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# COPPER ELECTROFORMING OF CRYOGENIC UPPER STAGE MAIN ENGINE

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**Electroforming is the highly specialized application of the electrodeposition process employed for the manufactures of finished components, structure, unique articles and patterns that can not be produced by any other conventional methods of fabrication. Parts having complex shapes, intricate contours and complicated patterns can be produced by the eltroforming techniques. This paper deals with the copper electroforming of cryogenic upper stage main engine by employing the aluminum mandrel.**

**Keywords: Electroforming, copper deposition, upper stage main engine, fabrication of complex shapes**

## INTRODUCTION

Electroforming process is established as the best method for the fabrication of the regeneratively cooled thrust chambers for advanced rocket engines [1-10]. The cooled thrust chamber section consists of a combustion chamber where burning of high energy fuel and oxidizer occurs, a throat restriction to convert the high pressure gases into high velocity vector flow and a nozzle to increase gas velocity and amplify the thrust. The inner liner of the chamber can be either electroformed or can be machined from OFHC forging. Electroformed copper inner liner is more advantageous as it produces the near net shape required and eliminates the tedious machining of the OFHC forging.

Channels are machined on the outer periphery of the copper inner liner to provide flow passages for a coolant to maintain the hot gas wall at a safely low operating temperature. The outer shell close out the coolant passages and provides structural support for the liner coolant system. Electroformed nickel is generally used for the outer shell due to its high mechanical properties when compared with copper. Electroforming provides the most economical means of fabricating the complex shape required for the inner and outer shell. This paper describes the copper electroforming of inner shell required for the cryogenic upper stage machine engine.

## EXPERIMENTAL

The machined aluminium mandrel was degreased with trichloroethylene, etched in 50 $g.l^{-1}$ sodium hydroxide for 5 minutes to remove the surface oxides, washed in tap water, and desmutting carried out in 20% V/V nitric acid to remove the sludge formed by the etching step. The mandrel was washed in tap water, rinsed in deionized water and double zincating carried out from the following bath.

| | |
|---|---|
| Zinc oxide | 20 $g.l^{-1}$ |
| Sodium hydroxide | 120 $g.l^{-1}$ |
| Rochelle salt | 50 $g.l^{-1}$ |
| Ferric chloride | 2 $g.l^{-1}$ |
| Sodium nitrate | 1 $g.l^{-1}$ |
| Temperature | 303-308 K |
| Immersion time | 45 seconds |

The mandrel was then washed in tap water, rinsed in deionized water and transferred to the alkaline copper plating bath of the following composition.

Mandrel aluminum mandrel
↓
Degreasing with trichloroethylene
↓
Alkaline immersion cleaning
↓
Washing in tap water
↓
Acid desmulling
↓
Desmulling
↓
Washing in tap water
↓
Rinsing with deionised water
↓
Dipping in zincating solution
↓
Washing in tap water
↓
Dissolve zinc coating in nitric acid
↓
Washing in tap water
↓
Rinsing with deionized water
↓
Dipping in the zincating solution
↓
Washing in tap water
↓
Rinsing with deionized water
↓
Copper strike plating from alkaline copper bath
↓
Washing tap water
↓
Copper electroforming in acid copper bath
↓
Washing in tap water
↓
Rinsing with deionized water
↓
Drying
↓
Rough machining
↓
Final machining
↓
Dissolve aluminium mandrel in sodium hydroxide solution after drilling holes
↓
Washing in tap water
↓
Drying

*Fig. 1: Flow chart for processing aluminium mandrels for electroforming of cryogenic upper stage main engine*

| | |
|---|---|
| Copper sulphate | 50 $g.l^{-1}$ |
| Rochelle salt | 70 $g.l^{-1}$ |
| Ammonium hydroxide to raise *p*H | 8-9 |
| Current density | 1-5 $A.dm^{-2}$ |

OFHC copper anodes were used. Copper plating was continued till an uniform coverage of copper was produced all over the mandrel surface. Deposition usually takes about 10-15 minutes the deposit, then washed in tap water and rinsed with deionized water. The mandrel was transferred to the copper electroforming bath. OFHC copper anodes bagged in terylene cloth were used. Current density used for deposition was 2-3 $A.dm^{-2}$ at room temperature. The electrolyte was filtered continuously by filter pumps to remove sediments and dust particles which

Intermediate machining of copper electroformed aluminium mandrel
↓
Intermediate machining of copper electroformed aluminium mandrel
↓
Degreasing with trichlorethylene
↓
Alkaline electrocleaning
↓
Washing in tap water
↓
Acid dip in 5% sulphuric acid
↓
Washing in tap water
↓
Rinsing with deionized water
↓
Copper electroforming in acid copper bath for further build up
↓
Washing in tap water
↓
Rinsing with deionized water
↓
Drying
↓
Rough machining
↓
Final machining
↓
Dissolve aluminium mandrel in sodium hydroxide solution after drilling holes
↓
Washing in tap water
↓
Drying

*Fig. 2: Flow chart for processing of electroformed mandrel after intermediate machining*

may cause roughness of the deposit. If treeing is observed during heavy deposition of copper, intermediate machining is done. After intermediate machining it is necessary that the mandrel is cleaned properly to receive further copper deposit. The following procedure was followed:

Machined copper mandrel was degreased with trichloroethylene, electrocleaned in the following alkaline solution.

| | |
|---|---|
| Sodium carbonate | 25 $g.l^{-1}$ |
| Trisodium phosphate | 30 $g.l^{-1}$ |
| Sodium hydroxide | 10 $g.l^{-1}$ |
| Temperature | 323 K |
| Current density | 3 $A.dm^{-2}$ |
| Treating time | 2-5 minutes |

The mandrel was washed in tap water and then dipped in 10% V/V sulphuric acid for 2 minutes. The mandrel was washed, rinsed in deionized water and transferred to the copper electroforming bath. In this processing sequence it is also necessary to follow the water break test to see that the surface is completely wet with water.

## RESULTS AND DISCUSSION

The flow chart for processing aluminium mandrels for electroforming of cryogenic upper stage main engine is shown in Fig. 1. The machined aluminium mandrel after degreasing and alkaline cleaning was double zincated. In double zincating, the zinc coating formed by the first immersion step was removed by dipping in 20% V/V nitric acid, washed in tap water, rinsed in deionized water and again zincated to form the zinc coating. This double zincating step produces uniform, strongly adherent and coherent zinc coating which act as starting base for further build up.

The mandrel after zincating, was copper plated with the current on in the bath to avoid the dissolution of zinc coating. During heavy deposition of copper, treeing are formed and hence intermediate machining was given after depositing 6 mm of copper. If machining was not followed lot of metal is wasted in the formation of trees. After building sufficient thickness of copper the mandrel was removed, washed in tap water, dried and then machined to required dimensions. Fig. 2 shows the flow chart for processing of electroformed mandrel after intermediate machining.

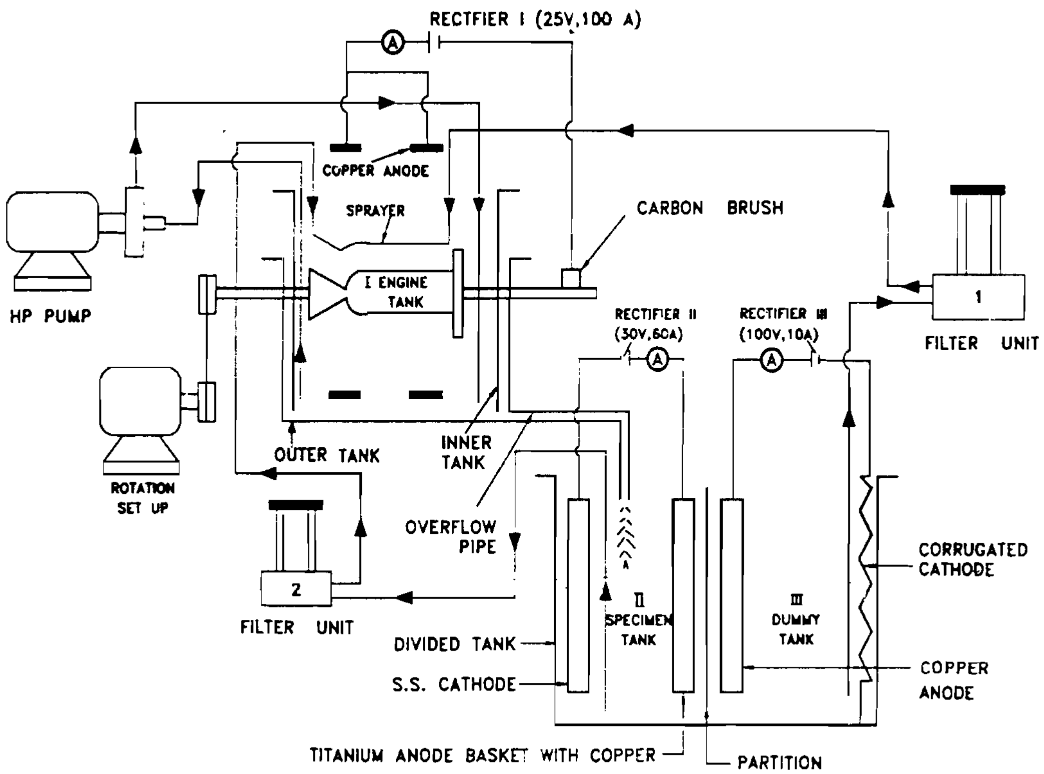


*Fig. 3: Advanced copper electroforming facility*

Advanced copper electroforming facility is shown in Fig. 3. After rough and final machining of the electroformed copper, holes are drilled on the aluminium mandrel of its complete dissolution using 50 $g.l^{-1}$ sodium hydroxide solution. This is a lengthy process and may take about 3-4 days for its complete removal. This operation has to be carried out in a ventilated room and requires solution circulation.

## CONCLUSION

The cryogenic upper stage main engine was successfully electroformed by copper to a thickness of 6-8 mm without any intermediate machining.

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