Impact of Electrode Paste on Soderberg Electrode Performance

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1. ABSTRACT

TEMCO has been operating for nearly 40 years producing manganese based ferroalloys in electric submerged arc furnaces using Soderberg electrode technology.

Electrode paste contributes up to 5% of total production costs. Indirect electrode costs through breakages also contribute to increased production costs. Continuous improvement of electrode performance has been a key component of cost reduction in improving business competitiveness at TEMCO.

TEMCO has been independent of any electrode paste suppliers and able to test various electrode pastes. In addition to comparative trials, TEMCO has extended experience operating with electrode paste from four suppliers.

The impacts of these pastes on electrode performance, as well as other key initiatives, are reviewed.

2. INTRODUCTION

There are a significant number of pyrometallurgical operations that utilize Soderberg electrode technology in the world. Producers of Ferro alloys are a major user of this technology.

TEMCO is one such operation that produces manganese ferroalloys. In the manganese alloy industry, electrode paste contributes up to 5% of the total production costs. Indirect process impacts due to electrode breakages, annually can lead to a reduction in power utilization (2%), reduced operating time (0.2%) and increased paste consumption (5%), which all further increase production costs. It is expected that a similar or greater relationship exists for other Soderberg electrode consumers.

Minimization of all direct and indirect electrode costs on the business, requires optimum electrode performance, which is made up of a combination of factors:

<u>Electrode Paste Selection</u>

- Composition
- Variability and quality control
- Level of contaminants from packaging/storage
- Baking characteristics
- Specific consumption

<u>Operations Performance</u>

- Safe packaging
- Stability during normal operations and following shutdowns
- Ability to maintain electrode length
- Consumption rates under varying furnace conditions

Historically electrode performance had been primarily focused on electrode paste consumption and unit cost. However evaluating electrode pastes should be based on total electrode performance.

This paper aims to present the chronological steps taken at TEMCO to improve electrode performance through paste selection as well as electrode management.

3. TEMCO BACKGROUND

TEMCO was established in 1960 by the Broken Hill Proprietary Company Ltd. (BHP)[1]. The Bell Bay site in Tasmania, Australia was chosen as the new site for ferroalloy production to replace the aging Newcastle alloy works. The Tasmanian site had access to a sheltered deep water port, as well as favorable electricity rates.

The production capacity was destined for internal BHP consumption at BHP's three steelworks in Australia. Initially South African manganese ore was smelted.

In 1966, BHP commenced production of manganese ore at the Groote Eylandt Mining Company Ltd. (GEMCO) and TEMCO began to use exclusively GEMCO manganese ore. At the same time TEMCO began the first of it's many expansions with the addition of Furnace 2. See Appendix 1 for other expansion details and Appendix 2/3 for furnace details/capacities.

The electrode systems installed on Furnace 1 and 2 were spring loaded conventional[2] Elkem contact clamps, which were replaced by the Elkem modular holder[2] system in 1987. On Furnace 3 and 5 the original membrane holder[2] Elkem contact clamp system has been retained.

In December 1998 TEMCO became part of a joint venture between Billiton plc and Anglo American Corporation.

4. CHRONOLOGICAL ELECTRODE PERFORMANCE HISTORY

1962 – 1986

All furnaces at TEMCO are designed by ELKEM A/S. From 1966 TEMCO used GEMCO manganese ore exclusively. This MnO_2 ore was high grade, but also contributed to a lower electrically resistive charge and higher oxidation rates of electrodes than alternatives. Consequently it became very difficult to achieve good electrode penetration. Electrode slipping was very sensitive to reductant levels/sizing. At this time slipping was manually initiated, and with insufficient feedback on amount of baked electrode and maximum slipping rates possible, the electrodes tended to be underslipped. Short electrodes, with high off gas temperatures and reduced smelting efficiency were often experienced. This necessitated frequent furnace stoppages to physically measure electrode lengths. Typically up to 4 times per month.

In 1976 sinter became available[3]. The Mn_3O_4 porous ore enabled a higher effective charge resistivity and enabled specific electrode consumption to be reduced. The combination enabled greater control over electrode penetration and reduced the requirement to physically measure electrode lengths to once per month. However overall electrode performance, while improved, was still average due to lost operating time and reduced smelting efficiency from variable electrode lengths.

From 1962 to 1982 TEMCO used paste from supplier A and then the opportunity arose to use alternate electrode paste. A 110 tonne shipment of supplier B paste was trialed in October 1982 on No. 3 electrode in Furnace 2. The performance was monitored closely against No. 2 electrode, which was on paste A. The results from this small basic trial showed paste B gave a slight increase in paste consumption compared to paste A. TEMCO decided to continue sourcing from supplier A who provided regular customer service, quality assurance, laboratory facilities and exchange of technical information.

The quality of paste from supplier A has improved over the period between 1962 to 1987.

1987

The most significant step change in electrode performance at TEMCO occurred in 1987 when computerized slipping was introduced as part of the installation of SAFEPAC-14[4].

This system results in:

- no regular requirement for physical length measurements
- stable electrical control as less top/bottom limit occurrences
- no green failures (provided system not bypassed)
- elimination of short electrodes
- more stable process control

At the same time the conventional electrode holders on Furnace 1 and 2 were replaced by the new Elkem modular electrode holders[2]. These enabled the baking zone to be raised in the column and improved the electrode break resistance.

1988 – 1994

This was a period of consolidation in electrode management and focus on reduction of electrode unit costs. It was recognized that the most competitive electrode paste unit cost would not come from a sole supplier arrangement. So a trial was arranged at Furnace

3 with two paste alternatives:– C and D, for 18 and 8 weeks respectively allowing one week for change over between each paste. The base period was the preceding 25 weeks on paste A.

Furnace 3 operated at a load of 25-26 MW, a current of 95-103 kA and a resistance of 0.95-0.82 mΩ during this period.

Electrode comparison trials should be designed to recognize:

- the difference in specific electrode consumptions in each electrode. It is incorrect to assume that the consumptions on all electrodes are equal, particularly over short time periods.
- that metallurgical conditions in furnaces do vary and impact on electrode consumption. Trial periods need to be of a minimum duration to reduce the statistical influence due to process variation.
- the need to have exposure to furnace interruptions which is difficult over short trial periods.

The weekly trend and summary of specific electrode paste consumption of Furnace 3 trial can be seen in Figure 1 and Table 1 respectively. The typical electrode paste specifications are in Table 2.

PASTE SUPPLIER	kg/MWhr
A	5.7
C	5.7
D	4.4

Table 1 – Furnace 3 Trial Paste Consumption Summary

The trial concluded that there was some difference between the three pastes.

The decision to adopt a two paste supplier policy in May 1995 became the focus for developing a competitive supply position. As a result, the unit cost for electrode paste at the time was reduced by 14%.

The typical plant consumption scenario for electrode paste became:

- F1/F2 supplier A 2170tpa HCFeMn
- F3/F5 supplier D 2200tpa SiMn

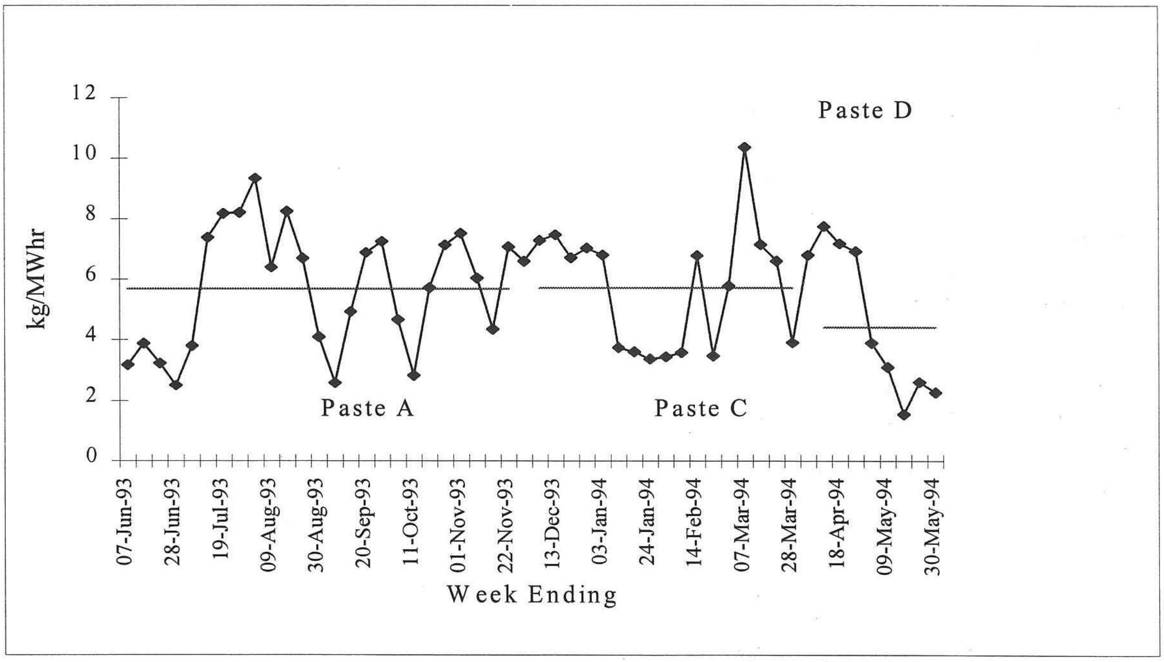

Figure 1 – Furnace 3 Trial Weekly Paste Consumption

PASTE SUPPLIER		A	C	D
Unbaked Paste				
Apparent Density	g/cc	1.55	1.60	1.60
Volatile Matter	%	10	13	13.8
Ash	%	6	7	6.4
Fixed Carbon	%	85	80	83.3
Plasticity	%	15-40	15-25	15-25
Binder Softening Point	C	63	60-65	53*
Baked paste				
Density	g/cc	1.36	1.42	1.41
Electrical Resistivity	μΩ.m	68	80	65.7
Compressive Strength	kg/cm^2	17	15	16.9
Ash	%	5	8	7.3

Table 2 - Typical Specifications of Paste used in Furnace 3 Trial

*The first shipment of paste was ordered with a binder softening point of 53°C. On arrival in Tasmania, some of the shipment had slumped and was badly deformed. Future shipments were ordered at 60-65°C.

1995 – 1996

With electrode costs reduced, the focus for cost reduction shifted to raw materials. During this period, significant changes were made:

- increased power loading and current density
- utilization of waste spillage raw materials directly back into the furnaces
- reduction in lump manganese ore bottom size from +11mm to +8mm
- closer plant maximum demand and furnace load control
- reduction in sinter bottom size from 6.7mm to 3mm
- increased slipping rates

The net result on the process saw increased charge density, a reduction in charge porosity and increased electrode movement. Electrode performance began to deteriorate, but was masked by other operational difficulties. See Table 3 for summary.

Furnace 5 began to exhibit fuming inside No.3 electrode column in 1996. As a consequence, supplier D was requested to provide electrode paste with a softening point of 75°C and plasticity of 30-50% to improve flowability. After extensive testing of the electrical system, it was found the over heating in No. 3 electrode, was due to circulating current caused by low tension flexible break down. After replacement of the broken/ damaged flexibles, the fuming problem at Furnace 5 ceased.

Period	**F3**			**F5**		
	No Shuts >4hr	Paste	% Breaks	No Shuts >4hr	Paste	% Breaks
1995 – 1996	21	63°C A	19.0	18	63°C A	27.7
	30	60-65°C D	16.7	14	60-65°C D	21.4
				10	60-65°C C	30.0
1997 – 1998	18	63°C A	44.4	3	63°C A	33.3
				23	70-75°C D	52.1
1999	14	63°C A	78.6	8	63°C A	62.5
	3	60-65°C D	0.0	2	60-65°C D	0.0
2000	2	60-65°C D	0.0	11	60-65°C D	0.0
	9	68°C E	0.0			

Table 3 - Electrode Breakage Summary for Shutdowns > 4 hours

1997 – 2000

Following the upgrade of Furnace 3 in 1997 as shown in Appendix 1, when the depth of the furnace was increased by 400mm and operated with higher current densities, the deterioration in electrode performance at Furnace 3 and Furnace 5 was highlighted.

Furnace 3, after the upgrade was aiming to operate at a load of 32 MW, a current of 110-115 kA and resistance of 0.85 mΩ.

Due to a deterioration in electrode performance (Table 3), pastes A and D were interchanged between Furnaces 1 and 2 and Furnaces 3 and 5. However electrode breakages continued to occur when shutdowns exceeded 4 hours.

The consequence of this change created problems with liquid paste levels at Furnace 1 and 2. These electrodes operated on lower current densities (see Appendix 2) and the conditions were unable to generate sufficient heat to adequately melt the 70-75°C softening point binder in paste D. This resulted in low liquid paste levels, layering of paste from successive drums and poor electrode formation. This lead to increased specific paste consumption by 13.8%, as shown when comparing two 15 week periods in Table 4. Therefore, supplier D was requested to reduce the binder softening temperature to 60-65°C as a compromise paste quality that could service all TEMCO furnaces. Furnace 1 and 2 would have preferred a lower temperature but slumping of paste cylinders and fuming in electrode columns at Furnace 3 and 5 might have been an issue.

Period	2/6/97 to 15/9/97	8/6/98 to 21/9/98
PASTE	63°C A	70-75°C D
Consumption kg/MWhr	3.61	4.11

Table 4 – F1/F2 Specific Paste Consumption

During this period, extended campaigns were run on both suppliers A and D paste at Furnace 5. See Figure 2 and Table 5. However due to the electrode breakage problems and process changes, the consumption rates are difficult to compare.

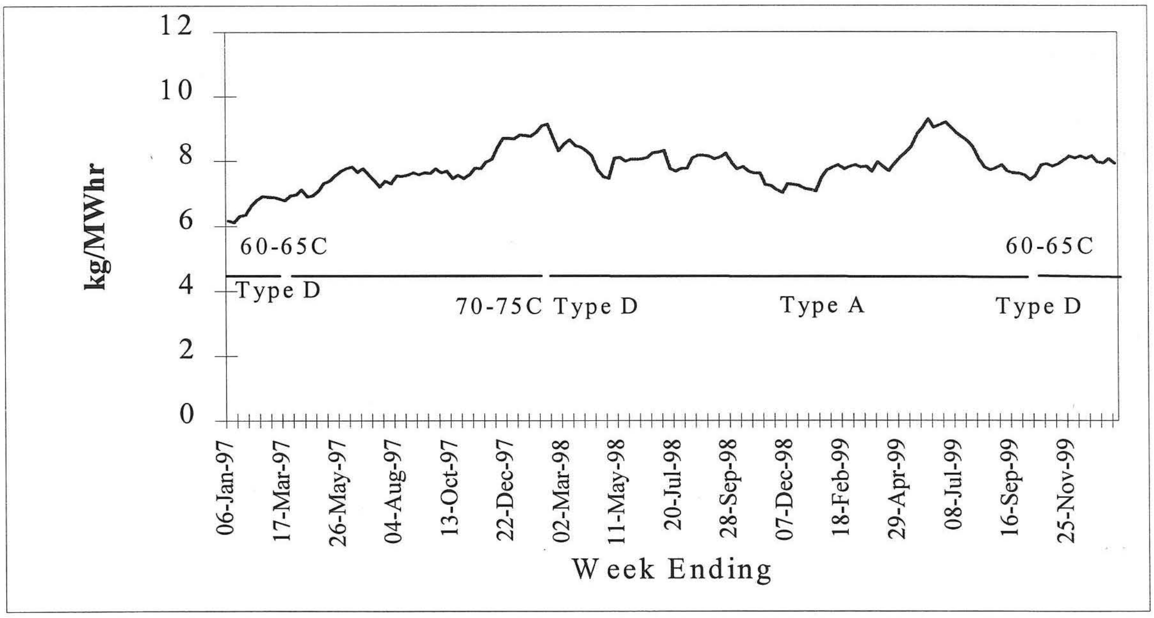

Figure 2 - Paste Consumption Comparison at Furnace 5

Period	1/1/97 to 16/3/97	24/3/97 to 7/4/97	14/4/97 to 16/2/98	23/2/98 to 14/10/99	21/10/99 to 31/12/99
PASTE	60-65°C D	63°C A	70-75°C D	63°C A	60-65°C D
Consumption kg/MWhr	6.79	6.77	7.78	8.00	8.06

Table 5 – Paste Consumption Comparison at Furnace 5

A review was conducted of the electrode breakages, and it was observed at Furnace 5 (open furnace) that the electrodes were initiating small cracks just below the contact clamps. It was postulated that with the high slipping rates, high electrode current operation, additional mechanical stress from higher fines loading and increased electrode movement, cracks were being generated before the electrode was fully baked and cured.

An electrode management plan was prepared in 1999 whose key initiatives were to:

1. Limit the maximum current density to 5.8 A/cm^2 from 6.2 A/cm^2
2. Improve the shear stress capability of the electrodes by increasing the electrode fin window area are by 50%.
3. Slow down the amount of electrode movement through refinements to the computer control algorithms by over 100%.
4. Increase the contact clamp cooling water by 5°C to 40°C to raise the baking zone behind the contact clamps
5. Modify the shutdown routines to minimize thermal stresses.
    - Ramp down electrode current prior to shutdown
    - Lift electrodes on power off
    - Coverage of exposed electrode
    - Minimize draft in furnace
6. Modify the startup routines to minimize thermal stress.
    - Higher starting currents
    - Slower ramp rates
7. Evaluate the quality of the paste required for the process.

The electrode management plan was expanded in 2000 to include additional items:

- Increase the fin window area by an additional 50% to improve the shear strength
- Remove the stress concentrating square corners in fin windows as cracks were observed starting at the corners
- Conduct a trial at Furnace 3 using high conductivity electrode paste from supplier E to reduce the thermal stress gradients in the electrodes

A comparison of the paste specifications used in the Furnace 3 trial is shown in Table 6. Table 7 compares the operating data from the trial.

During the trial period both electrode pastes performed well with paste E having a consumption of 3.93 kg/MWhr and paste D 4.52 kg/MWhr. This is a 13% better consumption on paste E.

Figure 3 shows how paste consumption can vary with furnace operating conditions. Therefore average consumption values as shown in Table 7 can not be accepted as absolute.

	TEMCO Specifications	Paste D	Paste E
Green Paste			
Apparent density	1.55-1.60 g/cm^3	1.6 g/cm^3	1.64 g/cm^3
Plasticity	15-25%	25%	40-60%
Ash	5-7%	6.4%	3.1%
Volatiles	10-13%	13.6%	15.3%
Fixed Carbon	80-85%	79.8%	81.6%
Binder Softening point	62 °C	60-65 °C	68 °C
Baked Paste			
Apparent density	1.36-1.41 g/cm^3	1.4 g/cm^3	1.41 g/cm^3
Electrical resistivity	68 Ohm.mm^2/m	65.7 Ohm.mm^2/m	47.0 Ohm.mm^2/m
Young's Modulus	350-450 kg/mm^2	440 kg/mm^2	530 kg/mm^2
Thermal conductivity	8.0 W/mK	8.8 W/mK	5.1 W/mK

Table 6 – Typical Paste Specifications for high conductivity paste trial

Paste	E				D			
Average on time load	30.0 MW				30.0 MW			
Availability	97.1 %				97.2 %			
MWhrs / Tapped Tonne	3.77				3.70			
MWhrs / cm	8.0				7.0			
kg / cm	31.43				31.5			
kg / MWhr	3.93				4.52			
kg / Tapped Tonne	19.6				22.6			
Slipping rates cm / day	E1 34	E2 40	E3 39	Ave 38	E1 41	E2 45	E3 46	Ave 44
Average kA's	103	102	105	103	104	104	106	105
Average mΩ	0.88	0.93	0.95	0.92	0.87	0.89	0.91	0.89
Shutdowns > than 4 hours	9				4			
Electrode breaks	0				0			

Table 7 – Furnace 3 Trial Operating data

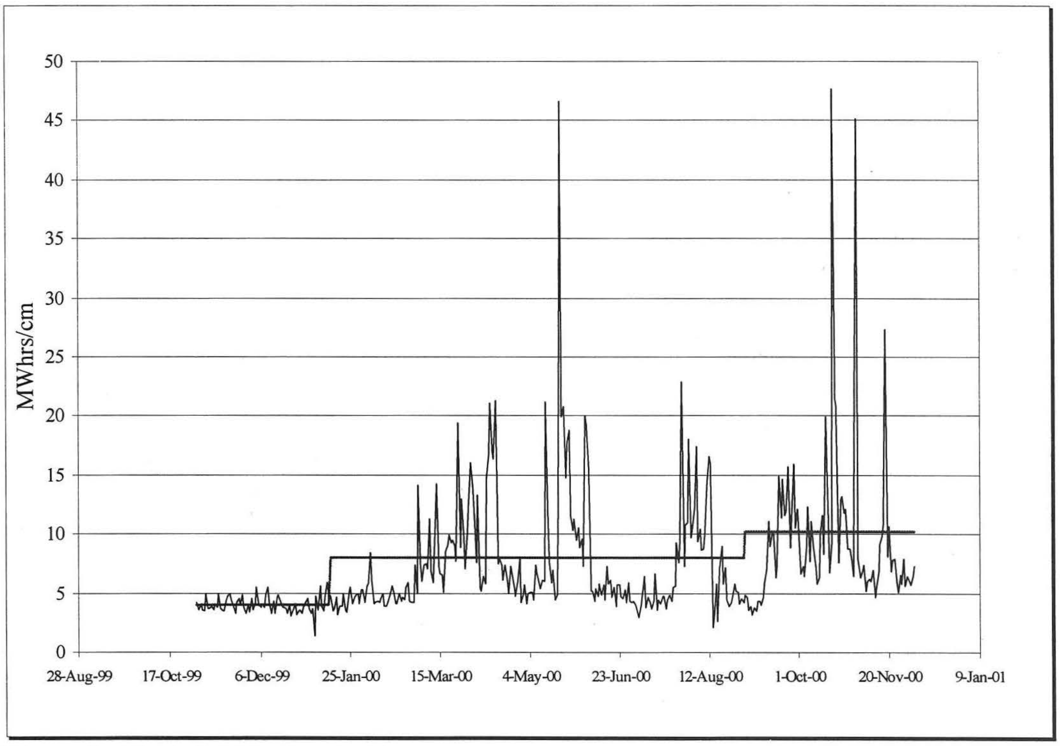

Figure 3 – Daily MWhrs/cm for Furnace 3

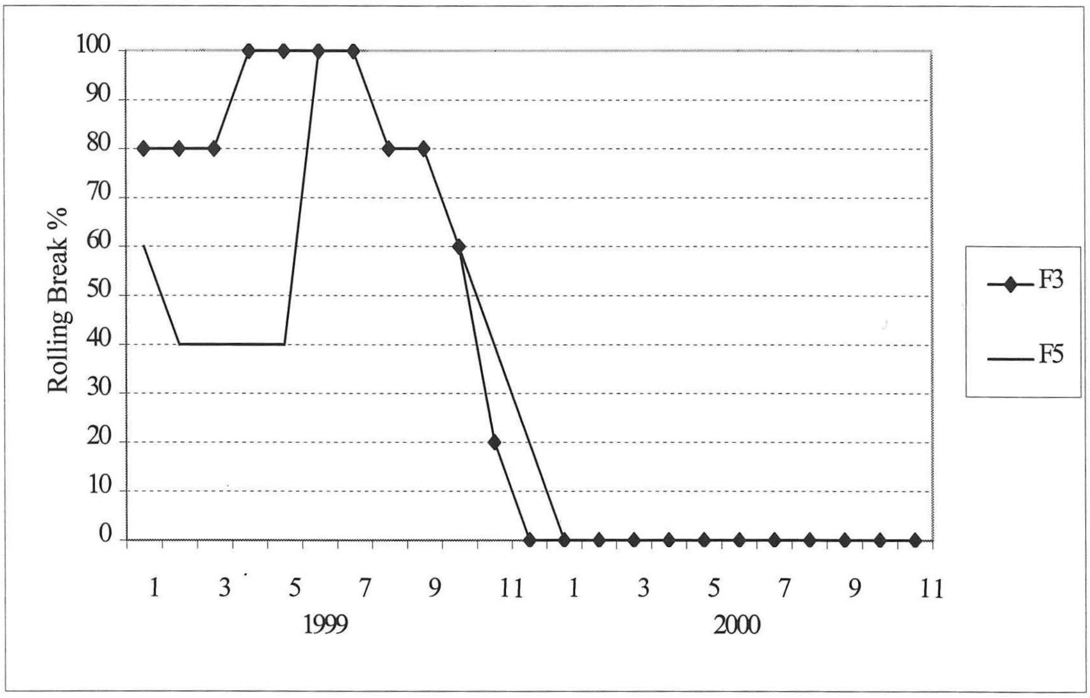

Figure 4 –Electrode Break Rate Improvements

The majority of the electrode management plan was implemented by July 1999. Results are encouraging as shown in Table 3. Figure 4 shows the trends for the rolling break failure rates at Furnace 3 and 5. The rolling period is for the last six shutdowns that exceeded 4 hours in length.

It shows how a complete electrode management project at TEMCO has contributed to reducing the number of electrode breaks.

5. CONCLUSION

Properties of electrode paste are important and must be selected to facilitate maintenance of adequate liquid paste levels. Paste quality from every supplier varies within a tolerance due to quality of raw materials used and the paste manufacturing process. All the major suppliers have the capability to produce good quality electrode paste to meet the criteria and TEMCO's quality specifications.

Provided quality meets the required specification, TEMCO experience has shown that good electrode management practices have a greater impact on electrode performance than type of electrode paste.

6. REFERENCES

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2. Asphaug, B., Innvaer, R. *Introduction to the Soderberg Electrode*, Elkem Carbon publication, 1997
3. Hooper, R. T. *Production and Smelting of Manganese Sinter*, Electric Furnace Conference, Toronto, Ontario, Canada, 5-8 December, 1978
4. Ray, C. T., Olsen, A. H. *Computer Control of Four Furnaces in Tasmania*, 1987 Electric Furnace Proceedings.

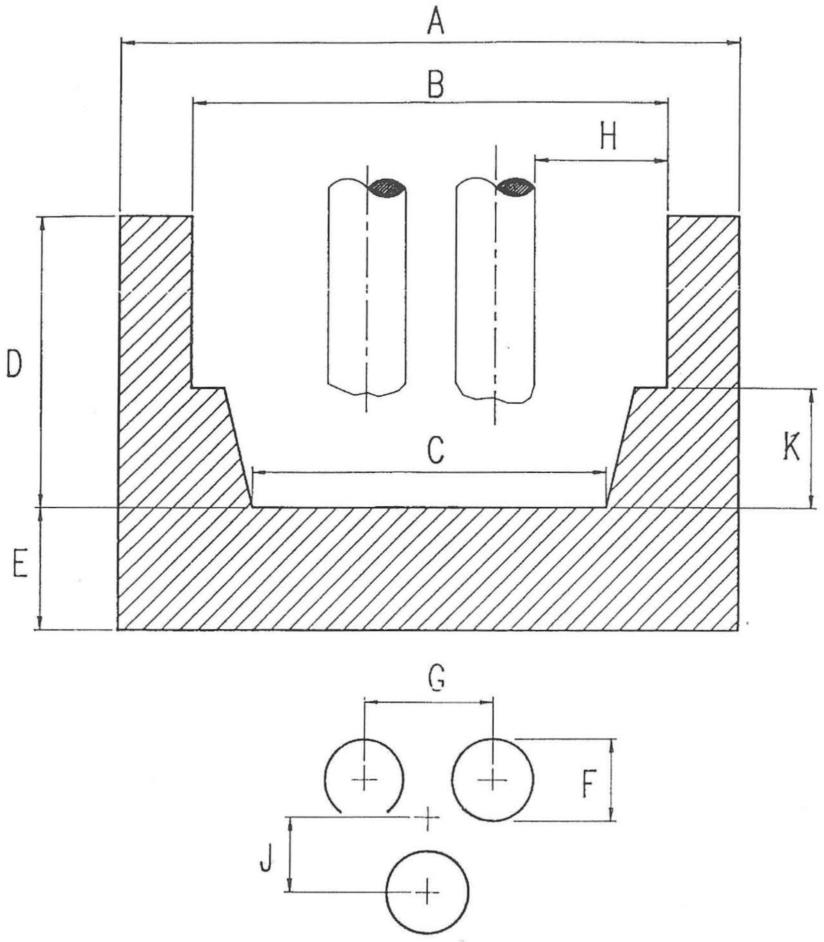
APPENDIX 1 - TEMCO HISTORY

1960	1962	1966	1976	1987	1993	1997	1999	Products	Production
F1	13.2MVA /16MVA			27MVA		29MVA		**FeMn**/SiMn	56ktpa
F2		16MVA		29MVA		36MVA	33MVA	**FeMn**/SiMn	56ktpa
F3			27MVA	36MVA		54MVA		FeMn/**SiMn**	56ktpa
F5			45MVA FeSi		FeSi to SiMn 45MVA			**SiMn**	52ktpa
Sinter Plant			600tpd	1000tpd				Acid Sinter	280ktpa
ERU				11MW				Power	71GWH
				Computer Control Casting Machines Wharf Crane Product Crushing Plant		Extend F3 Casting machine			

APPENDIX 2 - TEMCO DETAILS

PRODUCTION UNITS	No 1 Furnace F1	No 2 Furnace F2	No 3 Furnace F3	No 5 Furnace F5
First Commissioning year	1962	1966	1977	1977/1993
Product	FeMn & SiMn	FeMn & SiMn	FeMn & SiMn	75% FeSi/SiMn
Type	Man Rotating - closed	Man Rotating - closed	Stationary - closed	Man Rotating - semi closed
Shell diameter (mm)	10 008	10 008	12 250	9 640
Shell depth (mm)	5 614	5 614	7 110	5 430
Hearth diameter (mm)	9 234	9 234	11 550	9200
Crucible diameter (mm)	7 600	7 600	9 140	8 250
Top of shell to hearth (mm)	3 700	3 700	5 825	3 788
Taphole to shell top	3 700	3 700	5 475	3 488
Electrode diameter (mm)	1 420	1 420	1 550	1 550
Electrode spacing (f / f mm)	1 980	1 980	2 700	2 050
Electrode spacing (c / c mm)	3 404	3 404	4 250	3 600
Transformer capacity (kVA)	29 000	33 000	54 000	45 000
Primary voltage (V)	22 000	22 000	22 000	22 000
Secondary voltage	150-235 V	126 - 230 V	180 - 310 V	190 - 300V
	87 - 136 V	73 - 133 V	103 - 179 V	110 - 173 V
Furnace reactance	0.95	0.95	0.95	0.95
Cos θ	0.67 - 0.70	0.67 – 0.70	0.67 – 0.70	0.67 – 0.70
Tap Changer	On load 21	On load 33	On load 34	On load 23
Tapholes	3	3	2	2
Hearth Details				
• **Brick**	152	228	227	230
• **Carbon Block**	taphole	taphole	taphole	taphole
• **Carbon paste**	1 563	1 068	1 036	1 065
Current Operating Data:				
• **Furnace load (MW)**	20 (FeMn)	20 (FeMn)	32 (SiMn)	28
• **Max. Electrode current (KA)**	90	90	115	115
• **KW/M^2 of Hearth**	440.9	440.9	487.7	523.8
• **Current Density A/cm^2**	5.8	5.8	6.1	6.1
Last Reline Date	Aug 1991	Dec 1999	Sep 1997	Mar 1993

APPENDIX 3 - TEMCO FURNACE DETAILS



Dimension	Furnace 1	Furnace 2	Furnace 3	Furnace 5
A	10 008	10 008	12 250	9 640
B	9 234	9 258	11 550	9 200
C	7 600	7 600	9 140	8 250
D	3 700	3 700	5 825	3 788
E	1 914	1 914	1 285	1 490
F	1 400	1 400	1 550	1 550
G	3 404	3 404	4 250	3 600
H	1 951	1 953	2427	1 636
J	1 965	1 965	2598	2 078
K	1 750	2 100	2 800	1 790