Advanced Nickel Electroforming Technology for The Regenerative Thrust Chamber of the Rocket Engine

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Abstract

Electroforming is one of the key technologies for the regenerative thrust chamber of the rocket engine. To use nickel electroforming method for the thrust chamber, direct electroforming of nickel on cupper and the welding method between different materials are needed.

Minimizing the internal stress is one of the important factor for making thick electroforming,.

Also minimizing contamination (ex. Sulfur containing compound) is another important factor for the stability of quality.

This paper includes advanced methods for thick nickel electroforming, those of strength test results and EDS/EPMA inspection results.

Advanced for electroforming process makes the achievement of Electro-beam welding between Inconel718(Manifold) and Nickel Electroforming .

This paper also includes the influence of the electroforming precipitation angle on strength.

Thus advanced electroforming improvement processes and the test results make achievement for manufacturing of the regenerative thrust chamber with direct nickel thick electroforming on cupper materials.

Back Ground

One of the primary methods of fabricating the outer shell of regenerative cooled thrust chambers for advanced design rocket engines is by electroforming.

Nickel electroforming is more useful for outer shell of regenerative cooled thrust chambers rather than Cupper electroforming because of structural reason.

However, the relation between electroforming procedure and stabilized deposit quality is not recognized well.

Generally, the difficulty of thick nickel electroforming is to keep purity of deposit.

Contaminations, such as organic, sulfur, or metal (ex. Cupper, lead and zinc) can contribute to deposit impurities which result porosity or embrittlement upon exposure to elevated temperature.

Such evaluation was critical since the deposits are subject to being brazed or welded as secondary fabrication operations in thrust chamber manufacture.

This activity is verification of developed procedure for thick (12-24mm) nickel electroforming to prevent impurities from deposit.

Verification methods are bond strength test, and deposit purity inspection by EDS/EPMA.

Electroforming Procedure Improvement

To make thick electroforming, minimizing tensile stress in the deposits is necessary.

Generally, to minimize tensile stress in the deposits, deposits purity is most important item.

Improved processes for deposits purity are as follows,

(1) To use double anode bags for preventing nickel chloride will reached for cathode. It is necessary to use sulfur depolarized nickel.
(2) Bubbling system for preventing contamination will reached cathode.
(3) Continuously filtration system to catch the contamination in sulfamate bath.
(4) To remove metallic contamination with "dummy" electrolysis using corrugated cathodes in another bath.
(5) To minimize organic contamination, there are no wax for channel filling procedure. Filling with aluminum.

Bond Strength Achieved Between Nickel Electroformed Outer Shell and Chamber Liner(Cupper Alloy)

Primary verification of electroforming quality is bond strength.

OFHC(ASTM C10200) and Cr-Zr Cupper Alloy (ASTM C18150) are selected as chamber liner material. Mechanical property of each materials are shown in Table.1.

Conducted 14mm nickel electroforming direct on two of cupper material with same electroforming condition.

Cupper material size is as follows,

- Cylindrical
- Inner diameter : 75mm
- Outer diameter : 200mm

- Length : 94mm

After electroforming, machined outer surface and strength test pieces.(Fig.1 shows test pieces configuration.)

Test conditions are as follows,

- heated treatment : 673, 923, 1123[K] (8 hours) : all test piece is exposed 8 hours of 464[K] prior to heat treatment
- Test condition(temperature) : 77, 293[K]

Table.2 shows bonding strength result at every heat treatment and test temperature condition.

All test piece are failed on cupper side. Fig.2 shows typical test pieces which are failed.

Those results says that bond strength between cupper alloy and nickel electroforming are over cupper alloy strength.

Table.1 Mechanical property of cupper
(At room temperature)

ASTM NO.	contents	strength	Elongation	hardness
-	%	MPa	%	Hv
C18150	Cu:Bal. Cr:0.5-1.5 Zr:0.05-0.15	400	40	120
C10200	Cu:>99.96	210	60	40

Fig.1 Strength test piece configuration

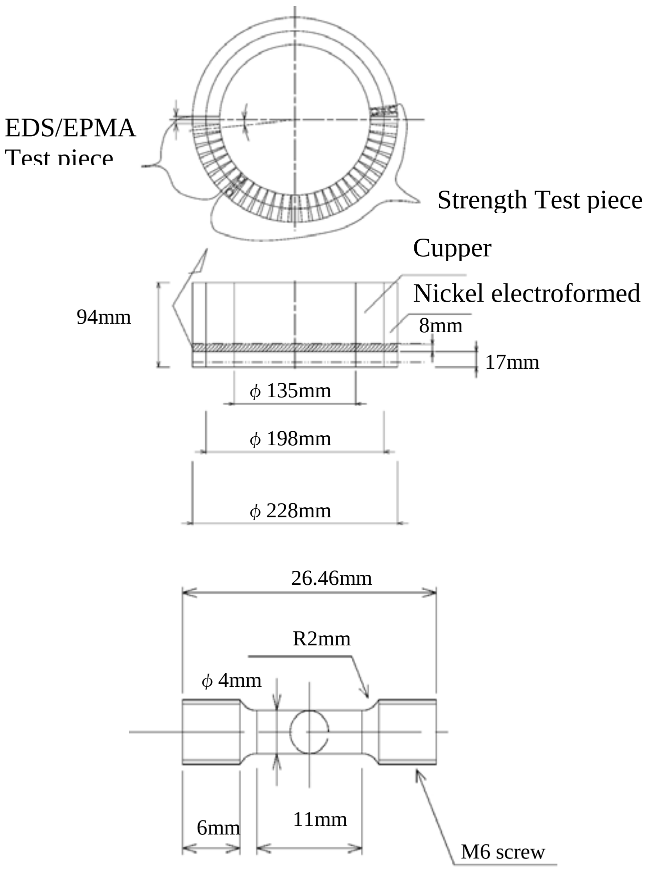
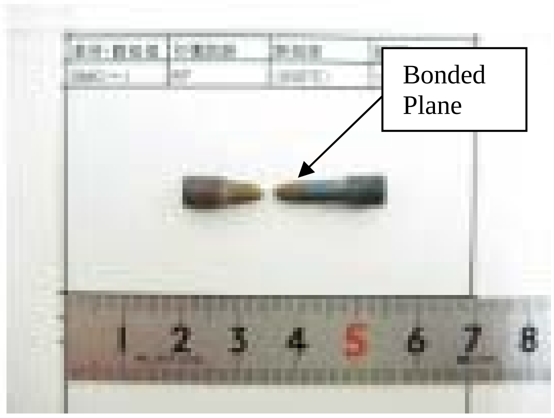


Table.2 Bond strength test result

ASTM No.	Test Temperature Condition [K]	Strength [MPa]			Elongation [%]		
		Heat Treatment [K]			Heat Treatment [K]		
		673K	923K	1123K	673K	923K	1123K
C18150	77	414	358	294	34.7	37.6	42.0
	293	398	334	247	30.4	34.7	40.6
C10200	77	247	263	151	34.8	52.2	21.7
	293	211	207	167	33.4	45.0	7.2

Fig.2 Typical failed test piece
(C18150, H/T:923[K], Test:293[K])



Deposit Quality(EDS/EPMA)

To evaluate nickel electroforming quality, diffusion domain around bonded plane and ingredient analysis are conducted.

EDS(Energy Dispersive Spectrometer) shows diffusion domain on line(included bonded plane).

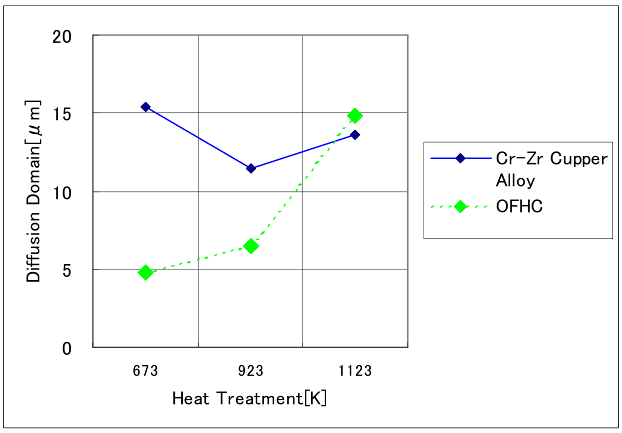
Fig.3 shows EDS result for nickel electroformed test pieces which are as same heat treatment condition as bond strength test.

Diffusion domain is 5 to 16 micron.

To use Cr-Zr Cupper Alloy as chamber liner is wider diffusion domain than OFHC.

It shows that to use Cr-Zr Cupper Alloy as chamber liner seems higher bond strength than OFHC.

Fig.3 EDS result



EPMA(Electron Probe Microanalyzer) shows ingredient around bonded plane.

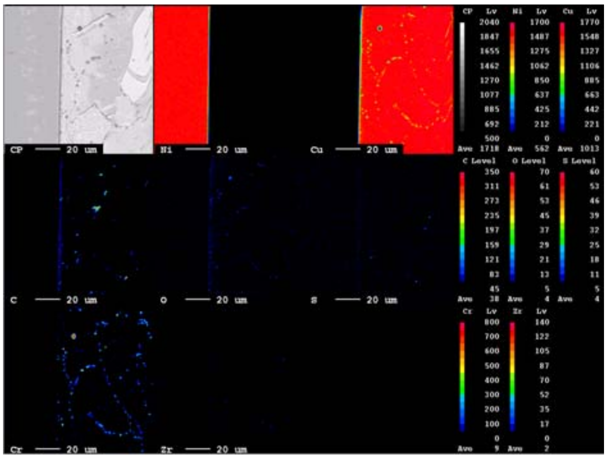
This analysis is for ingredient of 7 elements(Ni, Cu, C, O, S, Cr, Zr) around bonded plane for verification of deposit purity.

Fig.4 shows EPMA result which is the case of heat treatment condition at 673[K], to use Cr-Zr Cupper Alloy as chamber liner.

This result says sulfur segregation is not shown.

It means this nickel electroforming is high deposit purity.

Fig.4 EPMA result
(Heat treatment condition:673[K], Cr-Zr Cupper Alloy as chamber liner)



Electro-beam Welding

Thrust chamber consists of cupper alloy liner, nickel electroforming outer shell and Inconel 718 manifold.

Joining method of nickel electroforming outer shell and Inconel 718 manifold has two alternatives.

One is Blazing and another is EBW.

However, selected Cr-Zr Cupper Alloy as chamber liner, there is no Blazing option.

Over 773[K], Cr-Zr Cupper Alloy will be annealing softening. EBW is necessary for manufacture the thrust chamber.

Generally, electroforming material is difficult for welding.

Developed high deposit purity electroforming makes the achievement of Electro-beam welding.

Fig.5 shows typical microscope analysis result of welded Inconel 718 and nickel electroforming.

There are no defect on nickel electroforming.

Also fine columnar grain structure is indicated.

To verify the welding feasibility, conducted strength test of welded test pieces.

At the same time, influence of electroforming precipitation angle for strength are tested.

Test conditions are as follows,

- Precipitation angle: 0, 45,90 degree
- Test temperature condition: 77, 293 [K]

Table.3 shows strength test results.

The test pieces which are 0 and 90 degree of electroforming precipitation angle are approximately same strength and elongation rate.

However the test pieces which are 45 degree of electroforming precipitation angle are higher strength and larger elongation rate.

Fig.6, Fig.7, and Fig.8 shows failed test pieces, microscope analysis results of welded condition and failed test pieces.

The test pieces which are 0 and 90 degree of electroforming precipitation angle are failed on nickel electroforming.

However the test pieces which are 45 degree of electroforming precipitation angle are failed around welded point.

Those results says that following,

(1) Improved electroforming makes the achievement of Electro-beam welding between Inconel718 (Manifold) and Nickel Electroforming without influence of electroforming precipitation angle.
(2) Nickel electroforming may have strength anisotropy.

Fig.5 Typical microscope analysis result

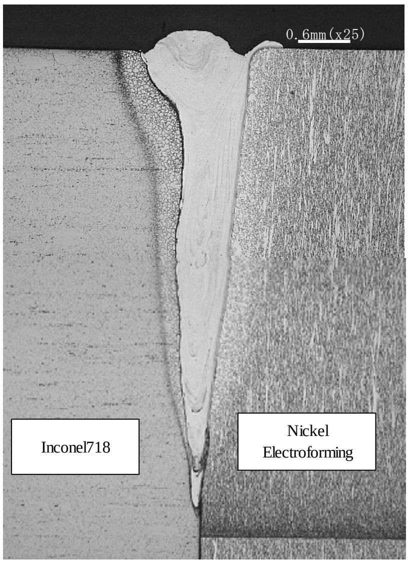


Table.3 Strength test results

Precipitation Angle / Test Temperature	0		45		90	
	Strength [MPa]	Elongation [%]	Strength [MPa]	Elongation [%]	Strength [MPa]	Elongation [%]
77K	5.42	16.0	5.66	27.6	5.18	16.7
	5.19	16.0	5.69	26.2	4.78	20.4
	5.18	16.0	5.69	26.9	5.07	15.3
293K	4.52	15.3	5.15	25.5	4.33	15.3
	4.61	14.5	5.13	23.3	4.21	17.5
	4.57	14.5	5.15	24.7	4.61	14.5

Fig.6 Failed test pieces, microscope analysis results of welded condition and failed test pieces (Precipitation angle: 0 degree)

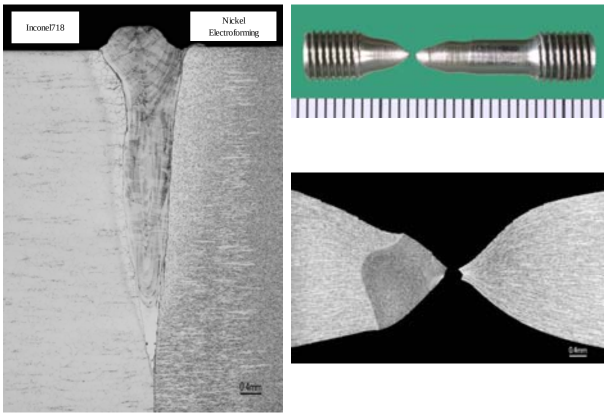


Fig.7 Failed test pieces, microscope analysis results of welded condition and failed test pieces (Precipitation angle: 45 degree)

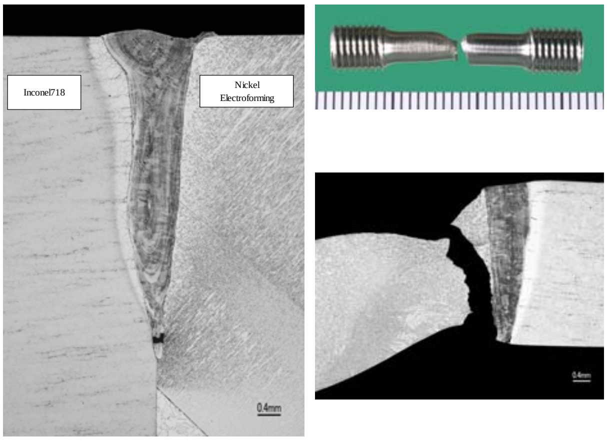
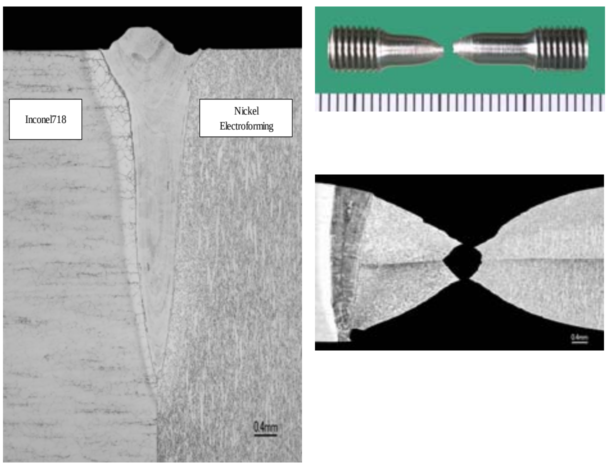


Fig.8 Failed test pieces, microscope analysis results of welded condition and failed test pieces (Precipitation angle: 90 degree)



Conclusion

Thick nickel electroforming procedure is not matured technology.

However, our improved procedure of nickel electroforming makes achievement keeping stabilized fine quality.

Those results introduce necessity of deposit purity for stabilized electroforming quality.

Further analysis are needed on electroforming strength anisotropy and method of keeping deposit purity.

References

1) G. A. Malone: Investigations of Electroforming Techniques, NASA CR 134959 , 1975.