# A New Composite Electrode Architecture For Energy Storage Devices

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# EVOLUTION OF ELECTRODE ARCHITECTURES

Nickel Hydroxide Half-Cell Reaction Studies

POWDER-BASED PLAQUES

↓

FIBREX MESH

↓

COMPOSITE ELECTRODE STRUCTURES

Tatarchuk and co-workers:

1. J. Electrochem. Soc., 137, 136 (1990).
2. J. Electrochem. Soc., 137, 1750 (1990).

## Research Objective

How does the electrode architecture (microstructure) affect the performance of the nickel hydroxide electrochemical system?

A. Determine if the properties of the FIBREX mesh can be improved by sinter bonding small diameter metal fibers into the electrode architecture.

* provide an increase in the surface area available for deposition without significantly reducing the void volume thereby reducing the thickness of the active material.
* provide an interior network of conducting pathways to reduce the ohmic resistance within the active material.
* create an interior void/microstructure which influences crystallite size and defect density in the deposited layer.

B. Compare the performance of several composite electrode architectures with that of FIBREX mesh and electrodes prepared by Eagle-Picher in short term life-cycle tests.

C. Determine if there is a synergism between the impregnation method and the electrode architecture (microstructure)

D. Determine if the composite electrode architectures influence the conditioning time required for full utilization of the active material.

1. Nickel FIBREX mesh (28 um dia.)

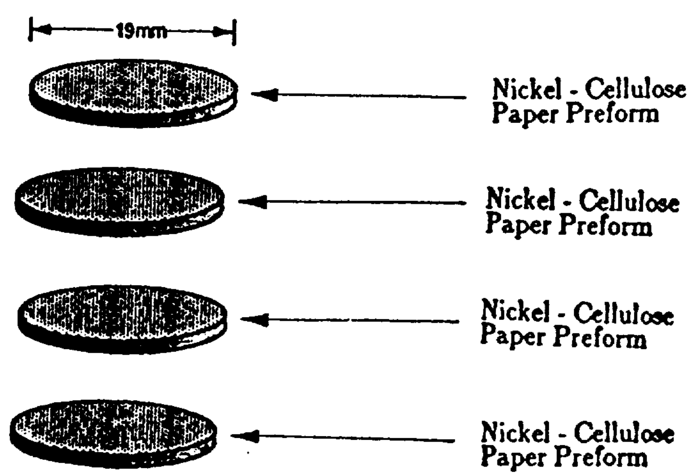
2. Nickel FIBREX mesh/ stainless steel fibers (2 um dia.)

3. Stainless steel fibers

4. Nickel FIBREX mesh/ nickel fibers (2 um dia.)

5. Nickel fibers

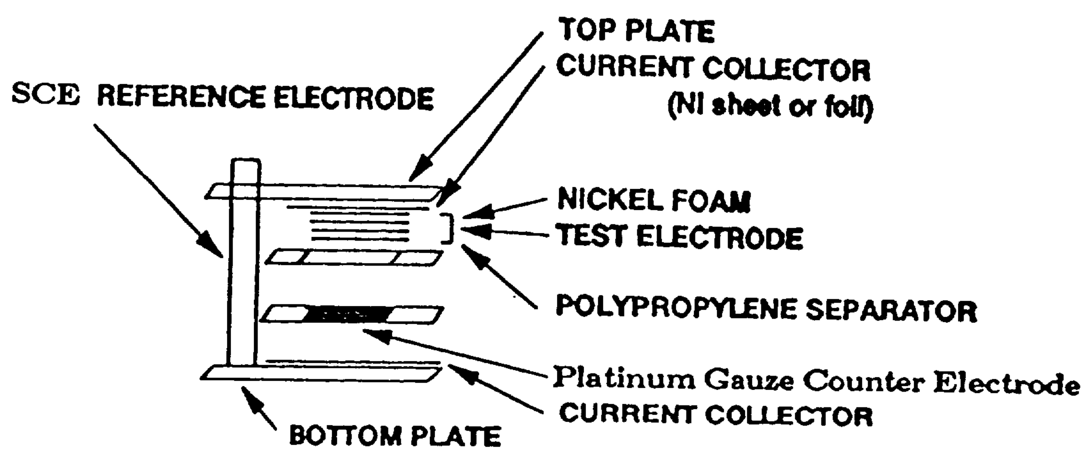
**Electrode Preparation**




**Sintering Conditions**

## Cell Design For Electrode Cycle Tests

Computerized software developed and tested in our laboratory which provides computer control of the potentiostat/galvanostat and data acquisition during the cycle tests.



## Results and Discussion

I. Unique attributes and properties of the composite electrode architectures.

II. Discussion of the important variables involved in the electrochemical impregnation of nickel hydroxide and for a given electrode architecture do the characteristics of the impregnation method influence the performance of the electrochemical system.

III. Evaluation of the performance (% utilization) of the electrochemical system using Eagle-Picher, FIBREX mesh and a variety of composite electrode architectures in short term life-cycle tests.

- effect of electrode architecture on performance.
- effect of discharge rate on performance.
- comparison of times required to reach full utilization.

IV. Electrode Reaction Kinetics - determine the ohmic, polarization and mass transport resistances as a function of loading (thickness) and state of charge using linear sweep and cyclic voltammetry, current-time transients and AC impedance analysis.

## I. Unique attributes and properties of the composite electrode architectures

1. High specific surface area (>100 fold increase in $m^2/g$ over FIBREX).

2. Low ohmic resistance within the architecture due to the sinter bonded fibers.

3. Low mass transport resistance within the architecture voids resulting in easy acessibility of electrolytes.

4. Adjustable void volume and surface area over several orders of magnitude.

5. Electronic properties are not dependent on mechanical pressing.

### PHYSICAL PROPERTIES OF ELECTRODES

| | FIBREX | FIBREX+SS | FIBREX+Ni | SS | Ni |
|---|---|---|---|---|---|
| **BEFORE IMPREGNATION** | | | | | |
| Thickness (mils) | 35 | 35 | 35 | 19 | 19 |
| Weight/ Surf. Area ($g/cm^2$) | 7.8 | 5.8 | 5.0 | 0.11 | 0.14 |
| Density ($g/cm^3$) | 0.49 | 0.55 | 0.55 | 0.33 | 0.35 |
| Porosity (%) | 94.4 | 93.7 | 93.7 | 95.8 | 95.8 |
| **AFTER IMPREGNATION** | | | | | |
| WT. of $Ni(OH)_2$/ $cm^3$ of Void | 0.42 | 0.21 | 0.67 | 1.12 | 0.66 |
| Porosity (%) | 80.9 | 86.7 | 74.1 | 66.0 | 75.9 |
| Loading (vol %) | 14.3 | 7.53 | 21.0 | 30.8 | 20.5 |

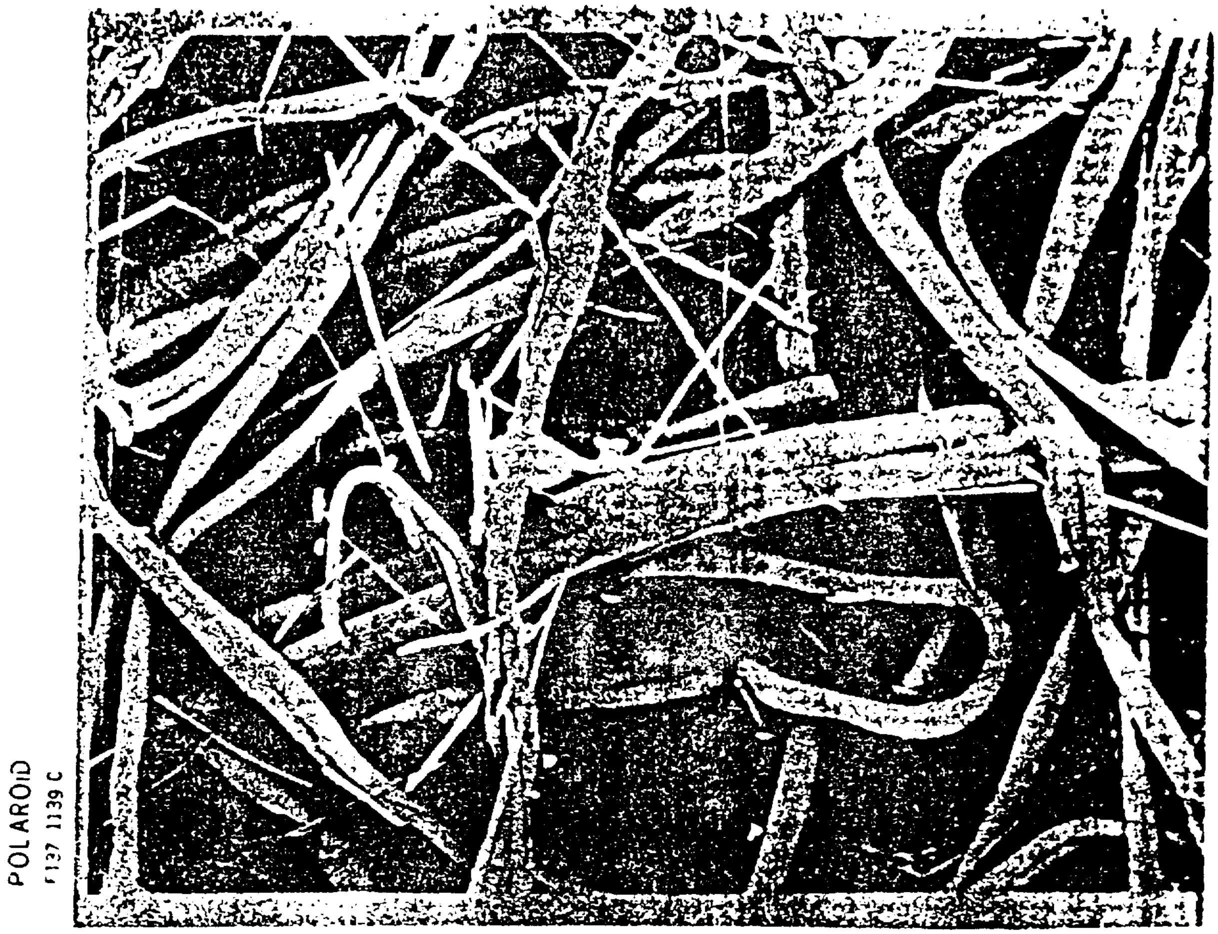



**Figure 1.** Electron micrograph of a FIBREX/nickel fiber composite electrode prior to impregnation.

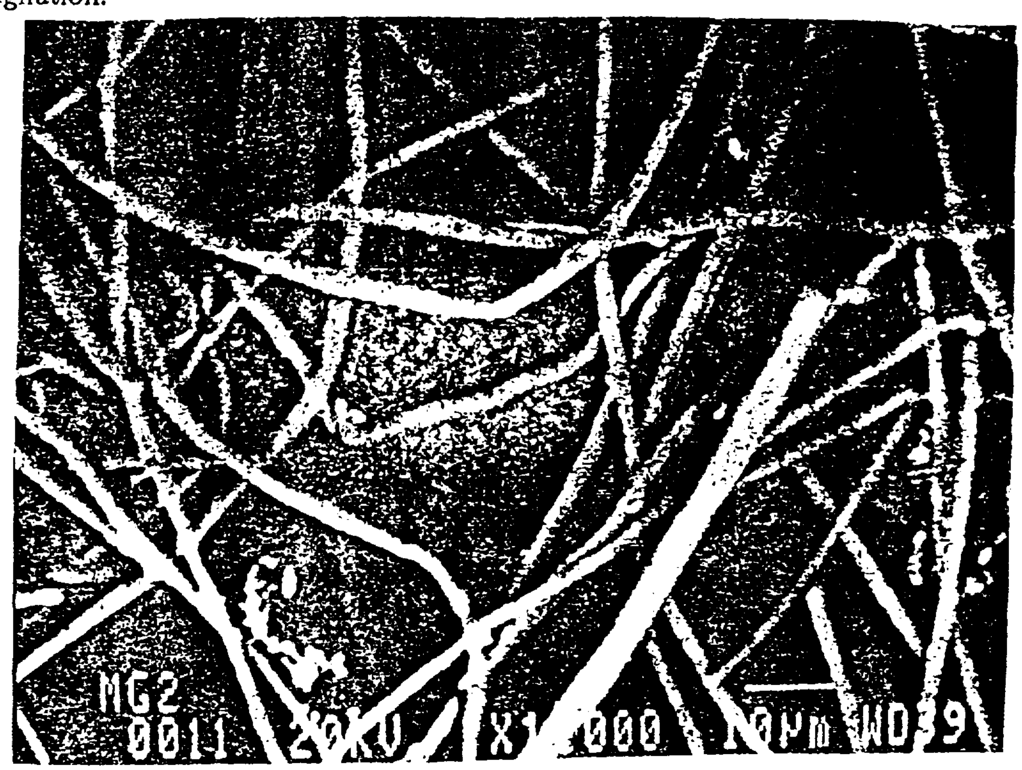



**Figure 2.** Electron micrograph showing the sinter bonded small diameter nickel fibers to the FIBREX mesh.

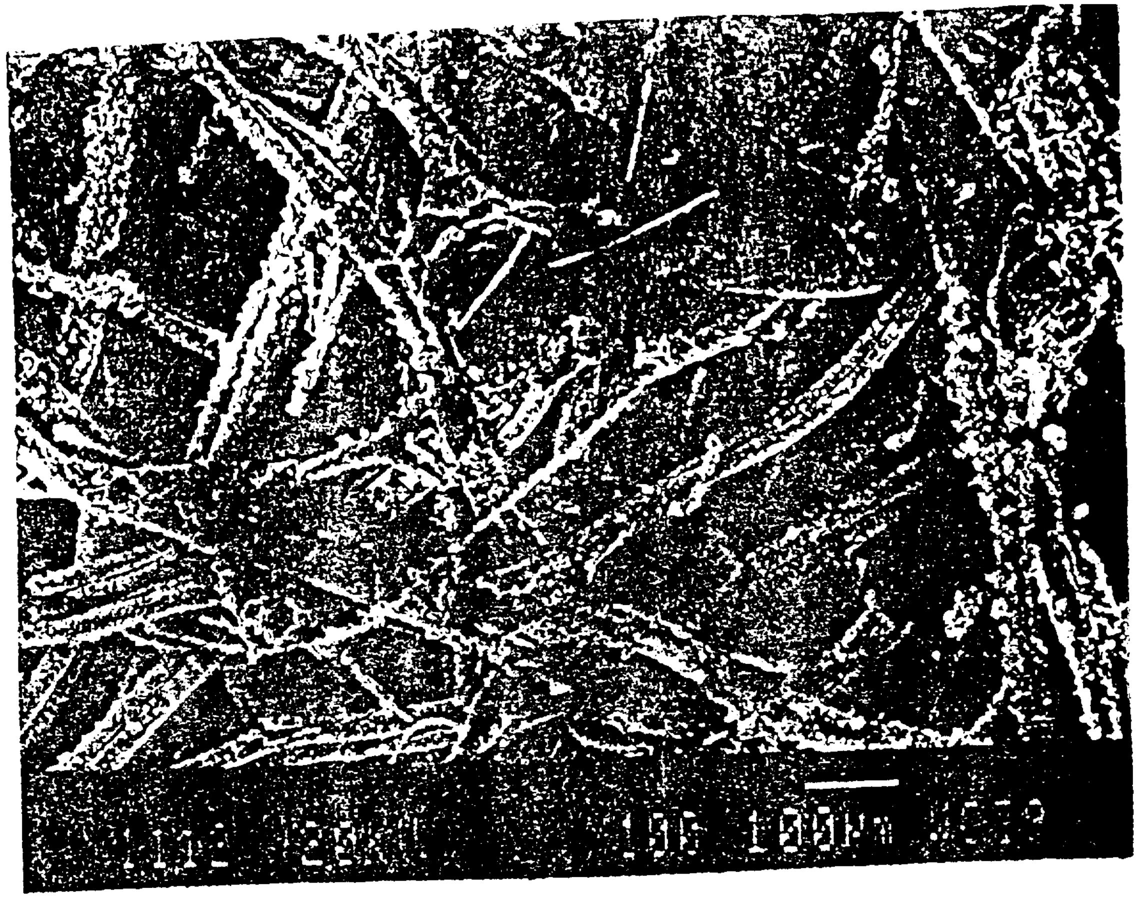



**Figure 3.** Electron micrograph of a FIBREX/nickel fiber composite electrode after aqueous impregnation galvanostatically at 10 mA/cm$^2$. for 3 hours.

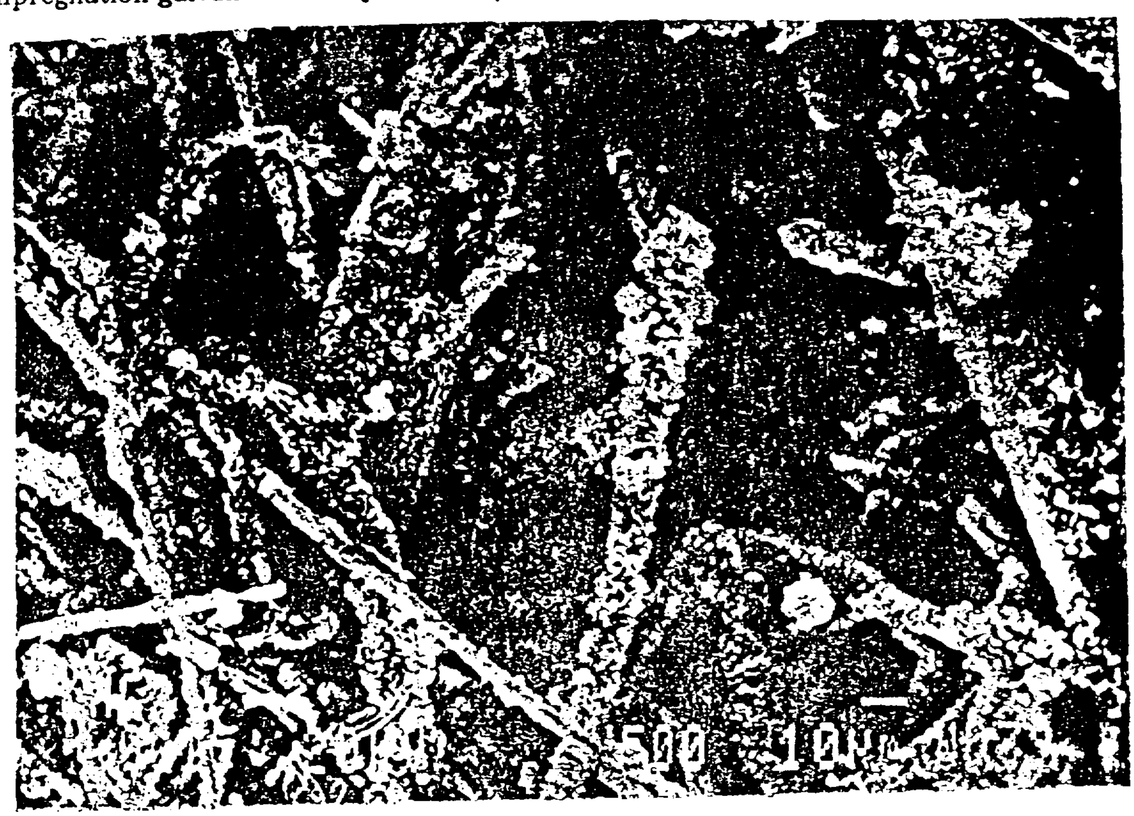
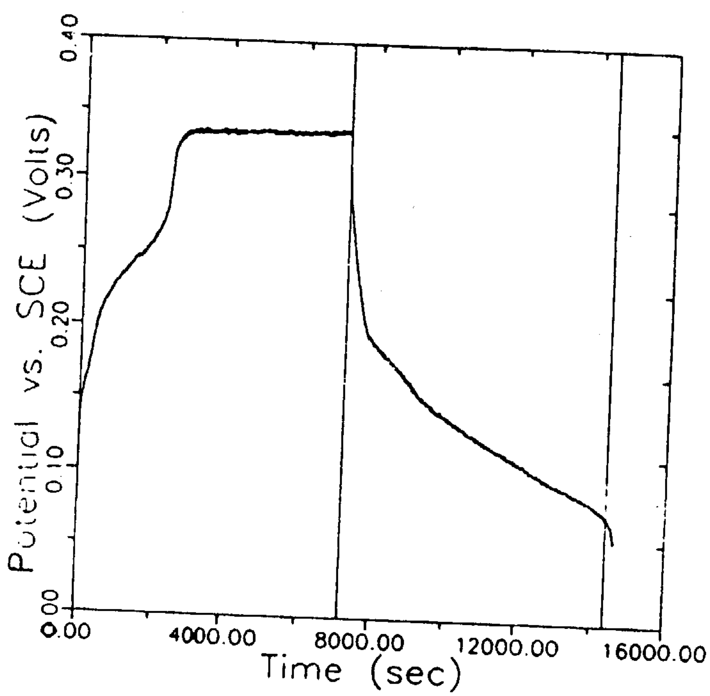


**Figure 4.** Electron micrograph of the same electrode as above but at higher magnification.

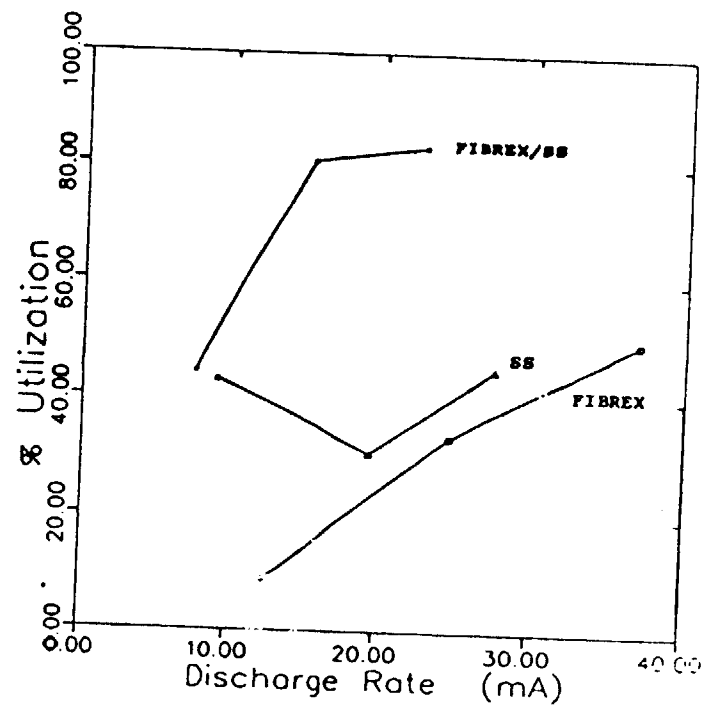
## Potential vs. Time Curve for a Nickel Fiber Composite Electrode During Charge and Discharge.

Solution = 26 wt% KOH
Active Material Weight = 44 mg
Electrode Weight = 31 mg
Geometric Area = 2.8 $cm^2$
Charge Rate = C/2
Discharge Rate = 3C/2



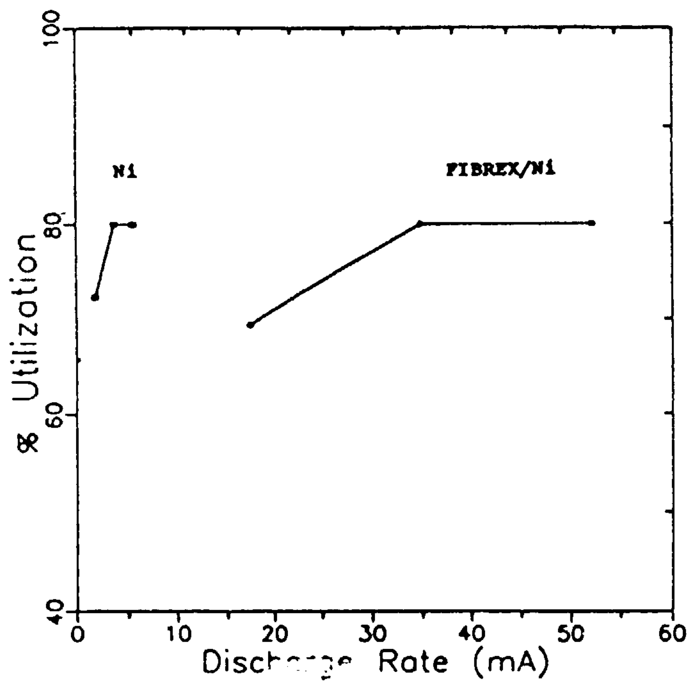

## Plot of % Utilization vs. Discharge Rate for Different Composite Electrode Architecture

Solution = 26 wt% KOH
Active Material Weight = 53 mg(FIBREX/SS)/64 mg(SS)/85 mg(
Electrode Weight = 27 mg (FIBREX/SS)/29 mg (SS)/125 mg(FIB
Geometric Area = 2.8 $cm^2$
Charge Rate = C/2



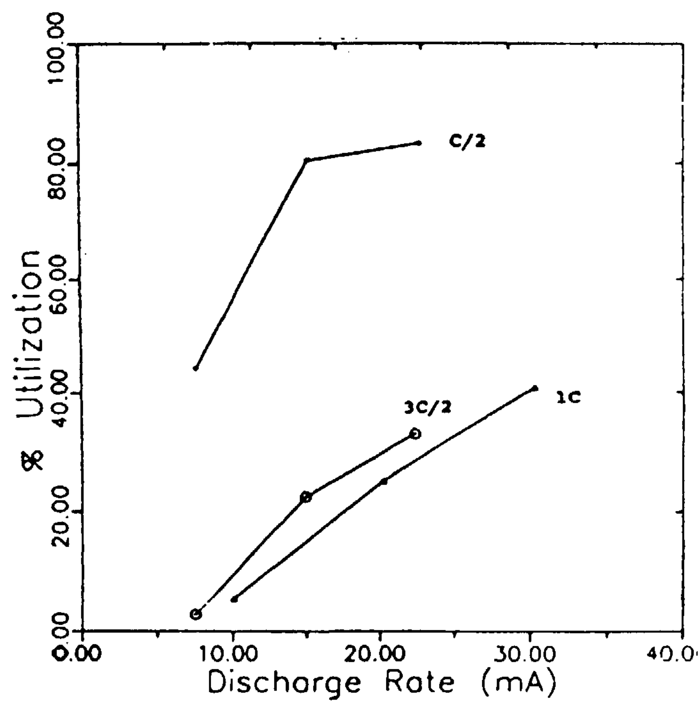
**Plot of % Utilization vs. Discharge Rate for a Nickel Fiber and a FIBREX/Nickel Fiber Composite Electrode.**

Solution = 26 wt% KOH
Active Material Weight = 44 mg (Ni) / 126 mg (FIBREX/Ni)
Electrode Weight = 31 mg (Ni) / 185 mg (FIBREX/Ni)
Geometric Area = 2.8 $cm^2$
Charge Rate = C/2




**Plot of % Utilization vs. Discharge Rate for FIBREX/Stainless Steel Composite Electro Different Charge Rates.**

Solution = 26 wt% KOH
Active Material Weight = 53 mg (C/2)/70 mg (1C)/52 mg (3
Electrode Weight = 268 mg (C/2)/249 mg (1C)/326 mg (3C/2
Geometric Area = 2.8 $cm^2$



# Summary

1. Microstructure and additional surface area make a difference! Best architectures are the FIBREX/nickel and nickel fiber composite electrodes.

2. Conditioning time for full utilization greatly reduced.

   < 5 cycles vs. 200 or more

3. Accelerated increase in capacity vs. cycling appears to be a good indicator of the condition of the electrode/active material microstructure and morphology. Conformal deposition of the active material may be indicated and important.

4. Higher utilizations obtained.

   > 80% after less than 5 cycles

   > 300%* after more than 5 cycles using nickel fiber composite electrode assuming a 1 electron transfer per equivalent.

## Current and Future Research Efforts

1. Broaden fundamental understanding of microstructural influence on utilization, efficiency, charge and discharge rates, proton diffusion rates, deposition synergy, etc.

2. Determine influences and physical mechanisms for limiting electrode kinetic processes.

3. Optimize electrode microstructure with respect to the above noted constraints, limits and rates for a desired application.

4. Examine selected candidate composite electrode structures during long term cycle-tests ( >200 ).

5. Evaluate promising candidates in full-cell $Ni\text{-}H_2$ batteries.