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STUDY OF HIGH PERFORMANCE ALLOY ELECTROFORMING
SIXTEENTH MONTHLY TECHNICAL PROGRESS NARRATIVE

APRIL 1, 1985 TO APRIL 26, 1985

ELECTROFORMING OPERATIONS DEPARTMENT

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STUDY OF HIGH PERFORMANCE ALLOY ELECTROFORMING

ABSTRACT

Using the two nickel-manganese alloy electroforming baths of near identical compositions, panels were electroformed under the same deposition parameters of current density, bath temperature, pH, and pulse plating conditions of duty cycle and frequency. By changing the electrolyte agitation conditions, significant effects on mechanical properties were noted. Since electrolyte agitation conditions on the typical flat panels studied to date will not be identical to those existing on a complex curved shape such as the SSME combustion chamber simulation, it is most important that these effects be evaluated prior to Phase B studies. The subscale chamber has been fabricated and shield support tooling is being made. Electroforming of optimized alloy test bars is being deferred until the electrolyte agitation effects are more fully appraised.

I. INTRODUCTION

The purpose of this work is to develop and demonstrate a system for electroforming materials with improved strength and high-temperature properties. The Space Shuttle Main Engine employs a main combustion chamber (MCC) where final combustion of propellant at high temperature and pressure takes place. This critical component must be structurally supported by a nickel-base alloy jacket. Producing this jacket from formed wrought metal segments requires numerous weldments which alter the mechanical properties of the base metal through heat affected zones. This requires thickening the alloy where joints are to be made to meet the structural requirements of the shroud. The use of electroformable alloys with great strength would have the potential for simplifying fabrication procedures for structural jackets and reducing overall weight by removing weldments. Such an electroformable alloy might also afford a possible use in advanced engines where light weight and good strength at high temperatures are necessary.

II. TECHNICAL PROGRESS SUMMARY

- A. Task I - Literature Survey (Phase A) - Previously completed.
- B. Task II - Alloy Characterization and Optimization (Phase A)

Summarizing the effects of various electrolyte and pulse plating parameters on mechanical properties of nickel-manganese electroformed alloys:

1. Increasing the manganese content of the electrolyte results in an increased manganese content in the alloy. This results in increased mechanical strength and a decrease in ductility (which can often be restored by a moderate heat treatment). Manganese contents in deposits exceeding 2500 ppm by weight require more prolonged or severe heat treatments to restore ductility while 5000 ppm, or more, manganese in the alloy usually results in a brittle and highly tensile stressed "as deposited" metal. The form in which the manganese is codeposited with nickel (i.e. - whether in the composition Ni_3Mn or $NiMn$) may have an important influence on stress and mechanical properties.

2. Increasing the current density in the conventional dc plating mode or the average current density in the pulse plating mode increases manganese concentration in the alloy in a logarithmic manner. In the pulsed current mode and for a constant average current density, it appears that increasing the peak current density also increases manganese content and mechanical strength - provided the pulse off time is sufficiently long. Pulse off times of 10 to 30 milliseconds appear to produce better mechanical properties than lesser times. This is probably due to the longer diffusion time for manganese to reach equilibrium concentrations in the diffusion layer at the cathode. Since this may also be strongly influenced by electrolyte agitation which leads to thinner diffusion layers, we will discuss this subsequently.

3. Electrolyte pH - at least in the normal range of 3.8 to 4.3 - has not been noted to have a significant effect on alloy manganese concentration or mechanical properties. Hydrogen ion may play a part in electron transfer in the reduction of nickel and manganese (or coordinated nickel-manganese ions which might resemble coordination complex ions). Since hydrogen is reduced, or "plates" at the cathode, the diffusion layer tends to become less acidic. This is easily offset by electrolyte agitation which thins out the diffusion layer and allows quicker hydrogen ion diffusion to restore the proper pH. Pulse plating permits the same hydrogen ion diffusion to occur during the pulse off time.

4. Bath temperature increase results in a significant decrease in alloy manganese concentration. Ion migration in the diffusion layer should be easier as the layer temperature increases. This would indicate that nickel ion diffusion is enhanced by increases in temperature while manganese ion diffusion is not - or, if nickel-manganese ion coordinations exist, the relative mobility of such complexes is not improved by higher bath temperatures.

5. Deposition voltage is directly related to manganese content in the alloy. High voltages lead to high manganese concentrations in deposits. Since increased current densities are accompanied by increased overvoltages, it is to be expected that this would occur.

6. Pulse frequencies (particularly the length of off time) appear to affect the codeposition of manganese with nickel. As was mentioned in the report of the previous month, high pulse frequencies with off times as short as 2 milliseconds resulted in less manganese (and lower mechanical strength) than lower frequencies with off times in the 20 millisecond range. In each case the pulse duty cycle was the same (50%). There seems to be a practical limitation on use of longer off times since sufficient chemical equilibrium is restored if good bath agitation exists to keep the diffusion layer thin.

The above discussion has in many cases pointed to electrolyte agitation and the resulting "thinning" of the diffusion layer to permit better diffusion of manganese ions for codeposition with nickel. The serious effects of agitation on alloy composition and mechanical properties became clearly evident in the April work on flat panels. In this effort we were endeavoring to duplicate, or improve upon, the mechanical properties of Panel NM-25 where ultimate strength exceeded 175 ksi (even after heat treating at 427°C for four hours) and elongation was at least 10 percent. The panel fabrication matrix included use of several pulse duty cycles in the 25% to 60% range and lower frequencies of 25 to 50 Hz. Long pulse off times were being investigated since the off time for Panel NM-25 was 20 milliseconds.

When the duplicate nickel-manganese alloy electroforming facility was established, all spray systems were overhauled - including that in the first facility. Single "Fulljet" solid square spray nozzles were installed in each pumped electrolyte outlet perpendicular to the plane of the panel being electroformed. These sprays were 3/8HH24WSQ with a rated flow of 1.8 GPM at 5 psig and 2.4 GPM at 10 psig. Nozzle-to-electroform panel distance was 5 inches. Panels electroformed under this electrolyte spray condition are denoted by the word "Single" under the pulse plating information opposite "Sprays" on the attached tables of test data. A rearrangement of sprays was made whereby two "Fulljet" solid square spray nozzles pumped electrolyte on each panel being deposited. This permitted a higher volume electrolyte flow but a lower pressure. Such agitation conditions are described as "Double" under the pulse plating information for sprays on the attached data sheets. Any reference to "Single Square" means the same as "Single." All spray nozzles were obtained from Spray Systems Company, Wheaton, Illinois.

Data for Samples NMR-6A, -6B, and -6C afford an interesting comparison of spray effects on mechanical properties. Panel NMR-6A exhibited high yield and ultimate strengths using the "Single" spray set-up. Using double sprays of the same nozzle ratings and distance from the sample surface, a significant decrease in ultimate and yield strengths was observed. Most surprising is the fact that alloy analyses for Panel NMR-6B (using the double spray) was about the same as for Panel NMR-6A. For Panel NMR-6C, we moved the double spray from about 5 inches from the panel face to about 3.5 inches from the face. This maintained a high volume electrolyte turn-over at the panel face while increasing turbulence. Tests showed that ultimate and yield strengths were increased, and the manganese content was increased very significantly over that of Panel NMR-6A and Panel NMR-6B.

We interpreted this data to mean that the volume of electrolyte turn-over at the cathode face is not as critical as the shearing force of the spray at the cathode diffusion layer. The fact that Panels NMR-6A and B exhibited similar manganese contents and greatly differing mechanical properties can be accepted as compatible with the postulation that strong spray shearing action promotes a thinner diffusion layer and promotes codeposition of NiMn crystallographic cells while low shearing force favors Ni_3Mn cell formation. We have previously proposed that strengthening of nickel-manganese alloy is due to NiMn cells which are face-centered tetragonal and stable to fairly high temperatures. The mechanism whereby cathode surface turbulence controls the combinations in which nickel and manganese codeposition is not well understood.

Fabricated, or presently in electroforming, are panels representing the use of open pipe nipples for sprays, single solid square sprays mounted close to the cathode surface, and "Veejet" flat spray nozzles mounted close to the cathode surface. Results of tests for these panels should complete the parameters required to produce round test bars for optimum mechanical properties. We expect the "Veejet" nozzles to produce alloy with test results resembling those of Panel NM-25 (the best combination of mechanical strength and ductility thus far achieved).

In attached Tables I - V, it should be noted that mechanical testing was confined to the "as deposited" and heat treated at 650°F (343°C) conditions. Other heat treatments and testing at elevated temperatures was not performed in the interests of time and funding. Those samples showing best mechanical properties as electroformed will be submitted to a wide range of heat treatments and testing at MCC service temperatures. Tables I - V should be regarded as raw data to be expanded as appropriate.

TABLE II - ELECTROLYTE SPRAY EFFECTS EVALUATION

Sample Number	Fabrication Data	Pulse Plating Information	Plating Bath Analytical Data	Deposited Alloy Data	Strip No.	Heat Treatment	Test Temp (°F)	Mechanical Properties (psi)			
								Ultimate	Yield	Elong. (%)	
NMR-7A	Start 03-19 Finish 03-21 Tank No. E01 Amp Hrs. 720	Duty Cycle 40% Pulse On 8.0 Msec Pulse Off 12.0 Msec Peak C.D. 63.25 ASF Avg. C.D. 25.30 ASF Avg. Volts 4.82 Sprays Double	Ni Metal 76.84 g/l Mn Metal 4.6 g/l Boric Acid 31.17 g/l Acidity (pH) 4.05 Temperature 50.0°C	2 Each Size 4.38" x 8.12" Mn Comp. 1913 ppm S Comp. Flatness Fair Thickness .067 in to .068 in.	7A1A	None 650°F (24 Hr)	Ambient Ambient	170,705 160,095	129,850 137,675	7.2 7.5	4.9 4.4
NMR-7B	Start 03-24 Finish 03-26 Tank No. E02 Amp Hrs. 720	Duty Cycle 40% Pulse On 8.0 Msec Pulse Off 12.0 Msec Peak C.D. 63.25 ASF Avg. C.D. 25.30 ASF Avg. Volts 4.66 Sprays Double	Ni Metal 76.37 g/l Mn Metal 4.7 g/l Boric Acid 31.17 g/l Acidity (pH) 4.05 Temperature 50.0°C	2 Each Size 4.38" x 8.12" Mn Comp. S Comp. Flatness Fair Thickness in to	7B1A	None 650°F (24 Hr)	Ambient Ambient				
NMR-7C	Start Finish Tank No. Amp Hrs.	Duty Cycle 40% Pulse On 8.0 Msec Pulse Off 12.0 Msec Peak C.D. 63.25 ASF Avg. C.D. 25.30 ASF Avg. Volts Sprays Double	Ni Metal g/l Mn Metal g/l Boric Acid g/l Acidity (pH) Temperature °C	2 Each Size 4.38" x 8.12" Mn Comp. S Comp. Flatness Fair Thickness in to	7C1A						
NMR-8A	Start 03-21 Finish 03-24 Tank No. E01 Amp Hrs. 720	Duty Cycle 40% Pulse On 8.0 Msec Pulse Off 12.0 Msec Peak C.D. 50.60 ASF Avg. C.D. 20.24 ASF Avg. Volts 3.97 Sprays Double	Ni Metal 76.69 g/l Mn Metal 4.4 g/l Boric Acid 31.32 g/l Acidity (pH) 4.00 Temperature 49.4°C	2 Each Size 4.38" x 8.12" Mn Comp. 1288 ppm S Comp. Flatness Fair Thickness .068 in to .068 in.	8A1A	None 650°F (24 Hr)	Ambient Ambient	144,150 139,485	105,050 98,780	12.7 13.3	8.1 7.7
NMR-8B	Start 03-26 Finish 03-29 Tank No. E02 Amp Hrs. 720	Duty Cycle 40% Pulse On 8.0 Msec Pulse Off 12.0 Msec Peak C.D. 50.60 ASF Avg. C.D. 20.24 ASF Avg. Volts 4.00 Sprays Double	Ni Metal 77.34 g/l Mn Metal 4.6 g/l Boric Acid 30.70 g/l Acidity (pH) 4.12 Temperature 48.8°C	2 Each Size 4.38" x 8.12" Mn Comp. 1438 ppm S Comp. Flatness Fair Thickness .071 in to .072 in.	8B1A	None 650°F (24 Hr)	Ambient Ambient	125,105 133,520	96,660 114,790	13.0 13.0	7.4 6.6
NMR-8C	Start 03-31 Finish 04-03 Tank No. E01 Amp Hrs. 720	Duty Cycle 40% Pulse On 8.0 Msec Pulse Off 12.0 Msec Peak C.D. 50.60 ASF Avg. C.D. 20.24 ASF Avg. Volts 4.16 Sprays Double	Ni Metal 78.31 g/l Mn Metal 4.8 g/l Boric Acid 31.63 g/l Acidity (pH) 4.06 Temperature 49.4°C	2 Each Size 4.38" x 8.12" Mn Comp. S Comp. Flatness Fair Thickness in to	8C1A						

TABLE III - ELECTROLYTE SPRAY EFFECTS EVALUATION

Sample Number	PHASE I - TASK II NICKEL-MANGANESE OPTIMIZATION PANELS										Mechanical Properties (psi)			Hardness Rockwell C
	Fabrication Date	Pulse Plating Information	Plating Bath Analytical Data	Deposited Alloy Data	Strip No.	Heat Treatment	Test Temp (°F)	Ultimate	Yield	Elong. (%)	1 in	2 in		
NMR-9A	Start 03-24 Finish 03-27 Tank No. E01 Amp Hrs. 719	Duty Cycle 25% Pulse On 6.0 Msec Pulse Off 18.0 Msec Peak C.D. 80.96 ASF Avg. C.D. 20.24 ASF Avg. Volts 4.00 Sprays Double	Ni Metal 76.37 g/l Mn Metal 4.7 g/l Boric Acid 31.47 g/l Acidity (pH) 4.08 Temperature 50.0°C	2 Each Size 4.38" x 8.12" Mn Comp. 1758 ppm S Comp. Flatness Fair Thickness .068 in to .069 in.	9A1A B C D 9A2A B C D	None 650°F (24 Hr)	Ambient Ambient	185,880 181,065	141,990 157,960	5.8 5.8	4.2 3.6			
NMR-9B	Start 03-31 Finish 04-03 Tank No. E02 Amp Hrs. 720	Duty Cycle 25% Pulse On 6.0 Msec Pulse Off 18.0 Msec Peak C.D. 80.96 ASF Avg. C.D. 20.24 ASF Avg. Volts 3.90 Sprays Double	Ni Metal 77.66 g/l Mn Metal 4.6 g/l Boric Acid 31.78 g/l Acidity (pH) 4.04 Temperature 49.2°C	2 Each Size 4.38" x 8.12" Mn Comp. 1716 ppm S Comp. Flatness Fair Thickness .068 in to .068 in.	9B1A B C D 9B2A B C D	None 650°F (24 Hr)	Ambient Ambient	165,885 165,330	135,790 142,350	9.4 9.5	6.9 4.6			
NMR-9C	Start 03-27 Finish 03-30 Tank No. E01 Amp Hrs. 720	Duty Cycle 25% Pulse On 6.0 Msec Pulse Off 18.0 Msec Peak C.D. 80.96 ASF Avg. C.D. 20.24 ASF Avg. Volts 4.10 Sprays Double	Ni Metal 77.34 g/l Mn Metal 4.8 g/l Boric Acid 31.32 g/l Acidity (pH) 4.11 Temperature 49.1°C	2 Each Size 4.38" x 8.12" Mn Comp. S Comp. Flatness Fair Thickness in to	9C1A B C D 9C2A B C D									
NMR-10A	Start 04-18 Finish 04-20 Tank No. E02 Amp Hrs. 600	Duty Cycle 50% Pulse On 10.0 Msec Pulse Off 10.0 Msec Peak C.D. 40.48 ASF Avg. C.D. 20.24 ASF Avg. Volts 4.02 Sprays Sing. Square	Ni Metal 75.92 g/l Mn Metal 4.8 g/l Boric Acid 31.01 g/l Acidity (pH) 4.07 Temperature 49.4°C	2 Each Size 4.38" x 8.12" Mn Comp. S Comp. Flatness Fair Thickness in to .061	10A1A B C D 10A2A B C D	None None 650°F (24 Hr)	Ambient Ambient Ambient	150,975 165,340 140,755	112,015 127,570 123,480	5.9 11.7 10.0	6.2 9.2 6.0			
NMR-10B	Start Finish Tank No. Amp Hrs.	Duty Cycle 50% Pulse On 10.0 Msec Pulse Off 10.0 Msec Peak C.D. 40.48 ASF Avg. C.D. 20.24 ASF Avg. Volts Sprays	Ni Metal g/l Mn Metal g/l Boric Acid g/l Acidity (pH) Temperature °C	10B1A B C D 10B2A B C D										

TABLE IV - ELECTROLYTE SPRAY EFFECTS EVALUATION

Sample Number	NASA CONTRACT NAS 8-35817 PHASE I - TASK II NICKEL-MANGANESE OPTIMIZATION PANELS				Plating Bath		Deposited Alloy Data	Strip No.	Heat Treatment	Test Temp(°F)	Mechanical Properties (psi)		
	Fabrication Data	Pulse Plating Information	Analytical Data	Ni Metal	Mn Metal	Ultimate Yield					Elong.(%)		
NMR-11A	Start	04-19	40%	Ni Metal	76.55 g/l	2 Each	11A1A	None	Ambient	158,135	17.9	12.9	
	Finish	04-22	6.7 Msec	Mn Metal	4.7 g/l	Size 4.38"x 8.12"	B	None	Ambient	169,355	14.9	10.7	
	Tank No.	E01	Pulse Off	Boric Acid	1.78 g/l	Mn Comp.	C	650°F(24 Hr)	Ambient	160,055	139,700	8.0	5.0
	Amp Hrs.	600	Peak C.D.	50.60 ASF	Acidity(pH)	4.15	S Comp.	D					
			Avg. C.D.	20.24 ASF	Temperature	49.0°C	Flatness	11A2A					
		Avg. Volts	4.00	Temperature	49.0°C	Thickness .057 in	B						
		Sprays-SingleSquare	4.00	Temperature	49.0°C	to .058 in.	C						
				Temperature	49.0°C		D						
NMR-11B	Start	04-20	50%	Ni Metal	75.29 g/l	2 Each	11B1A	None	Ambient	137,110	11.6	9.3	
	Finish	04-23	20.0 Msec	Mn Metal	4.7 g/l	Size 4.38"x 8.12"	B	None	Ambient	149,795	125,255	11.4	8.6
	Tank No.	E02	Pulse Off	Boric Acid	30.55 g/l	Mn Comp.	C	650°F(24 Hr)	Ambient	165,550	124,165	8.0	5.0
	Amp Hrs.	600	Peak C.D.	40.48 ASF	Acidity(pH)	4.04	S Comp.	D					
			Avg. C.D.	20.24 ASF	Temperature	49.7°C	Flatness	11B2A					
		Avg. Volts	4.00	Temperature	49.7°C	Thickness .060 in	B						
		Sprays-SingleSquare	4.00	Temperature	49.7°C	to .061 in.	C						
				Temperature	49.7°C		D						
NMR-12B	Start	04-22	50%	Ni Metal	78.13 g/l	2 Each	12B1A	None	Ambient	162,715	131,340	11.5	9.1
	Finish	04-24	13.4 Msec	Mn Metal	4.7 g/l	Size 4.38"x 8.12"	B	None	Ambient	182,415	137,725	11.7	8.9
	Tank No.	E01	Pulse Off	Boric Acid	1.47 g/l	Mn Comp.	C	650°F(24 Hr)	Ambient	159,575	152,925	8.0	4.0
	Amp Hrs.	600	Peak C.D.	40.48 ASF	Acidity(pH)	3.97	S Comp.	D					
			Avg. C.D.	20.24 ASF	Temperature	48.9°C	Flatness	12B2A					
		Avg. Volts	4.05	Temperature	48.9°C	Thickness .055 in	B						
		Sprays-SingleSquare	4.05	Temperature	48.9°C	to .056 in.	C						
				Temperature	48.9°C		D						
NMR-13A	Start	04-22	40%	Ni Metal	78.13 g/l	2 Each	13A1A	None	Ambient	162,715	131,340	11.5	9.1
	Finish	04-24	13.4 Msec	Mn Metal	4.7 g/l	Size 4.38"x 8.12"	B	None	Ambient	182,415	137,725	11.7	8.9
	Tank No.	E01	Pulse Off	Boric Acid	1.47 g/l	Mn Comp.	C	650°F(24 Hr)	Ambient	159,575	152,925	8.0	4.0
	Amp Hrs.	600	Peak C.D.	50.60 ASF	Acidity(pH)	3.97	S Comp.	D					
			Avg. C.D.	20.24 ASF	Temperature	48.9°C	Flatness	13A2A					
		Avg. Volts	4.05	Temperature	48.9°C	Thickness .055 in	B						
		Sprays-SingleSquare	4.05	Temperature	48.9°C	to .056 in.	C						
				Temperature	48.9°C		D						
NMR-13B	Start	04-22	40%	Ni Metal	78.13 g/l	2 Each	13B1A	None	Ambient	162,715	131,340	11.5	9.1
	Finish	04-24	13.4 Msec	Mn Metal	4.7 g/l	Size 4.38"x 8.12"	B	None	Ambient	182,415	137,725	11.7	8.9
	Tank No.	E01	Pulse Off	Boric Acid	1.47 g/l	Mn Comp.	C	650°F(24 Hr)	Ambient	159,575	152,925	8.0	4.0
	Amp Hrs.	600	Peak C.D.	50.60 ASF	Acidity(pH)	3.97	S Comp.	D					
			Avg. C.D.	20.24 ASF	Temperature	48.9°C	Flatness	13B2A					
		Avg. Volts	4.05	Temperature	48.9°C	Thickness .055 in	B						
		Sprays-SingleSquare	4.05	Temperature	48.9°C	to .056 in.	C						
				Temperature	48.9°C		D						

TABLE V - ELECTROLYTE SPRAY EFFECTS EVALUATION

Sample Number	Fabrication Data	Pulse Plating Information	Plating Bath Analytical Data			Deposited Alloy Data	Strip No.	Heat Treatment	Test Temp (°F)	Mechanical Properties (psi)		
			Ni Metal	Mn Metal	Boric Acid					Yield	Elong. (%)	
NMR-14A	Start 04-23 Finish 04-25 Tank No. E02 Amp Hrs. 600	Duty Cycle 50% Pulse On 30.0 Msec Pulse Off 30.0 Msec Peak C.D. 40.48 ASF Avg. C.D. 20.24 ASF AVG. Volts 4.02 Sprays-SingleSquare	74.66 g/l 4.6 g/l 30.70 g/l 3.99 49.7°C	g/l g/l g/l °C	2 Each Panels Size 4.38"x 8.12" Mn Comp. S Comp. Fair Thickness .056 in to .057 in.	14A1A 14A1A 14A1A 14A2A C D	None None 650°F(24 Hr)	Ambient Ambient Ambient	134,340 138,095 135,915	15.7 9.2 3.0*	10.9 8.4 2.0*	
NMR-14B	Start Finish Tank No. Amp Hrs.	Duty Cycle 50% Pulse On 30.0 Msec Pulse Off 30.0 Msec Peak C.D. 40.48 ASF Avg. C.D. 20.24 ASF AVG. Volts Sprays-SingleSquare	Ni Metal Mn Metal Boric Acid Acidity(pH) Temperature	g/l g/l g/l °C	2 Each Panels Size 4.38"x 8.12" Mn Comp. S Comp. Fair Thickness in to	14B1A B C D 14B2A B C D	None None 650°F(24 Hr)	Ambient Ambient	171,520 184,505	4.2 3.0*	2.5 2.5*	
NMR-15A	Start 04-25 Finish 04-27 Tank No. E01 Amp Hrs. 600	Duty Cycle 40% Pulse On 20.0 Msec Pulse Off 30.0 Msec Peak C.D. 50.60 ASF Avg. C.D. 20.24 ASF AVG. Volts 4.02 Sprays-SingleSquare	78.07 g/l 4.6 g/l 30.70 g/l 3.94 48.8°C	g/l g/l g/l °C	2 Each Panels Size 4.38"x 8.12" Mn Comp. S Comp. Fair Thickness .056 in to .057 in.	15A1A B C D 15A2A B C D	None None 650°F(24 Hr)	Ambient Ambient	171,520 184,505	4.2 3.0*	2.5 2.5*	
NMR-15B	Start Finish Tank No. Amp Hrs.	Duty Cycle 40% Pulse On 20.0 Msec Pulse Off 30.0 Msec Peak C.D. 50.60 ASF Avg. C.D. 20.24 ASF AVG. Volts Sprays-SingleSquare	Ni Metal Mn Metal Boric Acid Acidity(pH) Temperature	g/l g/l g/l °C	2 Each Panels Size 4.38"x 8.12" Mn Comp. S Comp. Fair Thickness in to	15B1A B C D 15B2A B C D	None None 650°F(24 Hr)	Ambient Ambient	171,520 184,505	4.2 3.0*	2.5 2.5*	
NMR-16A	Start 04-25 Finish 04-28 Tank No. E02 Amp Hrs. 600	Duty Cycle 33.3% Pulse On 5.0 Msec Pulse Off 10.0 Msec Peak C.D. 60.72 ASF Avg. C.D. 20.24 ASF AVG. Volts 4.02 Sprays-SingleSquare	75.84 g/l 4.5 g/l 30.40 g/l 4.02 49.4°C	g/l g/l g/l °C	2 Each Panels Size 4.38"x 8.12" Mn Comp. S Comp. Fair Thickness .059 in to .060 in.	16A1A B C D 16A2A B C D	None None 650°F(24 Hr)	Ambient Ambient Ambient	144,535 133,250	111,670 111,045	2.3 10.0	1.2 5.0
NMR-16B	Start Finish Tank No. Amp Hrs.	Duty Cycle 33.3% Pulse On 5.0 Msec Pulse Off 10.0 Msec Peak C.D. 60.72 ASF Avg. C.D. 20.24 ASF AVG. Volts Sprays-SingleSquare	Ni Metal Mn Metal Boric Acid Acidity(pH) Temperature	g/l g/l g/l °C	2 Each Panels Size 4.38"x 8.12" Mn Comp. S Comp. Fair Thickness in to	16B1A B C D 16B2A B C D	None None 650°F(24 Hr)	Ambient Ambient Ambient	144,535 133,250	111,670 111,045	2.3 10.0	1.2 5.0

C. Task I - Heat Treatment of Alloy Structural Shell (Phase B)

For reason of simplifying the alloy optimization effort and the fact that heat treatment of the alloy for best combination of strength and ductility is necessary, the planned work in this task is being reported under Phase A, Task II.

D. Task II - Tooling for EF of Prototype SSME - MCC (Phase B)

The subscale MCC mandrel machining was completed as scheduled. The mandrel is a two-piece design to facilitate separation of the electroformed shroud configuration specimens. Each section has been zincated for bonding and flash chromium plated to protect the surfaces from corrosion and scratching. We expect to use this mandrel for many electroforming trials.

E. Task III - Prototype MCC Preparation for Electroforming (Phase B)

The mandrel electroforming strongback and MCC rotating drive system are being integrated. Plexiglass shield support soft-tooling is in fabrication. Special provision is being made for a separate drive to rotate the upper shield support in a counter direction to the mandrel. This will enable the use of conformal rotating blades to provide additional electrolyte shear at the surface being electroformed. This will augment forced sprays to promote higher manganese concentrations in the alloy. We anticipate this may be required due to the fact that the mandrel is a complex shaped rotating mandrel which will be under continuous deposition over all areas regardless of whether these areas are "seeing" a strong diffusion layer shearing action, or not. By being able to independently drive a "squirrel cage" of conformal blades, it should be possible to provide high turbulence over a greater area of the mandrel.

Our plans for Phase B electroforming on the mandrel call for evaluation of alloy chemistry and hardness variability based on mandrel rotational speeds and multiple spray placement. If manganese content is not sufficient to promote proper hardness and retention of good hardness after heat treating, we expect to correct this condition by one or more of the following actions:

1. Increase the pulse off time for better manganese diffusion to the cathode surface.
2. Increase the manganese content in the electrolyte. This can only be done as long as residual stress is not prohibitive.
3. Increase spray agitation capacity.
4. Increase average current density for pulse plating.

Based on the magnitude of samples required for evaluation when we start electroforming MCC configurations, it is unlikely that novel agitation systems such as the counter rotating blades, it is recommended that such evaluations be considered in follow-on work - should continuation of the alloy electroforming program be considered appropriate.

III. CURRENT PROBLEMS

The previous discussions of this progress report have shown that

electrolyte agitation variations have more pronounced effects on mechanical properties than had been anticipated. Conditions which lead to specific mechanical properties on simple flat shapes will require modification when applied to cylindrical and conical shapes such as the MCC. Although corrective actions to solve this problem are generally defined, achieving desired mechanical properties and uniform alloy composition on complex configurations is now expected to consume more study than originally anticipated. We expect the Phase A work will provide an optimum alloy for mechanical properties at the expected MCC service temperatures; however, duplicating these properties on a complex round shape may require extending some efforts beyond the schedule and funding of the present contract.

IV. WORK PLANNED

1. Complete electrolyte agitation evaluation with respect to mechanical properties and manganese contents of alloys.
2. Select specimens for continued study with respect to effects of various heat treatments on ambient and elevated temperature properties.
3. Continue soft tooling for subscale mandrel - shield support, rotational drive connections, etc.

V. FINANCIAL DATA

See attached NASA Form 533P.

