Composite Overwrapped Nickel-Hydrogen Pressure Vessels

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COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- THE PURPOSE OF THIS PAPER IS TO STIMULATE INTEREST IN COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS.
- COMPOSITE OVERWRAPPED PRESSURE VESSELS SHOULD:
  - BE MORE ECONOMICAL TO PRODUCE
  - REQUIRE LESS SCHEDULE TIME TO PRODUCE
  - BE MORE RELIABLE
  - BE INHERENTLY MORE RESISTANT TO FATIGUE DAMAGE
  - POTENTIALLY IMPROVE HEAT TRANSFER CHARACTERISTICS
  - REDUCE MEMBRANE STRESS
  - ALLOW A POTENTIALLY WIDE RANGE OF LINER MATERIALS

States purpose of paper - stimulate interest in Composite Overwrapped pressure vessel technology as applied to Nickel-Hydrogen Battery pressure vessels. Includes technical and economic forces that could be utilized in such a design.

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- HISTORY OF NICKEL-HYDROGEN PRESSURE VESSELS
  - TECHNOLOGY IS FIFTEEN YEARS OLD
  - EXCEPT FOR THE LAST TWO YEARS ALL KNOWN APPLICATIONS HAVE BEEN IN GEO ORBIT AT 600 PSI
  - OVER THE LAST THREE YEARS APPLICATIONS HAVE MOVED TO LEO ORBITS WITH PRESSURE INCREASED TO EXCESS OF 1000 PSI
    - DEPTH OF DISCHARGE HAS ALSO BEEN INCREASED FROM 10% TO PRESENT REQUESTS THAT ARE NOW APPROACHING 40%
    - WEIGHT HAS BEEN REDUCED AT THE EXPENSE OF PRESSURE VESSEL WALL THICKNESS
  - BOTH EUROPE AND JAPAN ARE PLANNING NICKEL-HYDROGEN BATTERIES FOR SPACE APPLICATIONS

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- HISTORY (cont)
  - INCONEL 718 HAS BEEN THE MATERIAL OF CHOICE SINCE EARLY DESIGNS
    - ALL PRESENT DESIGNS KNOWN TO THE AUTHORS PRESENTLY USE OR ANTICIPATE THE USE OF INCONEL 718
    - INCONEL 718 HAS PROVED TO BE VERY RELIABLE
  - THE ADVANTAGES OF COMPOSITE OVERWRAPPED MATERIAL HAVE BEEN SUGGESTED SEVERAL TIMES BUT THE TECHNOLOGY HAS ALWAYS BEEN ELIMINATED EARLY ON DUE TO:
    - FEAR OF ADVERSE THERMAL REACTIONS' EFFECTS
    - UNKNOWNS OF DESIGN
    - LACK OF COMPOSITE OVERWRAPPED EXPERTS IN THE DESIGN PROCESS
  - DESIGNERS HAVE ACKNOWLEDGED THE ABILITY OF COMPOSITE OVERWRAPPED TECHNOLOGY TO REDUCE THE OVERALL STRESS IN THE CRITICAL GIRTH WELD(S) AREA

Presents the history of Nickel Hydrogen Pressure Vessels over the last 15 years including materials, operating conditions, and market expansion to Internationals.

Discusses minor interest in Composite Overwrap technology as applied to Nickel-Hydrogen Batteries to date.

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- MATERIAL PROPERTIES DESIRED FOR PRESSURE VESSEL
  - COMPATIBILITY WITH KOH
    - GENERAL CORROSION
    - FRACTURE CONTROL
  - GOOD THERMAL CONDUCTIVITY
  - HIGH STRENGTH-TO-WEIGHT RATIO
  - HIGH CYCLE LIFE
    - APPROXIMATELY 41,000 ACTUAL CYCLES FOR 15 YEAR SERVICE LIFE
      - 164,000 ANALYTICAL CYCLES

Itemizes basic materials properties: thermal, corrosion, strength.

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- APPROACHES TO ACHIEVING DESIRE PROPERTIES
  - MONOLITHIC METAL CONSTRUCTION
    - DIFFICULT TO OPTIMIZE PROPERTIES IN ONE ALLOY
    - COMPROMISE OF SOME PROPERTY USUALLY REQUIRED
  - COMPOSITE OVERWRAPPED CONSTRUCTION
    - EACH DESIRED PROPERTY CAN BE OPTIMIZED IN DIFFERENT COMPONENTS OF COMPOSITE VESSEL
      - COMPATIBILITY IN INNER LINER
      - THERMAL CONDUCTIVITY IN OUTER LINER
      - STRENGTH-TO-WEIGHT RATIO IN COMPOSITE OVERWRAP
      - CYCLE LIFE IN INNER LINER

Monolithic and Composite Overwrapped construction approach compared.

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- POTENTIAL ADVANTAGES OF COMPOSITE PRESSURE VESSEL
  - OPTIMIZED PROPERTIES
  - POTENTIALLY LOWER COST
    - COMPOSITE HIGH-PRESSURE GAS STORAGE VESSELS COST APPROXIMATELY 20% OF EQUIVALENT TITANIUM VESSEL
    - POTENTIAL FOR ELIMINATION OF WELDS
  - POTENTIALLY SHORTER MANUFACTURING SCHEDULE
    - COMPOSITE VESSELS ARE BEING PRODUCED IN APPROXIMATELY ONE-THIRD TIME FOR EQUIVALENT TITANIUM VESSELS
  - IMPROVED FRACTURE CONTROL CAPABILITY
    - COMPOSITE VESSELS SHOW POTENTIAL FOR MILLIONS OF CYCLES BEFORE LEAKAGE
  - POTENTIALLY LOWER WEIGHT
    - COMPOSITE HIGH-PRESSURE GAS STORAGE VESSELS WEIGH APPROXIMATELY 20% OF WEIGHT OF EQUIVALENT TITANIUM VESSEL
  - PRECISE CONTROL OF VESSEL WALL GROWTH DUE TO PRESSURE WITH MINIMAL EFFECT ON WEIGHT

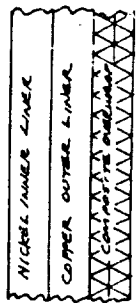
Detailed description of the advantages of Composite Overwrapped Pressure vessels showing weight savings, manufacturing schedule reductions, and improved fatigue life.

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- GRAPHITE/EPOXY OVERWRAPPED PRESSURE VESSEL WITH INCONEL X-750 LINER IS CURRENTLY FLYING ON B-1 BOMBER
- NO KNOWN REASON WHY INCONEL 718 LINERS OR LINERS OF ANY DUCTILE NICKEL ALLOY COULD NOT BE OVERWRAPPED WITH GRAPHITE/EPOXY

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

OPTIMIZED PROPERTIES



SCHEMATIC SECTION
OF VESSEL WALL

Discussion of B-1 application, wide range of usable materials, and a sketch of a possible optimized design.

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- THERMAL CONDUCTIVITY OF SOME CANDIDATE MATERIALS
  - COPPER: 226 BTU FT/HR FT^2
  - NICKEL: 50 BTU FT/HR FT^2
  - GRAPHITE: 46 BTU FT/HR FT^2 (PARALLEL TO FIBER)
  - INCONEL 718: 6.5 BTU FT/HR FT^2
  - GRAPHITE/EPOXY: 0.1 BTU FT/HR FT^2 (TRANSVERSE TO FIBER)

Table showing recent successes using Graphite/Epoxy Composite Overwrapped technology in actual flight systems.

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- POTENTIAL LINER FABRICATION METHODS
  - SPIN FORM AND CHEM-MILL
  - ELECTROFORM AND CHEM-MILL
  - FORGE AND CHEM-MILL

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- POTENTIAL ELIMINATION OF WELDS
  - JOIN VESSEL COMPONENTS WITH ADHESIVES
  - USE MECHANICAL CLOSURES WITH NON-STRUCTURAL SEALING WELDS

Discussion of joining technology and the opportunity to: reduce risk in manufacturing, increase production, and improve reliability by adopting Composite Overwrapped technology.

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- FRACTURE CONTROL ISSUE FOR NICKEL-HYDROGEN PRESSURE VESSELS
  - NDI METHODS FOR CRACKS ARE NOT SENSITIVE ENOUGH FOR 164,00 ANALYTICAL CYCLES
  - ENVIRONMENTALLY AFFECTED SUSTAINED LOAD CRACK GROWTH DUE TO EFFECT OF KOH REDUCES CYCLE LIFE

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- POTENTIAL FRACTURE CONTROL METHODOLOGY
  - ELIMINATE STRUCTURAL WELDS
  - ELIMINATE ALL CRACKS BY CHEM-MILLING INSIDE AND OUTSIDE SURFACES OF LINER

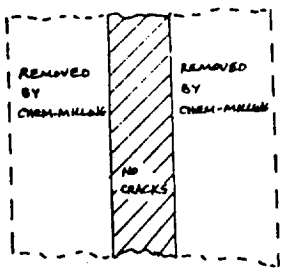
Fracture Control problems in present designs are addressed and possible solutions proposed. Emphasis is on the improvement possibilities with Composite Overwrapped technology in the area of a large analytical increase in total pressure vessel life.

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

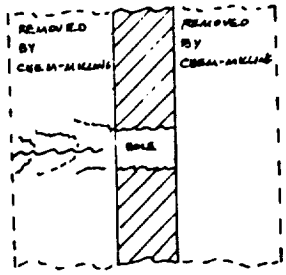
- NDI METHODOLOGY FOR WROUGHT METAL LINER
  - WROUGHT METAL IS CONVENTIONALLY MACHINED TO A THICKNESS OF 0.030-0.040 INCH PER SURFACE GREATER THAN FINAL DESIRED THICKNESS
  - BOTH SURFACES OF WROUGHT METAL ARE INSPECTED USING NSTS "SPECIAL" PENETRANT INSPECTION
  - EXTRA 0.030-0.040 INCH THICKNESS IS CHEMICALLY MILLED FROM EACH SURFACE
  - REMAINING MATERIAL IS "CRACK-FREE"
    - CHEM-MILLING SOLUTIONS DO NOT GENERATE CRACKS
      - NASA AND DoD SPECIFICATIONS REQUIRE "ETCHING" BEFORE PENETRANT INSPECTION
    - ANY SURFACE CRACK IN ORIGINAL 0.030-0.040 INCH THICKNESS RESULT IN HOLES THROUGH FINAL THICKNESS

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- NDI METHODOLOGY



RESULT IF NO CRACK EXISTS



RESULT IF CRACK EXISTS

Non-destructive testing is described for monolithic designs and for the proposed Composite Overwrapped technology. The elimination of virtually any flaw by using Chem-milling to reduce the overall membrane thickness is detailed. Adopting this technology proves the extended analytical life predicted above.

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

FLIGHT HISTORY OF GRAPHITE-OVERWRAPPED PRESSURE VESSELS WITH THIN METALLIC LINERS

PROGRAM	TYPE OF TANK	DATE FLOWN	FLUID	FIBER	OPERATING PRESSURE (PSIA)	BURST PRESSURE (PSIA)
MEDI	PRESSURANT	JAN. 1990	GN_2	T-40	7,000	14,000
PEGASUS	PRESSURANT	APR. 1990	GN_2	HT 46-9	2,500	5,000
ERIS	PRESSURANT	JAN. 1991	GHe	T-1000	9,400	24,000
ERIS	PROPELLANT	JAN. 1991	NTO/MMH	HT 46-9	2,550	6,500
BRILLIANT PEBBLES	PRESSURANT	MAR. 1991	GHe	T-1000	9,000	28,000
PEGASUS HAPS	PROPELLANT	JULY 1991	HYDRAZINE	T-1000	464	696
	PRESSURANT	JULY 1991	GHe	T-1000	6,800	10,200
	PRESSURANT	JULY 1991	GN_2	T-1000	5,800	8,700
MICROSAT	PRESSURANT	JULY 1991	GN_2	T-1000	6,000	12,000

Pictorial of how NDI combined with chem-milling assure total freedom from flaws.

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- NOW IS THE RIGHT TIME TO STUDY THIS ALTERNATIVE
  - THE COMPOSITE OVERWRAP TECHNOLOGY HAS TOTALLY SUPPLANTED CONVENTIONAL MONOLITHIC METAL TECHNOLOGY IN MANY SPACE FLIGHT APPLICATIONS IN THE LAST FIVE YEARS
    - IT IS INHERENTLY SAFER
    - USED EXTENSIVELY WITH MONOPROPELLANT SYSTEMS AS WELL AS OTHER HIGH PRESSURE APPLICATIONS
    - LOW-PRESSURE BIPROPELLANT VESSELS CURRENTLY BEING DEVELOPED
- THE USA SHOULD STRIVE TO MAINTAIN ITS TECHNOLOGICAL SUPERIORITY IN THIS TECHNOLOGY BY EXPLORING ALL FACETS AND APPLICATIONS (BOTH NICKEL-HYDROGEN AND COMPOSITE OVERWRAPPED TECHNOLOGIES)

Suggests that now is the correct time for the USA to thoroughly investigate composite overwrapped technology. This activity will protect our market share while promoting greater knowledge of Nickel-Hydrogen Batteries.

COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- A PRELIMINARY INVESTMENT OF 300k$ WOULD BE ADEQUATE TO DEVELOP THE BASIC FEASIBILITY OF PRODUCING SUCH A DESIGN.
  - THIS INVESTMENT WOULD PRODUCE A PROTOTYPE PRESSURE VESSEL ALONG WITH ALL PRELIMINARY DATA REGARDING THERMAL PROPERTIES, MANUFACTURING METHODS AND FRACTURE CONTROL
  - A MANUFACTURING PLAN WOULD ALSO BE ESTABLISHED WITH COST PER UNIT ESTIMATED FOR PRODUCTION
- WORK COULD BEGIN IN 3 - 6 MONTHS
- COMPLETION WOULD BE EXPECTED IN 16 - 20 MONTHS

Presents cost and schedule information.