Operation of Søderberg Electrodes
Methods to Avoid and Solve Electrode Failures

Gunnar Andersen, gunnar.andersen@elkem.no
Reidar Innvær, reidar.innvar@elkem.no
Bjørnar Larsen, bjornar.larsen@elkem.no
Elkem Carbon, N4620 Vågsbygd, Kristiansand, Norway

1. ABSTRACT

Operating Søderberg electrodes does not cause problems when certain procedures are followed, the electrode utilizes the proper equipment, and electrode paste and the operational staff know the basics of the electrode process. However, in some cases failures do occur and the reason why is not always easily understood by the plant staff.

This paper presents the various methods and tools Elkem Carbon (ECAR) can offer in the work of obtaining best possible electrode performance. We also demonstrate how these tools can be helpful to prevent problems that may occur and examples how to solve them are given.

2. INTRODUCTION

Elkem Carbon, a subsidiary of Elkem ASA Norway, is a carbon producer having *Søderberg Electrode Paste* for the ferroalloy and special pastes for the silicon industry as the main products. Since the early start in Kristiansand, Norway, back in 1919, the company has grown to become one of the world largest electrode paste producer. In addition to the plant in Kristiansand our production now includes Midwest Carbide in the US, Carboindustrial S.A. in Brazil, and the newly refurbished Carbon Plant in China. The production capacity has increased from about 100.000 Metric Tons (MT) to a total of about 250.000 MT through these acquisitions. For that reason we are now extending the technical service to a larger market area.

The product "Søderberg Electrode paste" does not only include the paste, but also encompasses a technical support to the electrode operation itself, Figure 1.

The technical service covers two main subjects; *preventative measures* and *trouble shooting*. The value of the preventative measures is obvious: eliminate the problems before they occur.

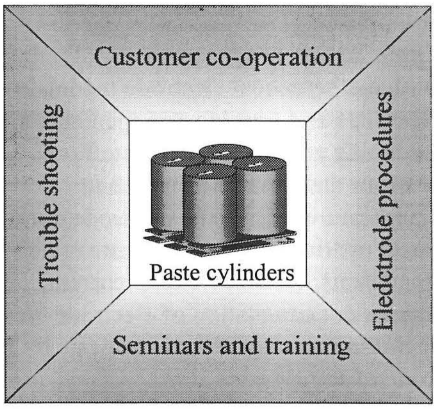


Figure 1 - The product definition of the Søderberg electrode paste

However, as most of the operating staff at the plants has experienced, serious problems may occur in the form of electrode breakage or other poor electrode performance. In such cases much can be gained through discussions with experienced and trained people. This paper discusses and exemplifies the different methods and tools we have found valuable for the technical service work.

3. TECHNICAL SERVICE

Operation of Søderberg electrodes must be considered as a "process within the process" What we often experience is that after a long period with good electrode operation, less attention is given to the electrodes. In some cases this will result in lowered knowledge about the electrode operation. Further, if the procedures and the quality system do not manage to prevent uncontrolled and "unknown" changes in the electrode process, the operation may run into serious problems. ECAR offers extensive refresher seminars and training, which include basic operating know-how as well as newly learned research and operating experience obtained from various plants throughout the world. The combination of seminar and a detailed electrode audit has been very successful.

4. TECHNICAL SERVICE – PREVENTATIVE MEASURES

To avoid severe electrode problems a close co-operation between our customers and our electrode specialists are important:

- Regular plant visits where the electrode operating procedures are evaluated and discussed.
- Optimization of procedures by simulations with mathematical electrode models[1].
- Seminars and training arrangements of the operating and maintenance staff.
- Various electrode measurements; temperatures inside the electrode during paste melting and baking, paste melting conditions, electrode clamp current.
- Proper documentation of electrode breakage, including tracing of the used paste by *bar code/id-tag systems*.
- The measurement of electrode consumption through proper methods including statistical analysis[2].

Figure 2 gives an example of the value of temperature measurements inside the electrode. A major mix-order change was expected to increase the electrode consumption. Due to the increased slipping rate the operating staff was afraid of lowering the baking zone, the 500 °C isotherm, to a critical level and thereby increasing the risk of a green breakage. Together with our customer an action plan was developed:

1. Measure temperatures in the electrodes during original conditions (normal slipping).
2. Change casing design by increasing the thickness of the fins and adding steel as reinforcement to the fins.
3. Measure temperatures in the electrodes after the new casing design was implemented and the slipping rate was increased.

The results of the temperature measurements are given in Figure 2, and show that the slipping could be increased from 73 to 87 cm/day (≈20%) without lowering the critical 500°C isotherm.

The increased amount of steel in the casing will influence the isotherms by several factors: e.g. higher heat transfer and thereby higher baking zone position. The steel thickness of the fins and reinforcement was increased more than the thickness of the outer casing, which allow a higher electric current to pass the casing from the contact clamps. The increased steel thickness will improve the heat transfer within the electrode.

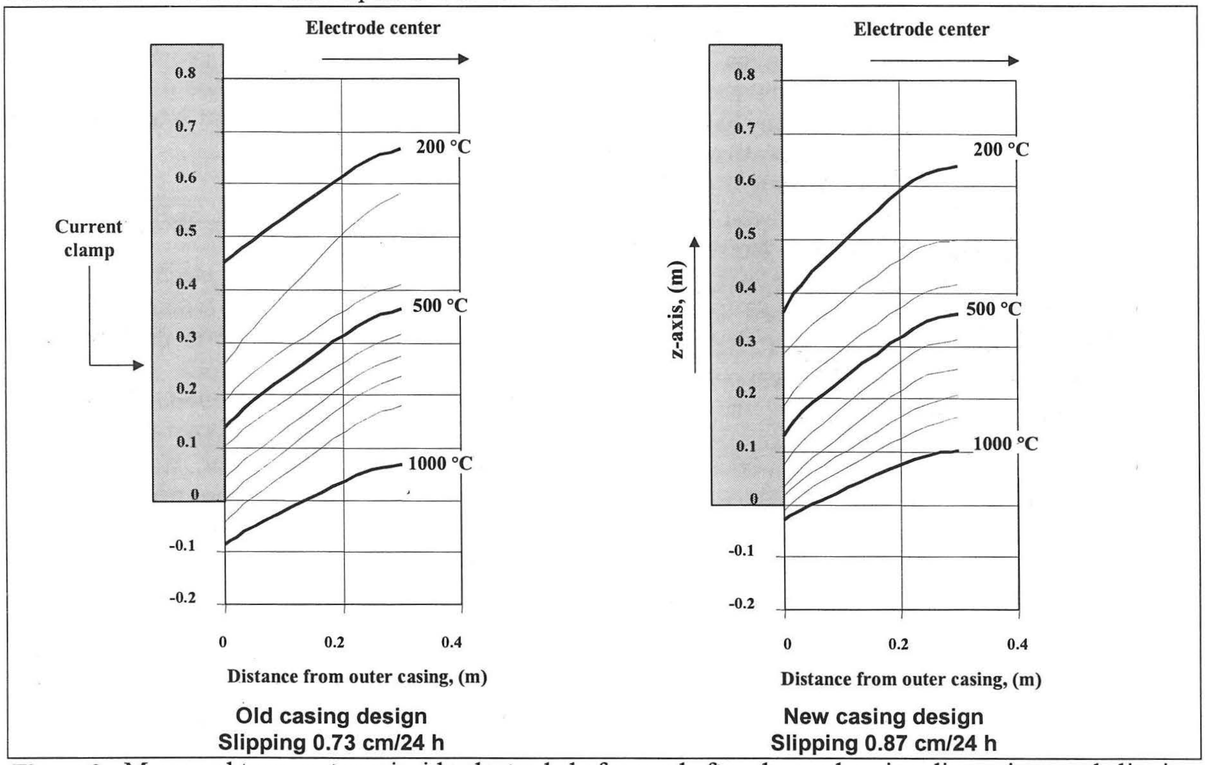


Figure 2 - Measured temperatures inside electrode before and after changed casing dimensions and slipping rate. Constant electrode current 107 kA.

The increased strength of the steel casing also contributes to a much safer electrode operation with a lesser risk of having a green breakage.

The quality of the casing depends on two factors: *design and fabrication*. The casing has two functions: 1) carry electric current and transfer heat and 2) be strong enough to carry the whole electrode column. The total strength is determined by the weakest part, and in most cases this would be the connection or joint between the casing sections. The pattern of the connection, e.g. fin welding or fin overlap, reinforcement steel welding and the quality of the welding itself are all important parameters for the strength of the electrode.

Poor welding may result in holes in the casing. Holes can cause paste leakage that may build up an insulating layer in the contact clamp area. Such layers may cause severe arcing and give uneven current distribution between the current clamps and can result in green breakage.

An example of poor weld connections is shown in figure 3. Some of the fin joints are not welded, some are partly welded and the reinforcement steel is not welded together for any of the fins.

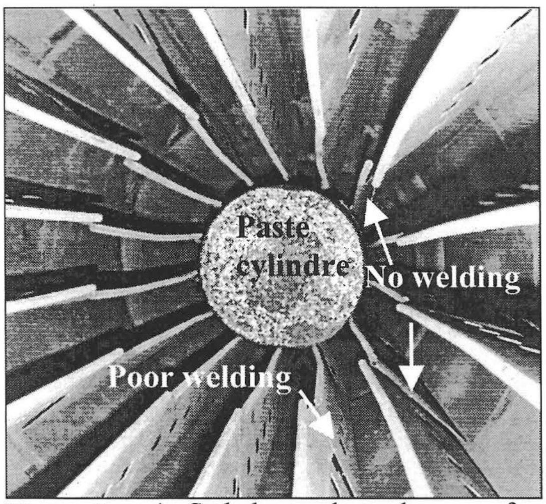


Figure 3 - A Søderberg electrode seen from above. Illustration of poor fins joint welding.

The poor connection between the fins will alter both the current path and the strength of the electrode when it enters the baking area. Consequently, every time a joint is close to the lower holder part, the risk of having a green breakage will be increased. Changes in casing are often difficult to discover. It may change over time and our experience has shown that an audit by our technical specialists is valuable identifying these conditions.

Electrode simulation models are useful tools in optimizing various electrode-operating conditions. A typical example how to improve the current recovery after a shut down is shown in Figure 4. The risk of having a hard breakage is high and using the right procedures could be the difference between a breakage or not. Figure 4 show an example using the mathematical model where recovery time/load-up time for the thermal stresses is determined. By changing the recovery time the maximal stress can be reduced from ≈ 3.8 N/mm^2 to ≈ 3.0 N/mm^2.

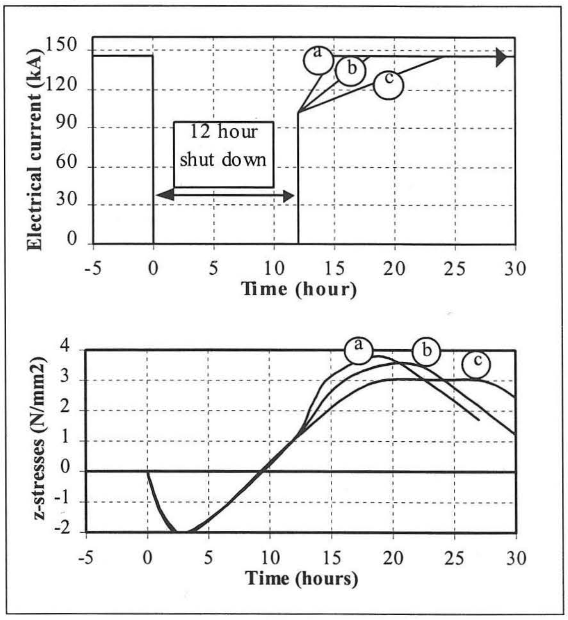


Figure 4 – Simulations of maximal thermal stresses in center of a 1.9 m electrode during a 12 h shut down. Recovery: a: 3 h, b: 6 h, c: 12 h.

Thermal stresses, and hence the optimized procedures, depend on electrode equipment and size, and the operating practices. There are some general rules for specific electrode diameters, which are implemented during an electrode survey.

Proper load-up procedures will minimize production losses and subsequently loss of revenue.

The model simulation is a useful tool that should be used before any problem occurs. The models are powerful tools in the analyses why a breakage did occur.

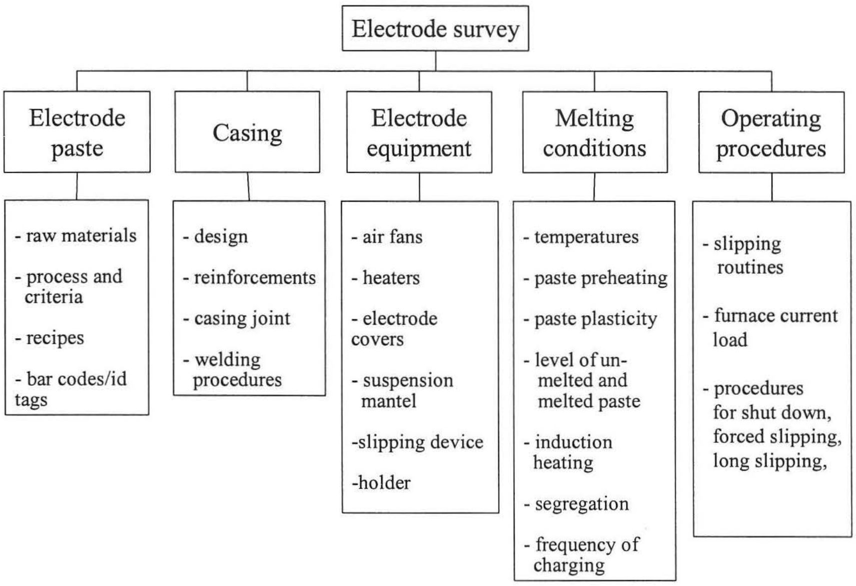


Figure 5- Technical service diagnostic form used in trouble shooting

5. TECHNICAL SERVICE – TROUBLE SHOOTING

When problems occur it is important that all factors related to the incidents are written down. The *breakage reports* are important for the analysis and to determine the reasons causing the problem. In many cases it is possible to make a diagnostic of the reason causing the problem. For example it could be related to the procedures in connection to the shut down demonstrated in Figure 4, or problems with the paste level or melting conditions. Using the *bar coding/id-tagging* makes the identification of cylinders/blocks used in a problem period easier. However, often the cause of the breakage is not determined by the breakage reports and a plant visit should take place. This is particularly the case with green breakage where the problems are solved together with the operating staff.

Figure 5 shows the most important factors that typically are investigated during a plant visit or electrode survey.

Lack of appropriate conditions for paste melting is one of the items that can cause problems. The energy needed to melt the paste is rather low, it is of an utmost importance to have the right temperatures and pressure for paste melting. In the worst case, a green breakage and explosion may happen as shown in Figure 6. After several weeks with no power, several electrode breakage's occurred during re-start. Consequently, the electrodes were short and had to be lengthened by a long slip. The electrodes were not equipped with heating elements for the air blown into the suspension mantle and the liquid paste level reached a critical low level close to the top of the current clamps. The electrodes were covered with heavy covers and not ventilated. The explosion occurred because of low liquid paste level resulting the gasses travelling upwards (chimney effect) instead of going downwards. With lack of ventilation the gases were collected inside the upper electrode and were ignited during the breakage.

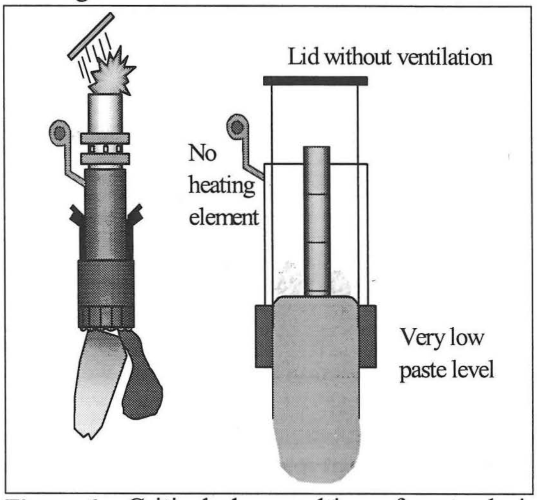


Figure 6 - Critical slow melting of paste during period with hard breakage and long slipping.

As a short-term solution, light covers and ventilation exchanged the heavy covers, and heated air was blown directly into the electrode. Heaters were later installed on the air blowing system.

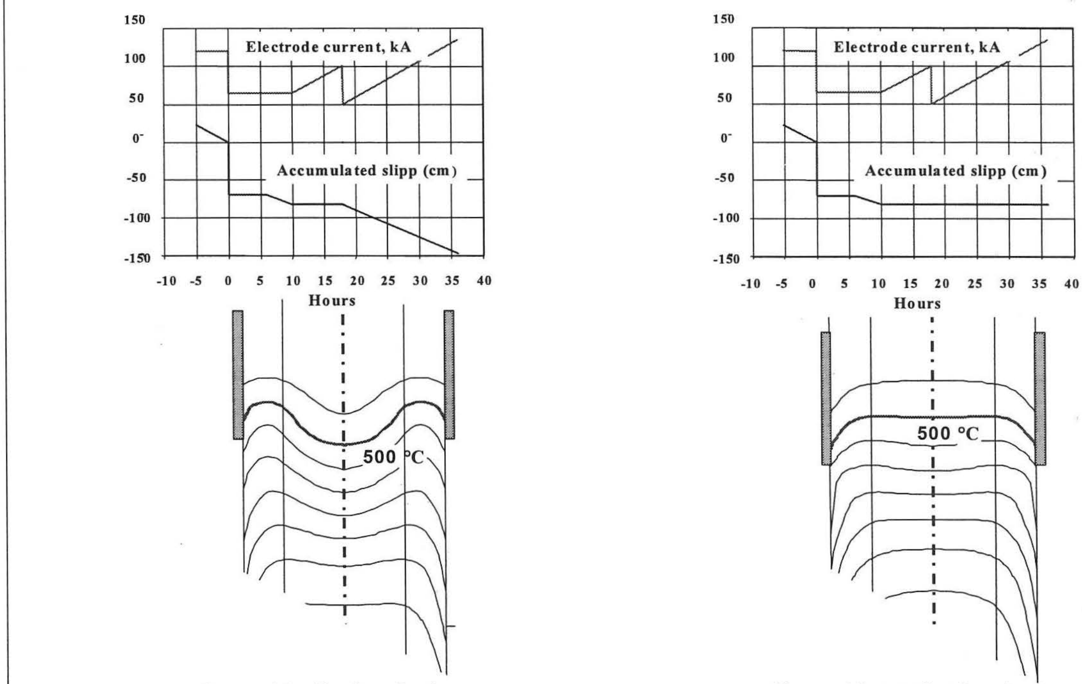
Another typical problem has been lack of incomplete procedures for current recovery after anomalous slipping. In Figure 7 a green breakage occurred as a result of high slipping during current recovery after a "long slipping". In this case, temperature plots showing the development of the critical 500°C isotherm during slipping and current recovery was simulated by use of the electrode models. The results showed that the baking zone, at the time when slipping was started, was still at the very tip of the contact clamps. The combination of slipping and current recovery resulted in current burning holes in the casing and a paste leakage occurred.

Lack of knowledge among the operating staff may in some cases result in a slow and uncontrolled change in procedures. One such case is demonstrated in Figure 8, showing the lack of coordination between the manufacturing department and the operating staff.

The windows in the fins used in this electrode were produced manually by moving the fins into a machine making the holes, but the operators doing this did not have the understanding of the importance of the window distance. Further, combined with lack of quality check before assembling, this resulted in a highly variable and in some cases a too long distance between the fin windows. Distances from 2 – 400 mm between the windows were found.

The correct distance should be in the range 100 – 130 mm. Knowing the important anchoring effect of the baked paste to the fins in the temperature range 500 – 800 °C, it was not surprising that a soft breakage had occurred.

The first corrective action was to change the fin design followed by a detailed seminar with special focus on casing design related to the function of the electrode for the operating and the maintenance staff



Case with slipping during recovery. Time = 36 h

Case without slipping during recovery. Time = 36 h

Figure 7 - Electrode simulations of baking zone position during an anomalous electrode slipping and current recovery. A soft breakage occurred at time 36 hours. In the isotherm plot to the left, the case with slipping, and lowering of the 500 °C isotherm in the center part of the electrode can be seen.

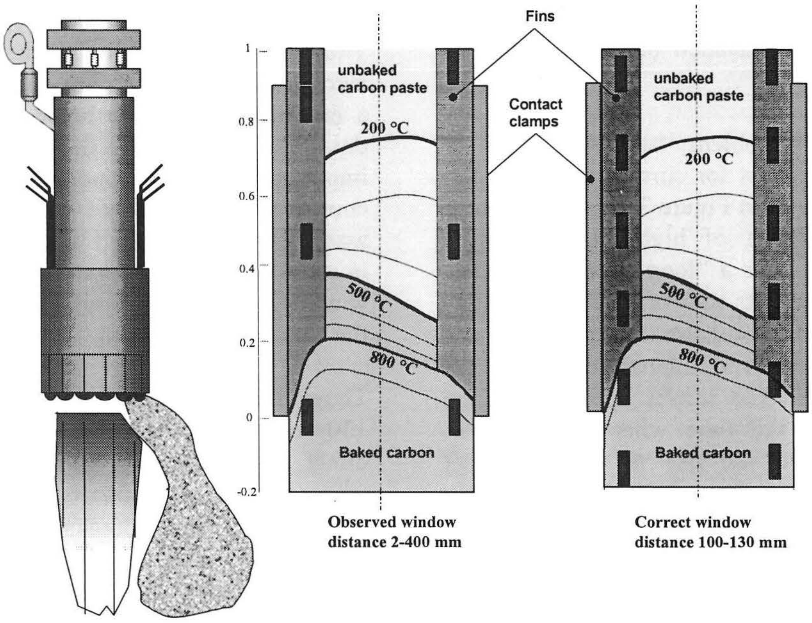


Figure 8 - Soft breakage. Sliding of baked electrode due to incorrect fin window distance and poor mechanical connection between baked carbon and steel fins. Improved anchoring with correct fin design is shown to the right. The temperatures are measured inside the actual electrode.

6. DEMAND FOR MORE ROBUST ELECTRODES

The industries continuing demand for higher alloy throughput require better electrodes and electrode performance. Figure 9. Illustrates today's trend of pushing the electrode current (kA) to attain higher furnace operating load (MW) and thereby the alloy throughput. To achieve this, ECAR is working and developing a more "robust" electrode to meet today's and future electrode performance requirements.

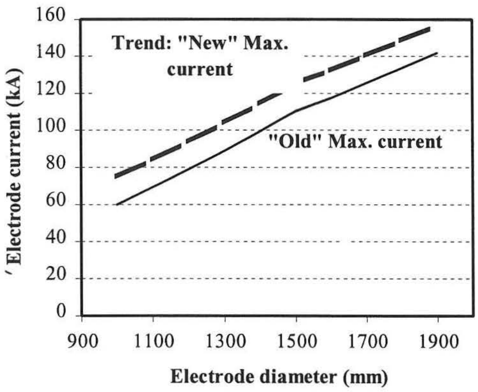


Figure 9 - Tendency of increased electrode load

Shown in Figure 4 are thermal stresses in an electrode during various recovery procedures. Thermal stresses are one of the most critical parameters to control to enable the best electrode performance.

New methods for electrode characterization has been developed for the fracture mechanical behavior of the resistance against crack propagation[3], Table 1. By changing both raw materials and composition, different production parameters, an improved electrode has been developed and tested in several furnaces.

		Fracture Energy, G_F Nm/m^2	Thermal shock parameter, R'st W/m
Regular	#1	240	250
electrode	#2	280	270
paste	#3	260	270
Improved	#1	310	650
electrode	#2	290	620
paste	#3	300	630

Table 1 - Fracture energy and thermal shock parameter in regular and improved electrode paste.

The fracture energy is measured in laboratory samples of baked electrode materials, and the thermal shock parameter R'st is calculated by the equation:

$$R'st = \sqrt{\frac{\lambda^2 G_F}{E\alpha^2}}$$

where

λ = Thermal conductivity
G_F = Fracture energy measured under controlled crack propagation
E = Young's modulus of elasticity
α = Coefficient of thermal expansion

The improvement of the electrode material can be demonstrated by use of the electrode simulation models, with the new material properties.

The case with thermal stresses following a shut down, as shown in Figure 4, has been used again, but now we have compared the stresses in the two cases: regular and improved electrode material, Figure 10.

Reduced stresses mean that the risk of having a breakage in the baked part is considerably reduced. This will shorten the recovery time and improve furnace throughput.

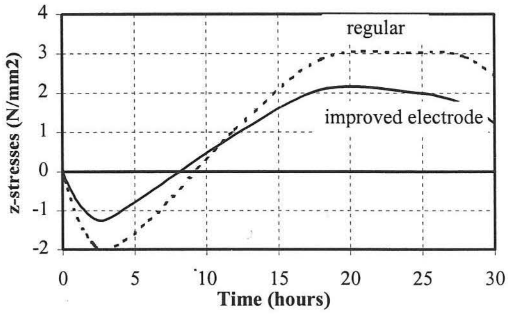


Figure 10 - Effect of an improved electrode and thermal stresses during 12 hours current recovery. See also Figure 4.

7 CONCLUSIONS

A safe and reliable electrode operation does include consistent electrode products, good electrode casing design and control, proper electrode equipment and operating procedures.

To maintain current knowledge about the Søderberg electrode operation and to maintain good operating routines and procedures, it is necessary to have regular staff training sessions.

Electrode simulations, various electrode measurements, and electrode surveys are all helpful tools in the work for improved electrode performance and the analyses for the reasons behind any specific problem.

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