro/M^3: 0.005
C	1005	0.33	-	0.12	13	Ro/T: 0.01
			58	**0.29**	**29**	
A	1002	0.74	62	-	-	
B	1002	0.45	26	0.29	31	Ro/M^3: 0.0045
C	1002	0.34	-	0.11	13	Ro/T: 0.0091
			88	**0.40**	**44**	**B_3**
A	1006	0.79	54	-	-	
B	1006	0.48	26	0.31	27	Ro/m^3: 0.0048
C	1006	0.38	18	0.10	13	Ro/t: 0.0096
D	1006	0.32	-	0.06	9	
			98	**0.47**	**49**	
A	1001	0.89	62	-	-	
B	1001	0.52	30	0.37	32	Ro/M^3: 0.005
C	1001	0.36	16	0.12	15	Ro/T: 0.0098
D	1001	0.31	-	0.05	8	
			108	**0.54**	**55**	**B_4**
A	1004	0.83	58	-	-	
B	1004	0.51	24	0.32	29	Ro/M^3: 0.0052
C	1004	0.42	14	0.09	12	Ro/T: 0.01
D	1004	0.33	-	0.09	7	
			96	**0.50**	**48**	

TABLE C
SUMMARY OF TABLE A (A_1 - A_4) IN RESPECT OF MILLSCALE

RANGE OF INITIAL CARBON CONTENT (%)	REDUCTION RATE PER HEATING TIME (RM/T)	REDUCTION RATE PER QUANTITY OF MILLISCALE CHARGED (RM/KG)
0.50 – 0.59	0.008	0.002
0.60 – 0.69	0.007	0.0023
0.70 – 0.79	0.0085	0.0029
0.80 – 0.89	0.008	0.0032
OVERALL REDUCTION RATE	0.008	0.0026

TABLE D
SUMMARY OF TABLLOE OF B (B_1 - B_4) IN RESPECT OF 0_2 - LANCE

RANGE OF INITIAL CARBON CONTENT (%)	REDUCTION RATE PER HEATING TIME (RM/T)	REDUCTION RATE VOLUME OF O_2 GAS LANCED (RO/M)
0.50 – 0.59	0.0098	0.005
0.60 – 0.69	0.0098	0.0053
0.70 – 0.79	0.0094	0.0047
0.80 – 0.89	0.0099	0.0051
OVERALL REDUCTION RATE	0.01	0.005

TABLE E
CARBON REDUCTION SEQUENCE WITH THE AID OF MILLSCALE

QUANTITY OF MILLSCALE CHARGED (KG)	20	40	60	80	100	120
INITIAL CARBON CONTENT (%)	0.90	0.85	0.75	0.59	0.38	0.12
CARBON REDUCTION OBTAINED	0.05	0.10	0.16	0.21	0.26	0.31
REDUCTION SEQUENCY (%)	0.85	0.75	0.59	0.38	0.12	-

TABLE F
CARBON REDUCTION SEQUENCE AS A FUNCTION OF HEATING PERIOD

HEATIG PERIOD (MIN)	10	15	20	25	30	35	40
INITIAL CARBON CONTENT (%)	0.90	0.82	0.70	0.54	0.34	-	-
CARBON REDUCTION OBTAINED	0.08	0.12	0.16	0.20	0.24	-	-
REDUCTION SEQUENCY (%)	0.82	0.70	0.54	0.34	0.14	-	-