Low Cost Titanium Pipe for Naval Applications

L.S. Kramer, J.A. Brougher, J.R. Pickens, W.T. Tack
Concurrent Technologies Corporation

P.M. Hoyt
Northrop Grumman Shipbuilding, Gulf Coast Operations

INTRODUCTION

The advantageous combination of low density, high specific strength and excellent corrosion resistance led to the use of CP grade 2 titanium in some Navy ship seawater piping applications. However, the increase in the cost of titanium has caused the Navy to return to using copper-nickel (Cu-Ni) piping for some of these applications, even though the titanium piping typically exhibits three times longer life than Cu-Ni pipe. The goal of this work is to investigate the possibility of using a low cost titanium starting stock, along with a novel low cost manufacturing process to produce titanium pipe that would be about equivalent to the cost per unit length of Cu-Ni piping. The approach taken was to utilize low cost titanium powder pressed preforms and flowform net shaped pipe. The details of this process and the properties of the resultant pipe will be described in this report. In addition to the near net shaped pipe, the properties of gas tungsten arc (GTA) weldments of pipe sections will be presented.

Although a small percentage when compared with steel and other materials, the amount of titanium aboard Navy ships is typically several tons with the largest use up to approximately 136,000 lbs for the LPD17 class [1]. One of the primary applications for titanium has been for piping, in which significant weight savings could be realized over Cu-Ni pipe. Even without utilizing the higher strength of titanium to reduce the wall thickness, a straight substitution of pipe results in an approximate 50% weight savings as the density of Ti is half of that of Cu-Ni (0.163 lb/in³ for the former, 0.323 lb/in³ for the latter). It is estimated that a titanium piping system could save $17M per ship (LPD) considering life cycle savings [1].

Because the primary hurdle preventing the wider scale utilization of titanium pipe is the acquisition cost, this study was undertaken to evaluate the properties of titanium pipe fabricated via an alternative lower cost production route. The starting stock used was a low cost powder supplied by ADMA Products, Inc. (Hudson, OH). ADMA processed the powder into tubular preforms by cold isostatically pressing followed by sintering. The cylindrical preforms (wall thickness = 0.80 in.) were then flowformed into net shaped 4-in. schedule 10 pipe (4.5-in. diameter x 0.120-in. wall) by Dynamic Flowform (Billerica, MA).

ADMA uses a patented metal hydride reduction (MHR) process [2] to hydrogenate titanium powder during the initial production of sponge. Unlike hydride-de-hydride (HDH) powder,
ADMA’s process results in powder with very low oxygen and without residual chloride and other interstitials (such as Na and Mg from sodium and magnesium-reduced titanium sponge fines), which create weldability problems. After compaction, the sintering steps drive out the hydrogen, resulting in high density preforms.

Flowforming is a highly controlled cold spinning process that can be used to make high tolerance seamless tubing. During this process, uniform compression is applied to the outside diameter of a cylindrical preform such that the metal flows along an internal mandrel in the axial direction. The compression is applied by axial and radial force from three rollers around the outside diameter (OD), which rotate along with the workpiece [3]. After production, the flowformed pipes are subjected to an annealing treatment at 1300 °F for 2 hours.

This production method has great potential to reduce pipe costs as the conventional production process encompasses many more steps, including the production and purification of sponge titanium, compaction into electrodes and the vacuum casting of ingots (usually multiple times). At this step conventional atomized powder could be produced to follow a P/M production route, or ingot metallurgy routes of sheet rolling and welding pipe could be performed. The production route used in this study circumvents many of these steps by producing powder from the initial titanium reduction stage and using this powder to produce net shape pipes. In addition, the ADMA process has been shown to be effective using lower grade, lower cost sponge, leading to further cost reductions.

The titanium hydride powder has also been shown to result in higher density compacts than those made from titanium metal powder. The hydride is relatively brittle at room temperature leading to finely crushed fragments and fine pores which heal during sintering. Therefore, in addition to low cost, the ADMA process should provide for high quality parts, since the compacts are high density and low in impurities.

Coupling the ADMA pre-forms with flowforming is an effective means of keeping both the production cost low and the quality high. Flowforming utilizes a thick-walled preform to produce a net shape pipe that requires no further machining to meet dimensional tolerances. The process variables include rotation and feed speed, force applied, roller geometry and the application of external heating or cooling. Since the initial feedstock is custom sized to result in a final tube with the desired final dimensions, flowforming is a very material efficient process. In addition to net shaped pipe, the process can be used to provide for integral flanges and other features that can be used to further reduce part count, joining and costs.

If the mechanical properties of these pipes are determined to be equivalent to that of conventional wrought titanium pipe, then the decision to implement their use in Navy ships becomes a relatively straightforward financial calculation.
EXPERIMENTAL PROCEDURE

The flowformed pipe was evaluated by chemical analysis, dimensional analysis and tensile testing per ASTM E 8 [4]. Metallography was performed on samples polished and etched with Kroll’s reagent that were cut from the mid-section of the pipe wall normal to the radius.

Gas tungsten arc (GTA) pipe-to-pipe butt weldments were made by P. Hoyt at the Northrop Grumman Shipbuilding Gulf Coast Operations, New Orleans, LA. The GTA pipe welds were fabricated and evaluated as per Navy Tech Pub 248 [5]. This encompassed non-destructive evaluation including visual, liquid penetration and radiographic inspections, followed by a macro etch, tensile testing and face and root bend testing. The welding procedures and weldment evaluation were identical to those used for conventional pipe.

RESULTS AND DISCUSSION

A concern with the use of hydride powder is whether the hydrogen is effectively removed during part processing and that excessive oxygen is not picked up. Table 1 shows that the hydrogen in the starting powder is effectively removed during sintering to well below the level allowed by ASTM B 861 [6]. Further, the annealing performed on the flowformed pipes after processing did not introduce significant oxygen.

Table 1. Measured Chemical Composition (weight %, balance Titanium)

<table>
<thead>
<tr>
<th>Source</th>
<th>Nitrogen</th>
<th>Carbon</th>
<th>Hydrogen</th>
<th>Iron</th>
<th>Oxygen</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADMA starting powder</td>
<td>0.03</td>
<td>0.01</td>
<td>3.50</td>
<td>0.08</td>
<td>0.10</td>
</tr>
<tr>
<td>ASTM B861 (max allowed)</td>
<td>0.03</td>
<td>0.08</td>
<td>0.015</td>
<td>0.30</td>
<td>0.25</td>
</tr>
<tr>
<td>Pipe 3A as-flowformed</td>
<td>0.02</td>
<td>&lt;0.01</td>
<td>0.0006</td>
<td>0.04</td>
<td>0.21</td>
</tr>
<tr>
<td>Pipe 1A1 as-flowformed</td>
<td></td>
<td></td>
<td>0.0013</td>
<td>0.21</td>
<td>0.18</td>
</tr>
<tr>
<td>Pipe 1A1 annealed</td>
<td></td>
<td></td>
<td>0.0019</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Due to the large amount of cold work imparted during flowforming, as-processed material typically attains a very high strength level. As shown in Table 2, the properties of two different pipes both show a very high strength in the as-flowformed condition with a lower strength and higher ductility condition realized after annealing. Annealing is necessary to satisfy the requirements of ASTM B 861. Also shown are the tensile properties of an original pre-form prior to flowforming. The high density and low hydrogen content of the compact is indicated by high ductility.
Table 2. Tensile Properties (mean of 3)

<table>
<thead>
<tr>
<th></th>
<th>YS (ksi)</th>
<th>UTS (ksi)</th>
<th>el (%)</th>
<th>Tube ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preform</td>
<td>62</td>
<td>78</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>ASTM B861 min</td>
<td>40</td>
<td>50</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>ASTM B861 max</td>
<td>65</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>As-flowformed*</td>
<td>94.6</td>
<td>110.4</td>
<td>16.3</td>
<td>4A</td>
</tr>
<tr>
<td>Annealed*</td>
<td>51.2</td>
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<td>69.3</td>
<td>22.8</td>
<td>2A</td>
</tr>
</tbody>
</table>

* data courtesy Dynamic Flowform

A dimensional analysis of the pipes was performed by taking thickness readings at three locations along the length of select tubes (at 8-in. from each end and mid-length) at 0° and 90° rotations. This is important to verify the net shape product and to determine if the anneal applied to the highly cold worked flowformed tube causes any dimensional variability as the stresses are relaxed. As per ASTM B 861, the permissible variation in the OD of the pipe is ± 1/32 in. giving a range of 4.469–4.531 in. for this pipe. As shown in Table 3, the tolerances of the pipes produced were very tight and varied little along the length or around the circumference and remained within the specification even after annealing.

Table 3. Pipe Wall Thickness Measurements (in.)

<table>
<thead>
<tr>
<th>Pipe</th>
<th>0°</th>
<th>90°</th>
<th>0°</th>
<th>90°</th>
<th>0°</th>
<th>90°</th>
</tr>
</thead>
<tbody>
<tr>
<td>5A annealed</td>
<td>4.511</td>
<td>4.515</td>
<td>4.503</td>
<td>4.509</td>
<td>4.497</td>
<td>4.512</td>
</tr>
</tbody>
</table>

The microstructure of the tubes is shown in Figure 1. The highly cold worked nature of the as-flowformed pipe is apparent, as is the effectiveness of the anneal in inducing static recrystallization.
Both manual and mechanized gas tungsten arc (GTA) pipe-to-pipe butt welds were made in the titanium weld shop at Northrop Grumman Shipbuilding, Gulf Coast Operations. The pipes were handled just as conventional titanium pipe and throughout machining and welding, no differences were noted. The resultant welds were deemed acceptable by liquid penetrant and radiographic inspection, and no differences were discerned between these weldments and those of conventional titanium pipe. The weldment strength, measured transverse to the joint, was equivalent to that of the base metal, as shown in Table 4. Root and face bend specimens were acceptable after a 2T radius bend.

<table>
<thead>
<tr>
<th>Failure location</th>
<th>YS (ksi)</th>
<th>UTS (ksi)</th>
<th>el (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM B861 min</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Base metal</td>
<td>72.6</td>
<td>76.1</td>
<td></td>
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<tr>
<td>Weld</td>
<td></td>
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</tbody>
</table>

CONCLUSIONS

The pipe produced by flowforming compacts of low cost titanium powder appears to have equivalent properties to conventionally manufactured titanium pipe. The pipes produced displayed excellent dimensional tolerance, well within the limits described in ASTM B 861. The oxygen impurity content of final flowformed product was consistently within standards. These flowformed pipes display an excellent combination of strength and ductility. To summarize, the
chemical, mechanical and dimensional properties all fall within the range acceptable for this material. Welding of these pipes is indistinguishable from the welding of conventionally produced pipe and the weldment properties are acceptable to the applicable standards.

It is recommended that a program to qualify this manufacturing method for all sizes of CP titanium pipe used for Navy shipbuilding be undertaken. The low initial starting stock cost and highly efficient flowforming production can be combined to produce titanium pipe at a low cost. The actual cost through scale up and development needs to be determined, but with both density and strength advantages over Cu-Ni piping, titanium piping should be more cost effective and should be reconsidered for use on Navy ships.

ACKNOWLEDGEMENTS

This work was conducted by the Navy Metalworking Center (NMC), operated by Concurrent Technologies Corporation (CTC) under Contract Number N0014-06-D-0048 to the Office of Naval Research as part of the U.S. Navy Manufacturing Technology Program. The authors wish to thank G. Mercier of the Naval Surface Warfare Center, Carderock Division; V. Moxon of ADMA Products, Hudson, Ohio; M. Fonte of Dynamic Flowform, Billerica, Massachusetts; and D. Radack and K. Appley of CTC, Johnstown, Pennsylvania.

REFERENCES

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• Vladimir Moxon, ADMA Products, Hudson, OH
• Matthew Fonte, Dynamic Flowform, Billerica, MA
• Dan Radack and Kevin Appley, CTC, Johnstown, PA
Introduction

- Ti pipe saves approx. 50% of the weight of Cu-Ni pipe for a straight substitution
  - Density
    - Cu-Ni 0.323 lb/in³
    - CP Ti 0.163 lb/in³
- Piping for LPD (CP Grade 2), approx. 12,000 feet per ship
- Ti system estimated to save $17M per ship (LPD) considering life cycle savings
- Construction reverted back to Cu-Ni to save initial cost

USS SAN ANTONIO (LPD 17)
Program Goals

- Devise a potentially low cost method to produce CP Ti pipe
- Evaluate the properties of CP Ti pipe formed via a low cost method
  - Low cost initial starting stock
    - ADMA powder
  - Low cost, net shape manufacturing
    - Flowforming
- If the properties are equivalent to traditional CP Ti pipe, the next steps would be:
  - Material certification
  - Production cost verification
Lower Cost Ti Production

- Metal Hydride Reduction process from lower grade sponge
  - Low O₂, Na, Mg
- Preforms cold isostatically pressed at 60,000 psi
- Compacts sintered at 2200 °F
  - Hydrogen driven out

(Courtesy ADMA Products)
Flowforming Process

- Compression from three rollers on outer diameter of preform causes metal to flow along internal mandrel
- Initial preform custom sized
  - Final tube is net shape
  - Can provide for integral flanges, etc.

(Courtesy Dynamic Flowform)
Conventional versus Low-Cost Production Processes

Comparison of conventional and subject processes

- Sponge compaction
- Remelt to ingot
- Homogenize
- Forge
- Anneal
- Hot Roll
- Anneal
- Cold Roll
- Anneal
- Seam Weld
- Anneal

- Powder hydrogenation
- Cold isostatic press
- Sinter
- Anneal
- Flowform
- Anneal

Seam Welding
Flowform Results

- Manufacturing process verified
- Pipes annealed after flowforming

4 in. schedule 10 pipe
(4.5 in. OD x 0.120 in. wall)
## Chemical Analysis

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(Weight %, balance Titanium)

- Hydrogen effectively removed during sintering
- No significant oxygen pick-up during processing or anneal
### Mechanical Testing Results

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- High pre-form properties indicates high density, low impurities
- Annealed pipe satisfies ASTM B861 standard properties
Uniformity Measurements

- Thickness readings from three locations along pipe length
- Readings taken at 0° and 90° around circumference

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- Variation falls within the ± 1/32 in. of ASTM B861
- Tolerances remain tight even after annealing
Annealing effectively induces recrystallization of the highly worked as-flowformed microstructure.
Gas Tungsten Arc Pipe Welding

- No differences with conventional titanium pipe found
- Welds acceptable by liquid penetrant, radiographic inspection and face and root bend tests
- Weldment strength equivalent to that of the base metal

Courtesy Northrop Grumman Shipbuilding, Gulf Coast Operations
Conclusion

- CP Titanium pipe made from flowforming low cost powder compacts:
  - Meets chemical requirements
  - Meets tensile requirements
  - Meets dimensional requirements
  - Welds are equivalent to those of conventional pipe
- Potential to significantly reduce weight over Cu-Ni piping, with no cost penalty
- Need for follow up to manufacture full range of pipes and verify cost savings