Chapter 6:

Exploratory Melting Studies of Reduced Pellets

6.1. Introduction

This chapter discusses the investigation of the melting behavior of reduced pellets in an oxyacetylene flame environment, aiming to recover metals present in the MMO. A minimum of 500 gm of Direct Reduced Iron (DRI) was necessary for a single melt in a laboratory-scale Electric Arc Furnace (EAF). However, generating such a large quantity of DRI, especially hydrogen-reduced pellets, posed challenges in this current experimental setup, especially for hydrogen reduced pellets. It was also crucial to assess the advantages of utilizing DRI produced from hydrogen reduction (H_2-DRI) and to compare the outcomes with those obtained from DRI produced through carbothermic reduction (C-DRI).

To address this, exploratory melting studies were carried out, wherein both C-DRI and H_2-DRI were separately melted under an oxyacetylene flame. An oxyacetylene flame is generated by the combustion of oxygen and acetylene gases, offering a versatile tool utilized in various applications such as iron or steel welding, metal heating, rust or scale removal, loosening corroded nuts and bolts, and as an inexpensive means for cutting ferrous metals [114]. The temperatures obtained with oxy-acetylene flames is above 1500 °C and thus can be used to melt pellets. This method of melting iron ores pellets and fines have been well established as evidenced by the existence of numerous patents [115-118].

Three types of flames can be produced by varying the amount of acetylene and oxygen. A neutral flame is produced when acetylene and oxygen are in equal ratio. Increasing the amount of oxygen produces an oxidizing flame, while increasing the acetylene content produces a reducing or carburizing flame[119]. The neutral flame and carburizing flame can be used to melt DRI. Due to excess acetylene, CO and H_2 gases are generated by the following reaction.

$$C_2H_2(g) + O_2(g) \Leftrightarrow 2\,CO\,(g) + H_2(g) \qquad (6.1)$$

The CO and H_2 gases help in maintainaing a reducing atmosphere. Excess acetylene also leads to carbon deposition[119], which may aid in reduction of Cr-oxides.

6.2. Results and Discussion

6.2.1. Preliminary Melting Studies: Single Pellet and DRI

Initially, preliminary studies were conducted using two types of raw material: one hardened MMO pellet and one C-DRI. To facilitate these studies, circular cavities of 20 mm dia were created in alumina bricks as shown in **Figure 6.1**. These cavities served as the receptacles or holders for the pellets during the experimental process. The C-DRI (DRI 1 and DRI 2 in **Figure 6.1**) was melted under a neutral flame, to limit oxidation of the DRI and prevent addition of impurities like carbon to the melt. Melting of hardened MMO pellets necessitated the use of a reducing flame. A reductant is essential to convert the iron oxides in the MMO pellet into metallic iron. This reductant was supplied by the reducing flame.

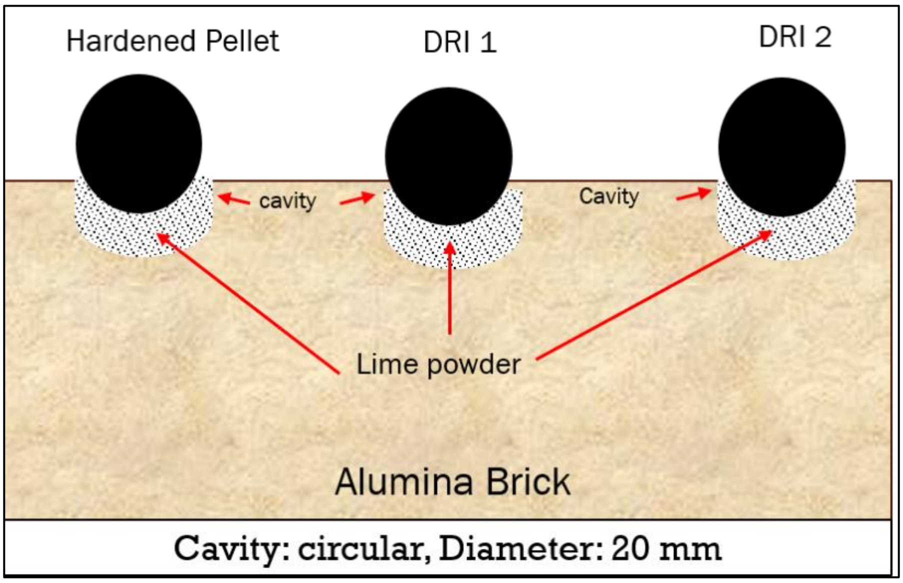

Figure 6.1: Preliminary melting studies of single hardened pellet and DRI

A single pellet/ C-DRI was placed in the cavity and was melted under the reducing/neutral flame. Basicity of 1 was maintained by adding lime (CaO) powder at the bottom of the cavity. After melting, the melt was allowed to cool down in the cavity itself. Metal nuggets were obtained in the form of spheres as shown in **Figure 6.2**. Bigger nuggets were obtained when DRI was melted**.**

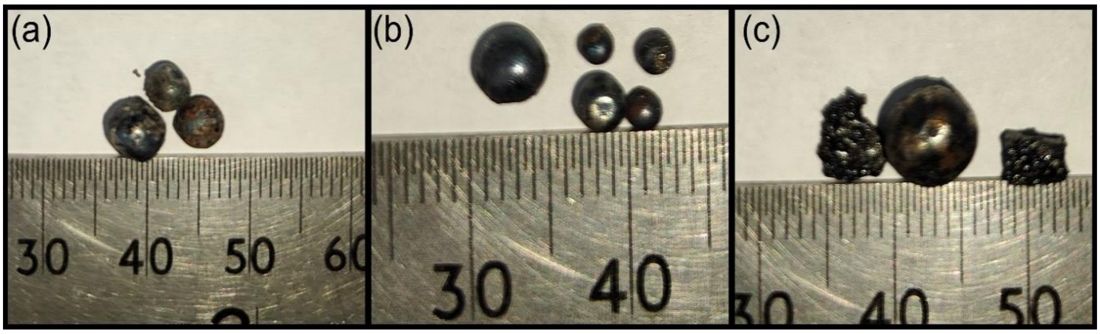

Figure 6.2: Metal nuggets obtained on melting (a) Hardened pellet (b) DRI 1 (c) DRI 2

Table 6.1 lists all the details of the preliminary melting studies conducted on single DRI and single hardened pellet. Yield was calculated according to **eqn 2.17** described in section 2.7 of Chapter 2.

Table 6.1: Particulars of single pellet and single C-DRI melting

Input	Wt. of input material (gm)	Flame Type	Maximum temperature attained (°C)	Wt. of metal produced (gm)	Melting Time (mins)	Yield (%)
Hardened Pellet	5.47	Reducing	1450 ± 10	0.812	5	14.8
C-DRI 1	6.16	Neutral	1450 ± 10	1.189	2	19.3
C-DRI 2	5.64	Neutral	1450 ± 10	1.102	3	19.5

Maximum yield of 19.5 % was achieved when DRI was melted in a neutral flame. The yield improved marginally with increase in melting time. A yield of 14.8% was obtained when hardened pellet was reduced under a reducing flame. As the metal-gangue separation is more enhanced in DRI than hardened pellet, the yield is higher and melting time is less in case of DRI. The quantity of slag and metal was too low for further characterization studies. Thus, it was necessary to produce a larger quantity of metal nuggets and slag for further studies.

6.2.2. Preliminary Melting studies: Multiple Pellets & DRI

Multiple pellets and C-DRI were separtely melted under a reducing amd neutral flame respectively in a setup as shown in **Figure 6.3**. Crater shaped cavities of 70mm diameter were made in an alumina brick. 10-12 hardened MMO pellets and 10-12 C-DRI were melted under a reducing flame and neutral flame respectively. Basicity of 1 was maintained by adding lime powder as per previous studies. After melting, the melt was allowed to cool down in the cavity itself. Metal nuggets were obtained in the form of spheres as shown in **Figure 6.4a and 6.4b**.

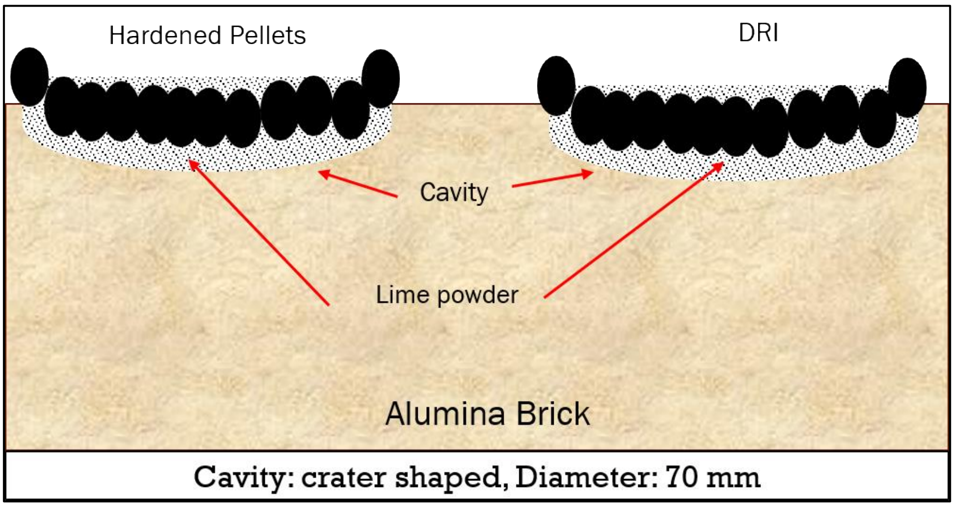

Figure 6.3: Preliminary melting studies of multiple hardened pellets and DRI

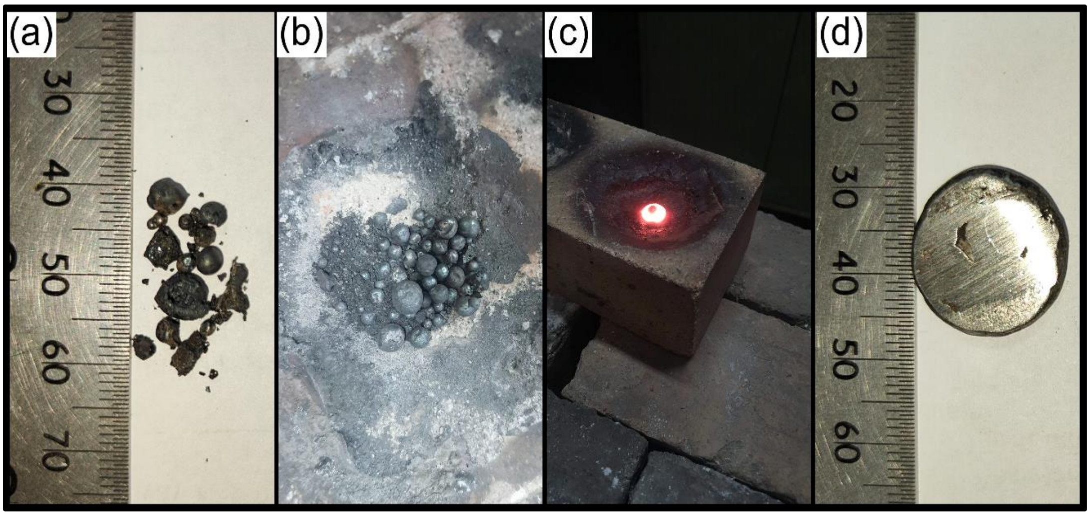

Figure 6.4:(a) Metal obtained from hardened pellets (b) Metal obtained from DRI (c) Fusion of metal obtained by melting DRI (d) Fused metal after rolling.

The weight of the metal nuggets was measured to determine the yield according to **eqn 2.17** described in section 2.7 of Chapter 2. **Table 6.2** lists all the details of the preliminary melting studies conducted on Multiple C-DRI and Multiple hardened pellets.

Table 6.2: Particulars of multiple pellets and multiple DRI melting

Input	**Wt. of input material (gm)**	**Flame Type**	**Maximum temperature attained (°C)**	**Wt. of metal produced (gm)**	**Melting Time (mins)**	**Yield (%)**
Hardened Pellets	47.7	Reducing	1500 ±10	2.25	13	4.7
C-DRI	48.1	Neutral	1500 ±10	7.24	14	15.1

A yield of 15.1% was obtained when C- DRI was melted. The yield drastically decreased from 14.8 % in case of single hardened pellet (**Table 6.1**) to just 4.7 % when multiple hardened pellets were used (**Table 6.2**). The crater shaped configuration used for melting was the reason for the decreased yield. In the case of multiple pellets, as depicted in **Figure 6.5**, torch movement (diameter: 8 mm) was necessary, unlike the scenario with single pellets where no movement was required. When the torch was moved, the adjacent areas experienced cooling and solidification compared to the nearby heated area. Subsequently, to fully melt these solidified regions, reheating was necessary, resulting in the intermixing of metal and slag phases. The separation between metal and gangue in hardened pellets was less distinct compared to DRI, resulting in poorer slag-metal separation during the melting of hardened pellets. Consequently, the yield was lower when multiple hardened pellets were melted.

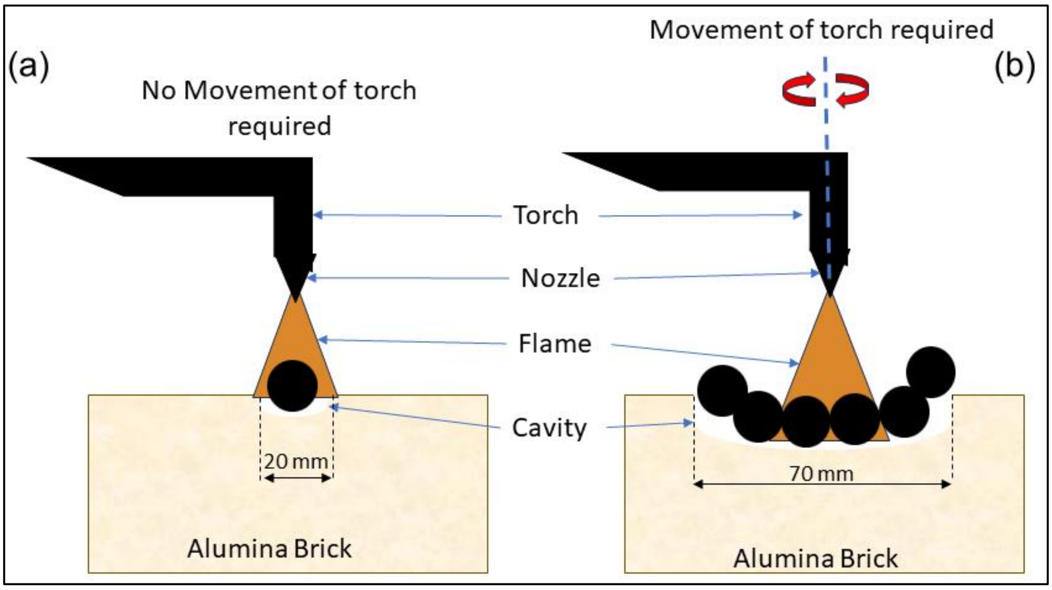

Figure 6.5: Melting of (a) single hardened pellet (b) multiple hardened pellet

The spherical metallic nuggets obtained from melting DRI were fused using a neutral flame from an oxy-acetylene torch (**Figure 6.4c**), and subsequently rolled and ground to prepare a flat specimen (**Figure 6.4d**). A neutral flame was chosen for fusing the metal nuggets to preserve the composition of the metal intact. The coin shaped metallic specimen was analysed using OES according to Section 2.3.4 of Chapter 2 to determine the composition of the metal, which is shown in **Table 6.3**. The slag obtained was analysed using XRF (Section 2.3.3 of Chapter 2) to determine the slag composition. The slag composition is shown in **Table 6.4**.

Table 6.3: Chemical composition of the metal obtained from DRI

Element	Fe	C	Si	Mn	P	S	Cr	Ni	Al	Co	Cu	Ti
Wt.%	96.9	0.294	0.012	0.118	0.165	0.201	0.593	0.81	0.082	0.054	0.071	0.003

Table 6.4: Chemical composition of the slags obtained from both hardened pellets and DRI

Slag Composition (Hardened Pellets)												
Oxides	TiO_2	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Na_2O	CaO	Cr_2O_3	MnO	**Fe_2O_3**	Co_3O_4	NiO
Wt.%	1.241	1.315	10.875	14.268	0.139	0.179	0.14	11.761	3.407	0.348	**56.139**	0	0.188
Slag Composition (DRI)													
Oxides	TiO_2	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Na_2O	CaO	Cr_2O_3	MnO	**Fe_2O_3**	Co_3O_4	NiO
Wt.%	1.898	2.299	18.510	24.931	0.138	0.173	0.12	11.130	2.850	0.379	**37.207**	0.265	0

The metal produced contained 96.9 wt.% Fe, 0.593 wt.% Cr, 0.81 wt.% Ni and 0.118 wt.% Mn (**Table 6.3**). Low values of Si (0.012 wt.%) and Al (0.082 wt.%) suggest a good separation between the metal and slag. The metal also contained 0.294 wt.% C and 0.201 wt.% S, which were picked up from the non coking coal used to make DRI. The Fe_2O_3 content in slag obtained by melting hardened pellet (56.139 wt.%) was much higher than that obtained by melting DRI (37.207 wt.%) (**Table 6.4**), which is directly related to the metallic yield obtained (**Table 6.2**). The higher the metallic yield the lower is the Fe_2O_3 content in slag.

6.2.3. Preliminary Melting studies: Multiple DRI

The metallic yield was hampered due to the wide crater shaped cavity used in Section 6.2.2 and thus another configuration of cavity was investigated which required minimal movement of torch. The yield of hardened pellet melted was lower than obtained with DRI, irrespective of quantity (**Table 6.1 and 6.2**). Henceforth only C-DRI was used for further studies. The new cavity configuration had a cylindrical shape as shown in **Figure 6.6. Table 6.5** lists the all the details of the preliminary melting studies conducted on Multiple DRI (4-5 nos) with different types of flame

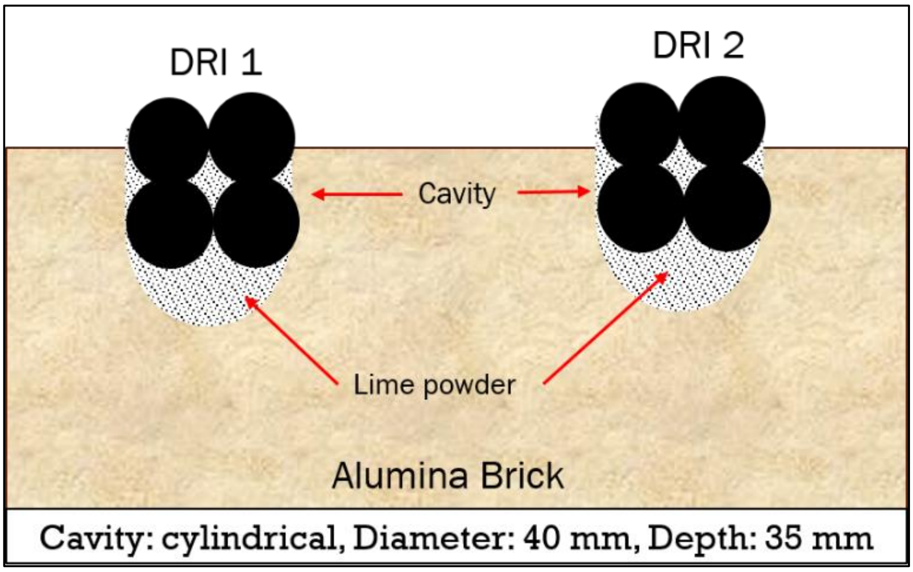

Figure 6.6: Melting of multiple pellets in a cylindrical cavity

Table 6.5: Particulars of multiple DRI melting test with different type of flames

Input	Wt. of input material W1 (gm)	Flame Type	Maximum temperature attained (°C)	Wt. of metal produced (gm)	Melting Time (mins)	Yield (%)
C-DRI	23.3	Neutral	1545 ± 10	4.272	8	18.3
C-DRI	23.7	Reducing	1600 ± 10	5.21	6	21.9

The highest yield of 21.9 % was obtained when DRI was melted under a reducing flame. The yield obtained and maximum temperature attained was highest among all the different flame-input material-cavity configuration used in the preliminary melting studies (**Table 6.1, 6.2 and 6.5**). The number of individual metallic pieces was lowest and metal phase consolidation was highest when DRI was melted in a reducing flame (**Figure 6.7a**). Larger metallic nuggets were obtained when DRI was melted in a reducing flame (**Figure 6.7a**). The metallic nuggets were fused under a neutral flame (**Figure 6.7b and 6.7d**) and analysed using OES according to Section 2.3.4 to determine the composition of the metal**. Table 6.6** shows the chemical composition of the metal obtained by melting DRI separately under reducing flame and neutral flame.

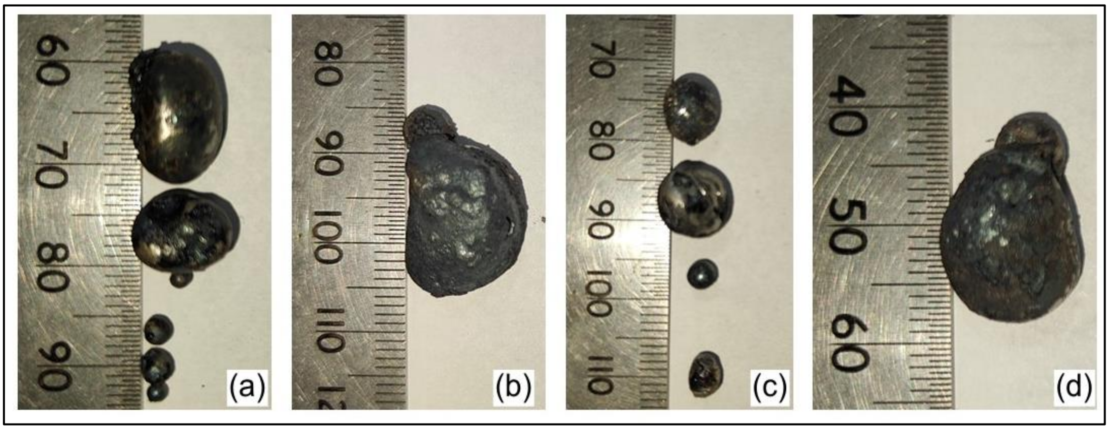

Figure 6.7: (a) Metal nuggets obtained by melting C-DRI in reducing flame (b) C-DRI-reducing flame Nuggets after fusion under a neutral flame (c) Metal nuggets obtained by melting C-DRI in neutral flame (b) C-DRI-neutral flame nuggets after fusion under a neutral flame

Table 6.6: Chemical composition of the metal obtained by melting DRI under different flames

Input material-Flame type	**Element (wt.%)**												
	Fe	C	Si	Mn	P	S	Cr	Ni	Al	Co	Cu	Ti	V
DRI-Reducing	97.1	0.38	0.23	0.10	0.15	0.13	0.96	0.74	0.09	0.08	0.05	0.01	0.03
DRI-Neutral	97.2	0.29	0.22	0.18	0.18	0.15	0.50	0.71	0.16	0.11	0.07	0.03	0.05

The Fe content remained consistent regardless of the flame type, as indicated in **Table 6.6**. However, notable variations were observed in the Carbon and Chromium content when transitioning from a neutral to a reducing flame. Specifically, the C content increased from 0.293 wt.% to 0.388 wt.%, while the Cr content rose from 0.504 wt.% to 0.962 wt.%. The rise in C content resulted from the additional carbon deposited by the reducing flame. Moreover, the reduction of Cr_2O_3 to Cr by carbon was intensified due to the higher carbon content present (**Table 6.6**). Most of the slag remained stuck to the cavity walls. Despite the best attempts, slag samples could not be prepared without incorporating the brick material, thus hindering the possibility of conducting slag analysis.

Based on the findings from Sections 6.2.1, 6.2.2, and 6.2.3, the cylindrical cavity emerged as the optimal configuration and was subsequently chosen for further studies. A cylindrical crucible, as described in Section 2.7 of Chapter 2, was employed for subsequent investigations. Additionally, the utilization of a reducing flame on DRI resulted in an improved yield, thus prompting its selection for further investigations.

6.2.4. Melting studies of C-DRI and H_2-DRI: a comparison

The effect of type of DRI and melting time on the yield and metal recovery was investigated by melting H_2-DRI and C-DRI separately according to the methods detailed in section 2.7 of Chapter 2. **Table 6.7** enlists the details of the studies conducted on H_2-DRI and C-DRI.

Table 6.7: Comparison of yield produced for different DRI type- time combinations

Raw Material	**Particulars**	**Melting Time (mins)**			
		4	**6**	**8**	**10**
C-DRI	Initial wt. of DRI (gm)	29.3	29.21	34.83	30.2
	Maximum Temperature attained (°C)	1550	1555	1608	1634
	Wt. of metal produced (gm)	5.10	7.21	9.60	10.50
	Yield	**17.40**	**20.80**	**27.60**	**34.80**
H_2-DRI	Initial wt. of DRI (gm)	29.30	28.05	27.88	30.20
	Maximum Temperature attained (°C)	1563	1571	1628	1640
	Wt. of metal produced (gm)	7.56	8.40	10.80	11.70
	Yield	**29.3**	**30**	**38.7**	**40.2**

In general, the yield increased with increase in melting time and temperature. In case of C-DRI, the yield increased from 17.4% to 34.8 %. Similarly in the case of H_2-DRI the yield increases from 29.3% to 40.2 % on increasing the melting time. An increase in melting time increases the duration for which the melt pool remains molten, which improves the slag-metal separation and the subsequent yield. The % R and % Fe_M in case of H_2-DRI was 90% and 89% (Section 5.4) respectively, which was greater than

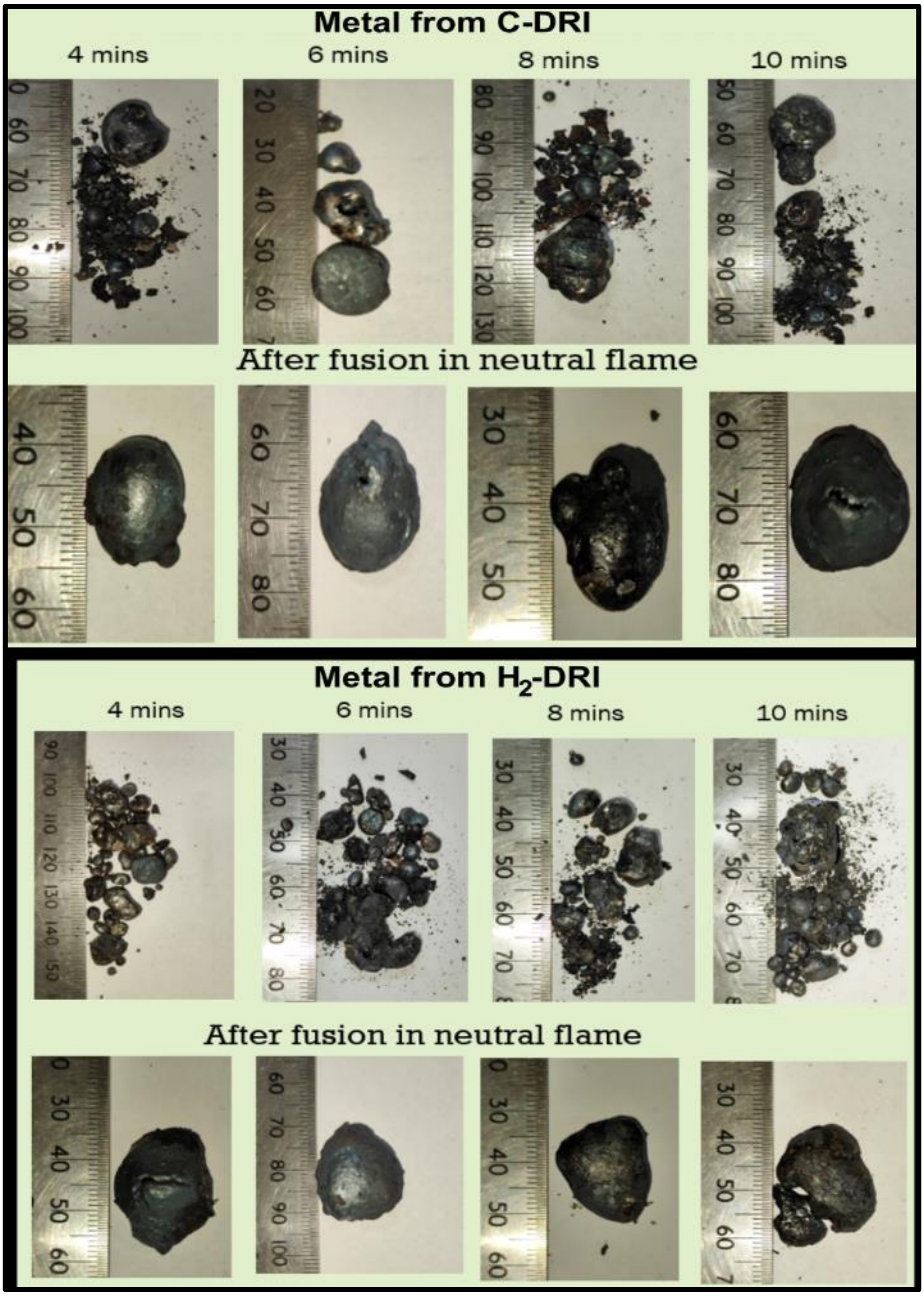

Figure 6.8: Metal nuggets obtained for various DRI type- melting time combinations

that for C-DRI (% R=80%, % Fe_M = 85%) (Section4.4). This meant that the metal-gangue separation in H2-DRI was more than that in C-DRI. Hence the yield obtained was better when H_2-DRI was used instead of C-DRI. **Figure 6.8** shows the images of metal obtained for dufferent DRI type-melting combinations.

The fused metal pieces obtained (**Figure 6.8**) were futher analyzed by OES to understand the variation in chemical composition with respect to change in melting time. **Table 6.8** shows the chemical composition of metal by using OES. The variation of C, S, Si, Fe and Cr with respect to changes in melting time is shown in **Figure 6.9**.

Table 6.8: Chemical composition of metal obtained for different DRI type- melting time combinations

Raw Material		**C-DRI**				**H_2-DRI**			
Melting Time (mins)		4	6	8	10	4	6	8	10
Element (wt.%)	Fe	96.50	96.70	96.80	97.30	97.00	97.20	97.48	97.50
	C	0.37	0.32	0.29	0.25	0.20	0.18	0.11	0.07
	Si	0.30	0.18	0.12	0.05	0.22	0.13	0.05	0.01
	Mn	0.15	0.10	0.08	0.03	0.05	0.05	0.03	0.02
	P	0.39	0.38	0.38	0.33	0.34	0.33	0.35	0.35
	S	0.15	0.15	0.15	0.15	0.09	0.08	0.02	0.02
	Cr	0.52	0.63	0.74	0.95	0.63	0.69	0.85	1.13
	Ni	0.82	0.81	0.84	0.80	0.85	0.84	0.81	0.80
	Al	0.40	0.35	0.21	0.03	0.27	0.26	0.11	0.01
	Co	0.25	0.24	0.23	0.05	0.19	0.07	0.09	0.08
	Cu	0.06	0.08	0.06	0.04	0.03	0.03	0.02	0.02
	Ti	0.03	0.02	0.04	0.01	0.01	0.02	0.00	0.00
	V	0.06	0.04	0.05	0.01	0.02	0.02	0.01	0.01

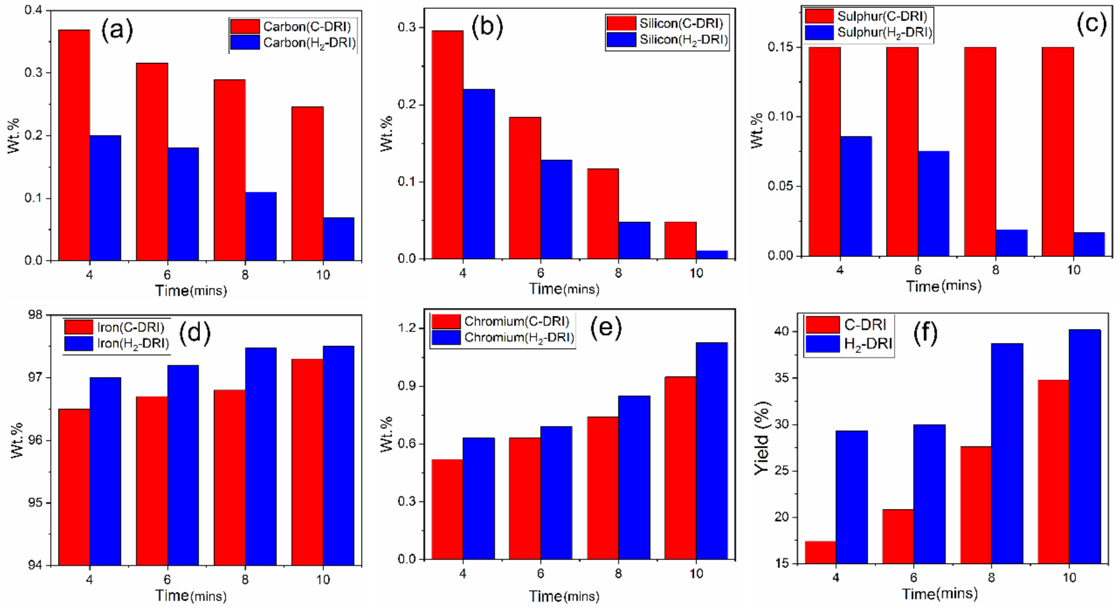

Figure 6.9: Comparison of (a) Carbon, (b) Silicon, (c) Sulphur, (d) Iron, (e) Chromium, (f) Metal Yield; with melting time and type of DRI

The carbon and sulphur content were significantly reduced when H_2-DRI was used (**Table 6.8 and Figure 6.10**). The carbon content in metal produced from C-DRI was a sum of the carbon present in the DRI and the carbon deposited from the reducing flame of oxyacetylene torch. Hence, it is higher than the carbon content of metal produced from H_2-DRI (**Figure 6.9a**). Sulphur content decreased to as low as 0.01 % when H_2-DRI was used instead of C-DRI (**Table 6.8 and Figure 6.9c**). The probable source of carbon and sulphur in C-DRI was the non-coking coal used for the reduction of pellets. The silicon content in metal also decreased when H_2-DRI was used (**Figure 6.9b**). The higher C content in C-DRI reduced some SiO_2 in slag back into the metallic phase according to the following chemical reaction that happens above 1513° C [17].

$$SiO_2 + C \Leftrightarrow [Si] + CO\ (g) \quad \text{..} (6.2)$$

The Fe & Cr content in metal was found to increase when H_2-DRI was used in place of C-DRI (**Table 6.8, Figure 6.9d and Figure 6.9e**). The % Fe_M of H_2-DRI with 89% was more than the % Fe_M of C-DRI (85%). Slag-metal phase separation was better in H_2-DRI and hence the Fe content was higher in the metal nuggets obtained from H_2-DRI.

Due to the lower metallization, the amount of unreduced iron oxides was more in C-DRI and hence more carbon was consumed to reduce the iron oxides in C-DRI. In other words, less carbon was consumed to reduce Iron oxides in H_2-DRI and most of it was used to reduce chromium oxides. Thus, the Cr content in H_2-DRI was higher than C-DRI.

The slag was characterized for its chemical composition by using XRF as described in Section 2.3.3 of Chapter 2. **Table 6.9** shows the chemical composition of slag. **Figure 6.10** shows the variation of Fe_2O_3 and Cr_2O_3 in slag with respect to changes in melting time.

Table 6.9 Chemical composition of slag obtained for different DRI type- melting time combinations

Raw Material		**C-DRI**				**H_2-DRI**			
Melting Time (mins)		4	6	8	10	4	6	8	10
Oxides (wt.%)	TiO_2	1.13	1.64	2.11	2.15	0.04	1.52	1.05	2.07
	MgO	1.45	1.92	1.18	1.01	1.84	1.81	2.00	1.71
	Al_2O_3	17.86	18.57	20.03	25.55	18.74	21.49	22.29	25.88
	SiO_2	23.54	27.01	33.55	36.69	25.37	30.71	36.61	37.06
	P_2O_5	0.11	0.13	0.08	0.06	0.12	0.10	0.15	0.15
	SO_3	0.07	0.09	0.11	0.12	0.04	0.04	0.03	0.03
	Na_2O	0.09	0.12	0.08	0.07	0.16	1.61	0.12	0.09
	CaO	5.37	6.17	7.49	7.11	11.08	11.67	7.68	9.97
	Cr_2O_3	**3.66**	**3.22**	**2.81**	**2.42**	**3.28**	**2.89**	**2.71**	**2.31**
	MnO	0.34	0.35	0.29	0.26	0.61	0.68	0.57	0.64
	Fe_2O_3	**46.52**	**40.53**	**31.81**	**24.20**	**37.69**	**26.55**	**26.40**	**19.47**
	NiO	0.21	0.22	0.24	0.21	0.24	0.21	0.24	0.23
	K_2O	0.05	0	0.12	0.13	0.12	0.03	0.07	0.15

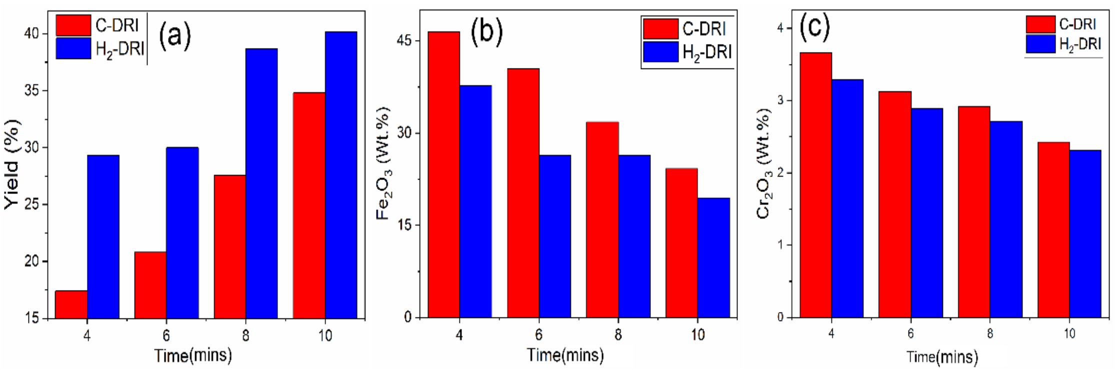

Figure 6.10: Comparison of **(a)** Metal Yield **(b)** Fe_2O_3, **(c)** Cr_2O_3; in slag with DRI type and melting time

The Fe_2O_3 content in slag decreased with increase in melting time for both C-DRI and H_2-DRI. Similar behaviour was observed with Cr_2O_3. The Fe_2O_3 and Cr_2O_3 content were noticiebly lower when H_2-DRI was used instead of C-DRI. The Fe_2O_3 and Cr_2O_3 content in slag was inversely proportional to metallic yield obtained. Higher metallization of H_2-DRI and better slag-metal separation withincreased melting times are the reason for such behaviour. Mass balance could not be done as it was difficult to determine the amount of slag produced. Some part of slag stuck to the cavity boundaries and it was difficult to remove them without including some amount of refractory material.

6.2.5. Mechanisms of recovery of valuable metals

Upon the application of the flame to the DRI, temperatures exceeding 1500°C (**Table 6.5 and 6.7**) were generated, melting the DRI and forming two distinct phases. The metallized iron in the DRI constituted the metallic phase. With a reducing atmosphere present due to the presence of C, CO gas, and H_2 gas, oxidation of the metallic phase was limited. Additionally, nickel (Ni) joined the metallic phase, primarily through the conversion of nickel oxide (NiO) to metallic nickel during the reduction stage itself. This is evident from **Table 6.8**, where the wt. % of Ni remained around 0.8, regardless of the choice of DRI and melting time, suggesting substantial conversion of NiO to Ni during the reduction stage.

The other oxides like Fe_3O_4, Al_2O_3, SiO_2, MgO and other oxides in the MMO formed the slag phase. Further recovery of Fe, Cr and transfer to the metal phase occurred due to various slag-metal and gas-slag interactions. The magnetite (Fe_3O_4) in slag transformed to Fe, which joined the metallic phase according to the following reactions

$Fe_3O_4 + 2\,C \Leftrightarrow 3\,Fe + 2\,CO_2(g)$ ΔG_r = -230.57 KJ (1500 °C)…………6.3

$Fe_3O_4 + 4\,H_2\,(g) \Leftrightarrow 3\,Fe + 4\,H_2O(g)$ ΔG_r = -32.69 KJ (1500 °C)…………..6.4

It is highly possible that the reduction of Fe_3O_4 and absorption of CaO in the molten slag occured simultaneously [17, 120]. Sulphur is usually present in the metallic phase. It is quite probable that sulphur is brought to slag phase by CaO [17] according to the reaction

$CaO + S + C \Leftrightarrow CaS + CO(g)$ ΔG_r = -181.68 KJ (1500 °C)……………6.5

The next important metal recovered in the metallic phase was Chromium (Cr). In the case of C-DRI, Cr was present as Cr_2O_3 and Cr_7C_3 (**Figure 4.6**). The Cr_2O_3 was reduced to Cr by C and it transferred to the metallic phase [13] by the reaction

$Cr_2O_3 + 3C \Leftrightarrow 2\,Cr + 3\,CO(g)$ ΔG_r = -120.11 KJ (1500 °C)…………6.6

At sufficiently high temperatures (> 1690 °C), the Cr_7C_3 was decomposed by Cr_2O_3 [13, 121] according to the reaction

$Cr_7C_3 + Cr_2O_3 \Leftrightarrow 9\,Cr + 3\,CO(g)$……………………………………………….6.7

In the case of H_2-DRI, Cr was present as a complex phase, Chromium Iron oxide ($Fe_{1.25}Cr_{0.75}O_3$) (**Figure 5.10**). As described in section 4.2.4.1 of Chapter 4, this sesquioxide was more reactive than chromite ($FeCr_2O_4$). Chromite was reduced to Cr_2O_3 and Fe by C according to the following reaction

$$2\,FeCr_2O_4 + C \;\Leftrightarrow 2\,Fe + 2\,Cr_2O_3 + CO_2(g) \qquad \Delta G_r = -34.89\text{ KJ }(1500\ °C) \ldots 6.8$$

The Cr_2O_3 formed is further reduced to Cr by **eqn 6.6.**

6.3. Conclusions

Exploratory melting studies were conducted on multimetallic pellets reduced with both carbon and Hydrogen. The following conclusions were drawn;

- The metallic yield obtained was increased from 34.8 % to 40.2 % when H_2-DRI was used instead of C-DRI.
- Using H_2-DRI, the Fe and Cr content in metal increased to a maximum of 97 wt.% and 1.2 wt.% upon increase in melting time. The C, S, and Si content simultaneously decreased to 0.069 wt.%, 0.0108 wt.%, and 0.0166 wt.%, respectively.
- The initial % R and %Fe_M of H_2-DRI (90%) was higher than C-DRI (85%) and thus it had a more pronounced effect on the recovery of iron and chromium.
- The metal produced from C-DRI has higher S and C contents than that by H_2-DRI. Coal used during reduction contributes to the S and C in the melt.
- The metal produced from C-DRI has higher Si contents than H_2-DRI. Carbon reduces SiO_2 to Si and brings it to metallic phase. Low initial carbon content could be the reason behind the low Si content of H_2-DRI.

Thus, H_2 reduction of MMO pellets are proven to give higher yield than C reduction.