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FABRICATION TECHNIQUES FOR
SHROUDED TITANIUM IMPELLER

Third Quarterly Progress Report
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INTRODUCTION AND SUMMARY

During the third quarter, effort on fabrication techniques of a shrouded titanium impeller was directed toward successful bonding of a simulated impeller sample, and fabrication of the full scale impeller pre-bond assemblies.

Two additional plasticity test specimens were pressed bringing the total to three. These tests indicated that a temperature of about 1550 degrees F with a pressure of approximately 2500 psi appears to yield the best bonding conditions for 5 Al-2.5 Sn (ELI) titanium alloy.

The simulated impeller with H-11 tool steel cores was repressed in an attempt to complete fillet formation with unsuccessful results. Difficulty was also encountered in core removal due to self-passivation of the H-11 tool steel in the acid bath. After core removal and chem-milling, this sample appeared about the same as the first simulated impeller that was bonded. On both of these samples, complete formation of the fillets did not occur in locations where the vanes intersected the shrouds with an acute angle. The final simulated impeller sample was bonded with titanium wire placed in the fillet voids during lay up. Inspection, after core removal and chem-milling, indicates fillets have been completely formed. Tensile specimens were taken from the final simulated impeller inlet areas and tested. Results yielded an ultimate tensile stress of approximately 122 ksi with an elongation of 10-15 percent. These specimens broke approximately 1/4 inch below the fillet area. Photo-micrographs of the bond area show no indication of the bond joint.
Fabrication of the two full scale impeller pre-bond assemblies has been initiated and estimated delivery of the first unit is 30 June 1968. Design of the ceramic restrainer has been completed and procurement initiated. The cumulative expenditure to date is approximately 2776 hours and $82,734.
PLASTICITY TESTS

Two additional test specimens to determine optimum bonding conditions were pressed, bringing the total to three. Figure 1 shows the three plasticity test specimens that were pressed and the conditions under which they were processed. From these tests, it was concluded that using the highest temperature possible (about 1850 degrees F) without exceeding the beta transition temperature (1925 degrees F), and employing moderate pressures (about 2500 psi on the pressure plate) appear to give the most satisfactory results when bonding titanium alloy 5 Al-2.5 Sn (ELI). As shown in Fig. 1(a) considerable die deformation occurred using 4340 die material; however, this should not be a particular problem where the titanium completely surrounds the core material prior to application of heat and pressure.

DIFFUSION BONDING OF SIMULATED IMPELLERS

Simulated Impeller No. 3 (H-11 Steel Cores)

The simulated impeller with the H-11 tool steel cores was repressed in an attempt to complete fillet formation. The required axial compression was not achieved during the first cycle because the impeller assembly was not completely seated in the tooling when the initial zero reading was obtained. To prevent this during repressing, the assembly was placed under an initial pressure of 5000 psi cold and heated at a pressure of 2000 psi to assure seating of all parts. The sample was then pressed at 1750 deg F for 16 hours at pressures between 2000 and 3000 psi. This sample was recycled using the same split ceramic restrainer as on the first cycle; however, the retainer directly surrounding the trial impeller assembly was fabricated from 4340 steel instead of stainless steel. Inspection of the part upon removal from the retort indicated that fillet formation appeared satisfactory. However, after partial core removal it was observed that complete fillets did not form in some areas where acute angles existed (refer to Fig. 2). Difficulty was encountered in removing the H-11 tool steel cores because of self-passivation in the acid bath; however, the
reaction was re-initiated by removal of the surface layer formed by passivating. The third simulated impeller is shown in Fig. 3 after complete removal of the H-11 tool steel cores, but prior to chem-milling. As can be observed, complete formation of the fillets did not occur. Subsequent to removal of .020-inch of material by chem-milling, this sample appeared very much the same as the first simulated impeller that was bonded.

Based on the first two simulated impellers bonded and the three plasticity test specimens that were pressed, it was concluded that complete fillet formation did not occur because of friction between the core material and the titanium. The extent of filling or fillet formation appears to be largely a function of the hardware geometry. A minimum of filleting occurred in areas where the vanes made acute angles with the shrouds; however, almost complete filleting occurred where the vanes formed obtuse angles with the shrouds. With reference to the plasticity test specimens (Fig. 1), it may also be observed that as the slot to be filled in the die becomes narrower, the depth of filling is decreased.

Simulated Impeller No. 2 (Final Unit Bonded)

In view of the above conclusions and observations, it was decided to place 5 Al-2.5 Sn titanium alloy wire in the fillet voids of the final simulated impeller during lay up, in an attempt to aid in complete fillet formation during the bonding cycle.

Figures 4 through 8 show the final simulated impeller sample in various stages of assembly prior to bonding. This sample used a core material of H36 steel; however, two of the cores were split in an attempt to simulate the effect of possible core shifting or deformation on passage geometry, whereas the first two samples bonded employed four one-piece cores. The configuration of the split cores is shown in Figs. 5 and 6. As shown in Fig. 7, titanium filler wires were placed only in fillet voids where the vanes formed acute angles with the shrouds.
The final simulated impeller sample was run through the bonding cycle under the following conditions:

- Temperature = 1850 Deg F
- Pressing Time at Temperature = 16 Hours
- Pressure, psi (on end plate) = 2500 (cold to seat parts)
  2000 (during heating)
  2000-2500 (at temperature)

The ceramic restrainer employed for the previous sample was also used for the final sample. Figures 9 and 10 show the final sample inlet and discharge area after bonding and tooling removal, but prior to core removal. As can be observed, complete filling occurred at both the inlet and discharge areas of the simulated impeller sample. Examination of Fig. 10 shows that shifting occurred on one of the split cores. Figures 11 through 13 show the final simulated impeller sample after core removal, but prior to chem-milling. Examination of these figures shows that complete fillet formation has occurred. Figure 13 shows lines in the fillet area where a wire was employed to fill the void during lay up. These lines disappeared after chem-milling .010 of an inch material from all surfaces and thus do not represent cracks of any significant depth. Figures 14 and 15 show the final simulated impeller after chem-milling .020 of an inch of material from all surfaces. In Fig. 16, .040 of an inch of material has been removed from all surfaces.

Photo-micrographs and tensile specimens were taken from the final simulated impeller because it was representative of the conditions under which the full scale impellers will be bonded. Figs. 17(a) and 17(b) show photo micrographs of the bond area at magnifications of 50X and 250X, respectively. As may be observed, no indication of the bond joint is visible, although considerable grain growth has occurred. Figure 18(a) shows a photo micrograph of the non-bonded area at a magnification of 250X. In comparing Figs. 17(b) and 18(a), no significant differences are noted between bonded and non-bonded areas. The photo-micrographs shown were taken of specimens from the impeller inlet.
Figure 18(b) shows three tensile specimens taken from the impeller inlet. These specimens were stress-tested in tension to failure with the following results:

<table>
<thead>
<tr>
<th>Spec. No.</th>
<th>Ultimate Load - lbs</th>
<th>Ultimate Strength - KS1</th>
<th>Elongation 1/2 in. - %</th>
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</thead>
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<tr>
<td>2</td>
<td>762</td>
<td>122.5</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>813</td>
<td>124.3</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>567</td>
<td>122.1</td>
<td>10</td>
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The values of ultimate strength and elongation are typical for titanium alloy 5 Al-2.5 Sn at room temperature. As can be seen from Fig. 18(b), failure occurred well below the fillet area.

**Comparison of Simulated Impellers**

Figure 19 shows similar views of the three simulated impeller samples for comparison. The first and third samples bonded have 0.010 of an inch of material removed by chem-milling from all surfaces, while the second sample bonded is shown with 0.020 of an inch of material removed. It can be observed from Fig. 19 that the fillets in the final sample are considerably larger than in the first sample. The radius of the fillet is increased during the chem-milling process.

**FULL SCALE IMPELLER FABRICATION**

Based on the successful results of the final simulated impeller sample, detail drawings of the full size impeller pre-bond assembly have been released for fabrication. Since no particular advantage of H-11 tool steel was noted during bonding of the simulated impeller samples, 4340 steel will be used as a core material. Design of the ceramic restrainer tooling for the full size impeller assembly has also been completed, and procurement has been initiated. Detail drawings for the ceramic restrainer are shown in Fig. 20.
PLANS FOR NEXT QUARTER

During the next quarter fabrication of the full scale impeller pre-bond assemblies and bond tooling will continue. Estimated delivery for the first pre-bond assembly is 30 June 1968.
Figure 1a.
Titanium
Die Material
Pressing Temp, °F
Pressing Time, hrs.
Pressure, psi
5 Al-2.5 Sn (ELI)
4340
1750
16
2000-4000
(4000 - 3 hrs)

Figure 1b.
Titanium
Die Material
Pressing Temp, °F
Pressing Time, hrs.
Pressure, psi
5 Al-2.5 Sn (ELI)
4340
1650
16
2000

Figure 1c.
Titanium
Die Material
Pressing Temp, °F
Pressing Time, hrs.
Pressure, psi
5 Al-2.5 Sn (ELI)
H-11
1850
16
4500 - cold
2000 - heating
2000-3000 at temp.

Figure 1. Plasticity Test Specimens
**Figure 2. Repressed Third Trial Impeller Sample After Partial Core Removal**

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**Fig. 2(a)** Eye View of Sample Impeller Showing Partial Removal of H-11 Tool Steel Cores

**Fig. 2(b)** Discharge View of Sample Impeller Showing Partial Removal of H-11 Tool Steel Cores
Figure 3. Third Simulated Impeller After Removal of H-11 Tool Steel Cores
Figure 4. Final Simulated Impeller Sample Showing Vanes and Shrouds
Figure 5. Final Simulated Impeller Sample Showing Complete Bond Assembly Before Lay Up
Figure 6. Final Simulated Impeller Sample Showing Partial Lay Up of Pre-Bond Assembly
Figure 6. Final Simulated Impeller Sample Showing Partial Lay Up of Pre-Bond Assembly
Figure 7. Final Simulated Impeller Sample Showing Titanium Wire Inserted in Fillet Voids Where Vanes Form Acute Angles with Shrouds
Figure 8. Final Simulated Impeller Sample Showing Pre-Bond Assembly After Lay Up Prior to Welding of Retort
Figure 9. Final Simulated Impeller Sample Showing Inlet Area After Bonding and Tooling Removal
Figure 10. Final Simulated Impeller Sample Showing Discharge Area After Bonding and Tooling Removal
Figure 11. Final Simulated Impeller Sample Showing Inlet Area After Removal of 4340 Steel Cores
Figure 12. Final Simulated Impeller Sample Showing Inlet and Discharge Area After Core Removal
Figure 13. Final Simulated Impeller Sample Showing Close Up of Discharge Area After Core Removal
Figure 14. Final Simulated Impeller Showing Discharge Area After Removing 0.020 of an Inch of Material From All Surfaces by Chem-Milling.
Figure 15. Final Simulated Impeller Showing Inlet Area After Chem-Milling 0.020 of an Inch Material From All Surfaces.
Figure 16. Final Simulated Impeller Showing Inlet Areas After Chem-Milling 0.040 of an Inch Material From All Surfaces.
Figure 17a. Photo-Micrograph of Bonded Area. 50X

Figure 17b. Photo-Micrograph of Bonded Area. 250X
Figure 18a. Photo-Micrograph of Non-Bond Area. 250X

Figure 18b. Tensile Specimens Taken From Simulated Impeller Inlet Area
Figure 19. Simulated Impeller Samples Bonded. Sample at Left was First Unit Bonded, Center Sample the Second, and Unit at Right the Final. It should be noted that the First and Final Sample Bonded Have .010 of an Inch Material Removed from All Surfaces While the Middle Unit Has .020 of an Inch Removed From All Surfaces.