INDUCTION MELTING OF FERRO-ALLOY FINES

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ABSTRACT

Ferro-alloys are sold according to the size grading specifications of users. Fines are produced during crushing and the amount produced depends on the crushing process and the physical characteristics of the ferro-alloy. The market value of fines has declined. Market demand is very weak and in some extreme cases is nonexistent. An induction furnace melt process has been developed to solve this problem. The process feasibility has been demonstrated on a small scale with charges of approximately 2.5 kg. The piloting was carried out using a 100 kW furnace with a metal liquid capacity of 140 kg. The operating parameters were determined during the pilot process. The procedures were defined and the equipment required for melting fines produced at the client's site was sized. With the production of ingots, the client can now recover the full value of ferro-alloy fines.

1. INTRODUCTION

The LTE provides research, development, and demonstration for electrical technologies used in industrial processes. Our primary objective is to provide industry with the essential tools to reduce their cost, and improve their productivity and product quality.

A ferro-alloy producer anticipates doubling production capacity. This expansion will involve an increase in fines produced during crushing. A market analysis has indicated that it will not be possible to recover the full market value of this fines surplus. These fines could be upgraded by melting them down to cast into ingots, to produce ferro-alloys with a larger size grading.

The melting temperature of ferro-alloys is generally between 1400ºC and 1600ºC. Induction and electric arc furnaces are technologies that are capable of melting fines. An electric arc furnace can easily treat metal fines, but the induction furnace is more appropriate for this case given the low tonnages involved. The operating principle of induction is as follows: an electric conductor must cut the flux lines (magnetic flux) generated by the passage of current in a coil; within this conductor a voltage is generated, which gives rise to the induction currents. These currents heat the object via the Joule effect. The material to be heated must accept a magnetic coupling, as induction heating occurs directly within it.

Firstly, charge characterization measurements were carried out and melt tests were run on a laboratory rig to validate the feasibility of melting fines by induction heating. The rig had an operating power of 10 kW. This work demonstrated the feasibility of induction as a technology to melt ferro-alloy fines.

An induction melting furnace with a maximum capacity of roughly 140 kg of liquid metal was used for the pilot tests. This furnace is connected to a power supply with a maximum power of 112 kVA. The induction melt experiments were conducted on approximately one tonne of ferro-alloy fines.

This process can be adapted to different ferro-alloys such as ferrochrome, ferromanganese, ferronickel, ferroniobium, ferrosilicon, ferrovanadium and others.

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2. CHARGE CHARACTERIZATION

Charge characterization measurements are shown in Table 1. System measurements between 1 and 30 kHz were performed. L is inductance of the system. The Q factor is an index of the coupling quality on the charge. The method for evaluating the percentage of energy to be transferred to the charge involves comparing the Q factor of the system with and without a charge. Those charges comprising only fines have a Q factor that is nearly identical with or without charge, indicating that there will be no coupling. The mixture of large pieces and fines facilitates coupling where 25-30% of the energy is transferred to the charge. For the feasibility experiments, a frequency of 30 kHz was chosen on the basis of these measurements. These result are summarised in Table2. From Table 2 it is evident that magnetic coupling will not occur with fines of 3 mm or less. The addition of larger pieces dispersed throughout the charge improves the magnetic coupling. These pieces are obtained using a 25 mm mesh sieve. The outcome of this system characterization was a charge configuration using large pieces combined with the fines.

Table 1. Inductor characterization without charge.

Frequency	**Inductor characterization**	
Hz	L (μH)	Q
1,000	12.8	0.9
5,000	12.51	4.3
10,000	12.48	8.3
20,000	12.44	15.5
30,000	12.42	22

Table 2. Inductor characterization with different charge.

Frequency	**Inductor characterization with different charges**							
	Fines 0-105 mm		**Fines 0-2 mm**		**Fines 0-3 mm**		**Fines 0-3 mm with 25 mm pieces**	
Hz	L (μH)	Q	L (μH)	Q	L (μH)	Q	L (μH)	Q
1,000	13.09	0.9	12.78	0.9	12.76	0.9	13.7	0.9
5,000	12.79	4.3	12.82	4.4	12.52	4.4	12.9	4
10,000	12.76	8.4	12.49	8.5	12.49	8.4	12.7	7.1
20,000	12.72	15.7	12.45	15.8	12.45	15.6	12.5	11.94
30,000	12.7	22.2	12.43	22.3	12.42	21.6	12.4	15.73

3. FEASIBILITY STUDY

3.1 Feasibility Study Rig Description

Figure 1 shows the rig used for the process feasibility study. In the first experiments only one alumina crucible was used, but the rapid heating of the charge created thermal limitations that caused it to fracture before the metal liquefied. It was necessary to stop the test when this occurred due to the dangers of liquid metal leakage. Different charge configurations and preheating the crucible were tried, but with no improvement. Finally, the rig design was modified by using two crucibles, one nested within the other with the space between the two filled with sand. The ferro-alloy charge was placed in the interior crucible. During the experiments, the interior crucible broke with the thermal shock but the rig layout prevented leaks of liquefied metal.

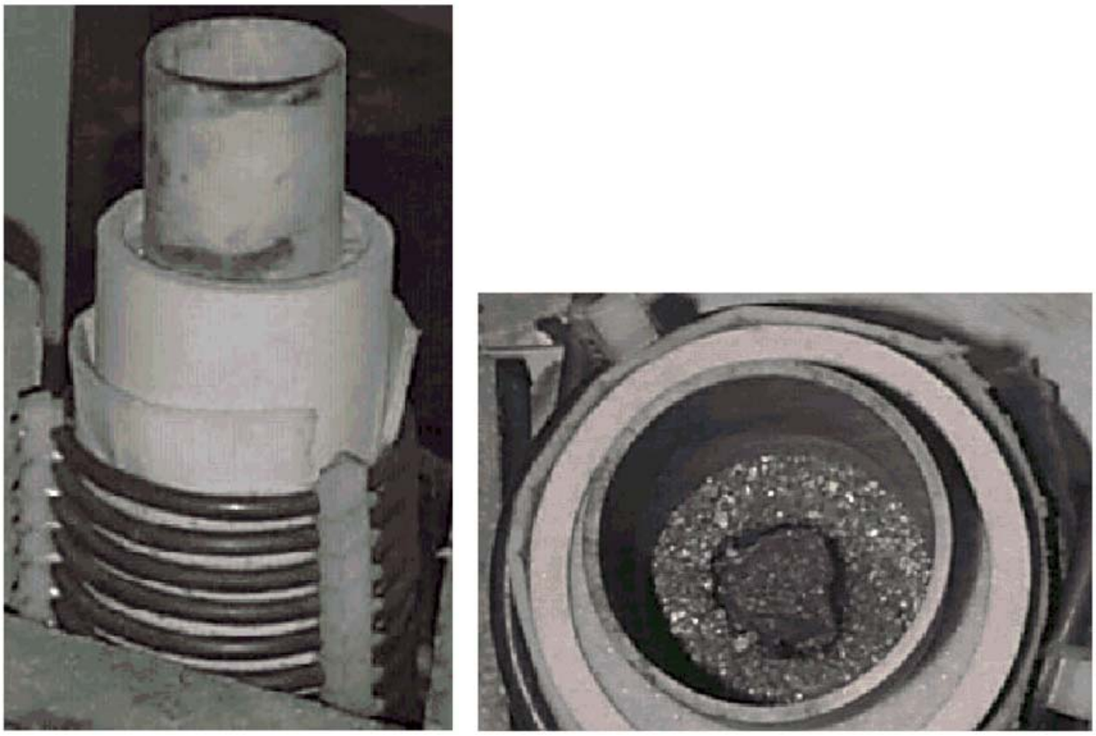

Figure 1. Rig setup.

3.2 Feasibility Demonstration Results

Inductive coupling first occurs on the 25 mm pieces that are heated. These then transfer energy to the fines via conduction and radiation. The experimental results are presented in Table 3. During the first experiment, the charge was heated for much too long. The last experiment was run using .0-105 □m-size material obtained from a dust collector comprised of metal fines and oxide. In the other experiments, the fines melted satisfactorily, producing a metal ingot corresponding to the charge weight. This ingot can now be crushed to produce the desired particle sizes for ferro-alloy users.

To successfully melt the fines, larger pieces must be included in the first charge during the furnace start-up. For successive charges, a liquid metal melt corresponding to 25-35% of the furnace capacity must be maintained in the furnace. These experiments showed the feasibility of using induction technology for melting ferro-alloy fines.

Table 3. Experimental results.

	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**
Fine sizes (size grading)	0-3 mm	0-3 mm	0-3 mm	0-2 mm	0-105 µm
Starting pieces	25 mm	25 mm	25 mm	25 mm	25 mm
Pieces weight	709 g	720 g	721 g	713 g	824 g
Fines weight	1792 g	1780 g	1880 g	1787 g	1676 g
Charge weight	2501 g	2500 g	2601 g	2500 g	2500 g
Metal weight after	2000 g				
Total weight after	2607 g	2510 g	2600 g	2519 g	2560 g
Slag	607 g				
Metal temperature		1754 °C	1744 °C	1731 °C	1733 °C
Heating duration	23 minutes	9 minutes	8.2 minutes	7.5 minutes	10 minutes

4. PILOT FURNACE

4.1 Pilot Furnace Description

The LTE induction furnace was used for the process demonstration. Figure 2 provides a diagram of an induction furnace. Its power supply has a maximum operating power of 112 kVA. Its maximum capacity is approximately 140 kg of liquid metal.

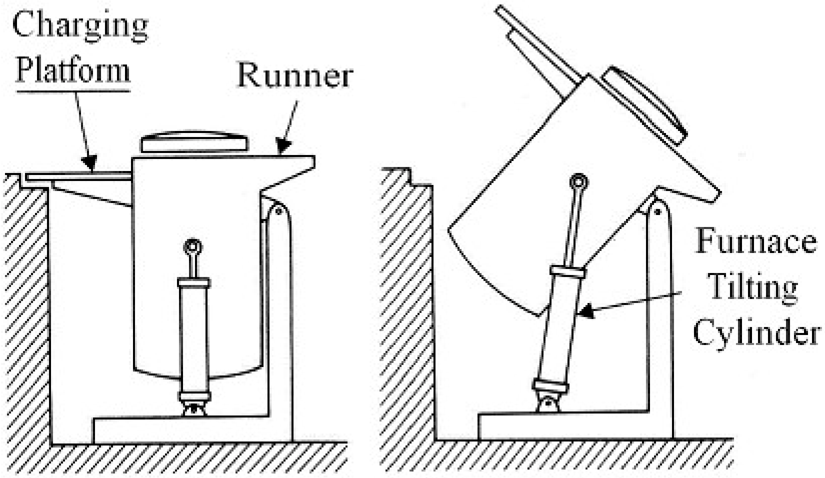

Figure 2. Induction furnace diagram.

The furnace chosen for piloting the process has a crucible refractory capable of withstanding a liquid metal temperature of 1750ºC and a conventional plastic refractory for the runner. The crucible refractory is a dry neutral spinel-forming vibratable refractory designed for installation by mechanical vibration. Its primary application is for lining coreless induction furnaces for melting carbon and alloyed steels.

To start up the ferro-alloy induction process, an ingot of the same ferro-alloy, weighing roughly 15 kg, must be placed in the furnace. It is positioned in the centre of the furnace and is surrounded with fines to protect the refractory during the furnace start-up.

4.2 Pilot Induction Furnace Results

The fines are loaded manually into the furnace. Table 4 presents an energy analysis of the experiments. The electric measurements were carried out at the system's 600 V input. The apparent power and energy represent the billable energy consumption for operating the furnace. The active power is the useful energy transferred to the metal in the furnace and also includes system losses, i.e. the losses in the conversion transformer, the high frequency power supply, the power cables and the coil. The power supply used has a maximum operating power of 112 kVA.

The energy needed to melt a metal is the sum of the energy calculated for bringing the metal to the desired temperature plus the losses of the melting furnace. The latter are a function of furnace size, operating temperature and heating time. After preheating, the furnace losses are considered only as a function of time because a liquid metal bath is maintained while the fines are being charged. The melting time depends on the operating power and the amount of fines charged. For experiments 2-5, 104-114 kg of fines were charged. Figure 3 shows the logarithm of the energy needed to melt a tonne of fines over time. A straight line was drawn through these points to extrapolate the energy needed to melt a tonne of fines in 45 min. The resulting energy consumption was 850 kWh/t of fines. On the basis of this figure it was determined that 140 kVA would be needed to melt 110 kg of fines in 45 min, using a frequency of 1.8-1.9 kHz.

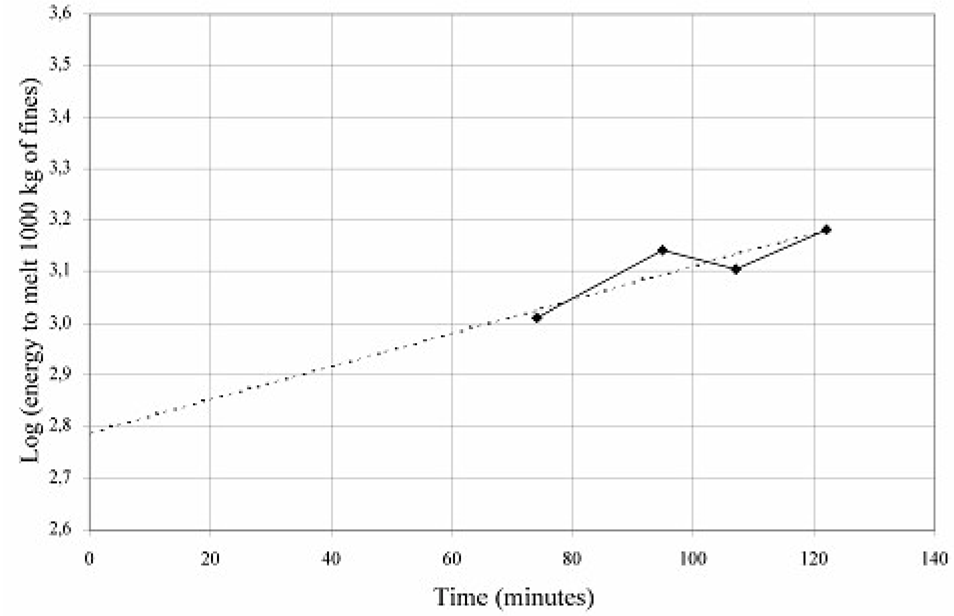

Figure 3. Logarithmic curve of the energy needed to melt a tonne of fines over time.

5. SIZING AND COST EVALUATION OF AN INDUCTION FURNACE

The melting experiments established that the energy consumption would be a maximum of 1000 kWh/t for melting fines, a value obtained during the experiments. An energy consumption of 850 kWh/t to melt 110 kg fines in 45 min was extrapolated from the experimental results. It is evident that a larger furnace is more energy-efficient. Energy losses in a furnace are a function of its surface, which increases with the square of its diameter. When the charging capacity increases with the cube of the diameter, the losses by weight of metal in the furnace will decrease. This consumption value will be used to size the furnace.

The underlying premises are an operation of 2000 h per year and two scenarios of quantity of fines to treat, i.e. 500 and 1000 t per year. The energy consumption is 850 kWh/t with a power factor of 85 %. The furnace dimensions are calculated as follows: the energy consumption is divided by the power factor to obtain the apparent energy consumption; this figure is then divided by the available time and then multiplied by the quantity of fines to be treated. The resulting figure is the apparent power required to treat the fines in the available time. For the first scenario, a processing capacity of 500 t per year requires a 250 kVA furnace. In the second scenario, a processing capacity of 1000 t per year requires a 500 kVA furnace.

The cost of a 250 kVA furnace is roughly US$150,000, and for a 500 kVA furnace the cost is roughly US$175,000.

6. CONCLUSIONS

The pilot study conducted with a 112 kVA furnace at the LTE demonstrated the feasibility of using an induction furnace to melt ferro-alloy fines. This process provides a solution to the problem of marketing fines, by producing superior size grading with an improved market and sales price.

A fines melting process has been developed for a type of ferro-alloy. It can also be used to melt fines of ferro-alloys such as ferrochrome, ferromanganese, ferronickel, ferroniobium, ferrosilicon, ferrovanadium and others.

7. REFERENCES

[1] Orfeuil, M., “Électrothermie Industrielle”, Dunod, France, 1981, 803 pages.

Table 4. Energy use.

	Time	Charge	Apparent average power	Apparent energy	Apparent energy use	Average active power	Active energy	Active Energy use	Average power factor
	minutes	kg	kVA	kVAh	kVAh/kg	kW	kWh	kWh/kg	(%)
Preheating	127		71.3	148.9		61.3	128		86
Charge #1	135	70	84.3	189.7	2.71	74.2	166.7	2.38	88
Preheating	122		73.2	146.1		66.1	131.9		90
Charge #2	122	112	95.5	195.6	1.75	83.4	170.9	1.53	87
Charge #3	107	114	92.4	165.3	1.45	81.1	144.9	1.27	88
Preheating	106		85.7	137.5		77.1	123.2		90
Charge #4	95	104	104.7	164.5	1.58	92.1	144.6	1.39	88
Charge #5	74	110	104.2	135.7	1.23	91	113	1.03	83