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MELLON INSTITUTE

Progress Report No. 40
for the period
August 1, through August 31, 1961

on

EVOLUTION OF ULTRA-HIGH STRENGTH STEELS, AND
RESEARCH ON MATERIALS AND VARIOUS
NOVEL TECHNIQUES OF FABRICATION
OF HIGH PERFORMANCE
ROCKET MOTOR CASES

Mellon Institute Project No. 381-3

Submitted to:
Bureau of Naval Weapons
Code SP-271
under
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<table>
<thead>
<tr>
<th>Test Number</th>
<th>Threshold (a) Yield Strength ksi</th>
<th>0.2% offset Yield Strength ksi</th>
<th>Tensile Strength ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>144</td>
<td>166</td>
<td>177</td>
</tr>
<tr>
<td>2</td>
<td>136</td>
<td>166</td>
<td>179</td>
</tr>
<tr>
<td>3</td>
<td>144</td>
<td>168</td>
<td>178</td>
</tr>
</tbody>
</table>

(a) Test conducted in accordance with ASTM specifications.

(b) As-drawn condition.

(c) Corresponds to 0.05% offset.
Figure 1 - Aluminum Filament Wound Sphere.
B. There have been a large number of persistent inquiries on Rocoloy 270. Several pressure vessel, missile motor case, aircraft component, and fastener manufacturers had asked for samples or sources for this material in order to initiate various application research programs. Samples sent to Mellon Institute from experimental heats made by Vanadium Alloys Steel Company for one of its customers have been evaluated. This particular composition was modified to achieve Charpy V-notch impact strength minimum of 15 ft. lbs. at 300,000 psi minimum ultimate tensile strength. This requirement has been fulfilled as indicated in Table II.

C. Tensile tests on center notched specimens of ML-2 and Rocoloy 270 have been conducted using several staining media and air to mark slow crack growth. Results shown in Table III and Figure 2 definitely show that there can be significant interaction between the cracked surface and the staining media. Such interaction seem to affect the results and validity of this test when used for comparing slow-crack growth in various engineering materials.

Work on Phases D, E, F and G has been brought to a satisfactory conclusion in view of contract termination.

H. Stress-corrosion evaluation studies on ML-2 and Rocoloy 270 are continuing. No specimen failure has occurred during the current reporting period.
TABLE II

Mechanical Properties\(^{(a)}\) of Rocoloy 270
(produced by Vanadium Alloy Steel Company)

<table>
<thead>
<tr>
<th>Test Number</th>
<th>0.2% offset Yield Strength ksi</th>
<th>Ultimate Tensile Strength ksi</th>
<th>Fracture Strength ksi</th>
<th>Hardness RC</th>
<th>Elongation Per cent in 1 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>257</td>
<td>302</td>
<td>367</td>
<td>53.0</td>
<td>12.0</td>
</tr>
<tr>
<td>2</td>
<td>254</td>
<td>304</td>
<td>356</td>
<td>53.0</td>
<td>10.0</td>
</tr>
<tr>
<td>3</td>
<td>254</td>
<td>302</td>
<td>340</td>
<td>53.0</td>
<td>11.0</td>
</tr>
</tbody>
</table>

\(^{(a)}\) Austenitized at 1730°F for 25 minutes, quenched in oil and triple tempered at 600°F.

Charpy V-notch room temperature impact strength 15 to 18 ft. lbs. (450°F temper).
### TABLE III
Effect of Staining Media and Air on the Notch\(^{(a)}\) Strength of Two Steels

<table>
<thead>
<tr>
<th>Substance</th>
<th>Average Net Section Stress(^{(b)}), ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>India Ink</td>
<td>100</td>
</tr>
<tr>
<td>India Ink(^{(c)}) + Na(_2)Cr(_2)O(_7) * 2H(_2)O</td>
<td>88</td>
</tr>
<tr>
<td>Salt Water(^{(d)})</td>
<td>108</td>
</tr>
<tr>
<td>Dye Penetrant(^{(e)})</td>
<td>122</td>
</tr>
<tr>
<td>Laboratory Air(^{(f)})</td>
<td>114</td>
</tr>
<tr>
<td>Rocol 270</td>
<td>59.7</td>
</tr>
<tr>
<td></td>
<td>45.1</td>
</tr>
<tr>
<td></td>
<td>43.8</td>
</tr>
<tr>
<td></td>
<td>74.0</td>
</tr>
<tr>
<td></td>
<td>65.0</td>
</tr>
</tbody>
</table>

(a) Specimens conform to ASTM specification for pin loaded center notch test pieces.

(b) \[
\sigma_{\text{net}} = \frac{\text{load at failure}}{t \left( W - 2a_0 \right)}
\]

\(t = \text{thickness} \quad W = \text{width} \quad 2a_0 = \text{original notch size}\)

(c) 1 gm. Na\(_2\)Cr\(_2\)O\(_7\) * 2H\(_2\)O in 5 ml. India Ink.

(d) 5 per cent by weight.

(e) Tradename SPOTCHECK, made by Magnaflux Corporation.

(f) Temperature = 80 F \quad R.H. = 80\%
<table>
<thead>
<tr>
<th>Notch Tensile Strength (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 85 90 95 100 105 110 115 120 125</td>
</tr>
<tr>
<td>India Ink</td>
</tr>
<tr>
<td>India Ink + Na$_2$Cr$_2$O$_7$ • 2H$_2$O</td>
</tr>
<tr>
<td>Dye Penetrant</td>
</tr>
<tr>
<td>Salt Water</td>
</tr>
<tr>
<td>Air</td>
</tr>
</tbody>
</table>

**Figure 2 - Effect of Staining Media and Air on the Notch Properties of ML-2 and Roscoloy 270.**
Studies directed toward determining the effect of surface
de-carburization on several low-alloy ultra-high strength steels loaded
to produce various basic stress conditions are nearing completion.
Results obtained to date may be summarized as follows:

Uniaxial Tensile Loading - Surface de-carburization has been
found to reduce the tensile and yield strengths of all steels tested.
However, de-carburization beyond a certain depth did not produce uni-
form incremental strength reduction. It is also observed that surface
de-carburization has little or no effect on ductility of the test speci-
men. Data of these studies are presented in Table IV.

Impact Loading - Impact tests using Charpy V-notched speci-
mens were conducted to investigate the notch-blunting effect of de-
carburization. Data of these tests are given in Table V which indicate
that the effect of surface carbon reduction up to a certain level is to
increase the energy absorbed or increase the effective radius at the
root of the notch. Beyond this level of de-carburization the energy ab-
sorbed seems to decrease.

Plastic Deformation without Fracture - These studies were
conducted by bending strips (4" x 1/8" x 0.050") into a U-shape and
then removing them from the bending press to observe the extent of
spring-back. Significance of these tests to the metal forming indus-
try hardly needs any explanation.
### TABLE IV

The Effect of Surface Decarburization\(^{(a)}\) on the Tensile Mechanical Properties\(^{(b)}\) of Several Low Alloy Steels

<table>
<thead>
<tr>
<th>Material Designation and Decarb Depth</th>
<th>0.2% offset Yield Strength ksi</th>
<th>Ultimate Tensile Strength ksi</th>
<th>Elongation Per cent in 1 in. in 2 in.</th>
<th>Per cent Reduction in Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-270 (No Decarb)</td>
<td>270</td>
<td>323</td>
<td>11.0 5.5</td>
<td>21.0</td>
</tr>
<tr>
<td>R-270 (.012&quot; Decarb)</td>
<td>250</td>
<td>303</td>
<td>10.6 6.0</td>
<td>20.7</td>
</tr>
<tr>
<td>R-270 (.018&quot; Decarb)</td>
<td>248</td>
<td>297</td>
<td>10.3 5.0</td>
<td>20.0</td>
</tr>
<tr>
<td>300-M (No Decarb)</td>
<td>250</td>
<td>296</td>
<td>12.0 6.0</td>
<td>21.7</td>
</tr>
<tr>
<td>300-M (.012&quot; Decarb)</td>
<td>234</td>
<td>281</td>
<td>12.3 6.2</td>
<td>21.7</td>
</tr>
<tr>
<td>300-M (.018&quot; Decarb)</td>
<td>237</td>
<td>283</td>
<td>11.6 5.3</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Continued...
<table>
<thead>
<tr>
<th>Material Designation and Decarb Depth</th>
<th>0.2% offset Yield Strength ksi</th>
<th>Ultimate Tensile Strength ksi</th>
<th>Elongation in 1 in.</th>
<th>Elongation in 2 in.</th>
<th>Per cent Reduction in Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI 4340 (No Decarb)</td>
<td>193</td>
<td>197</td>
<td>13.0</td>
<td>6.0</td>
<td>23.6</td>
</tr>
<tr>
<td>AISI 4340 (.012&quot; Decarb)</td>
<td>187</td>
<td>192</td>
<td>10.7</td>
<td>6.1</td>
<td>28.9</td>
</tr>
<tr>
<td>AISI 4340 (.018&quot; Decarb)</td>
<td>185</td>
<td>194</td>
<td>12.0</td>
<td>5.2</td>
<td>21.0</td>
</tr>
</tbody>
</table>

(a) Surface decarburization depth determined by microscopic examination and microhardness.

(b) Materials heat treated as follows:

Roooloy 270 - Austenitized at 1730°F for 25 minutes at temperature, oil quenched and triple temper at 600°F.

300-M - Austenitized at 1700°F for 25 minutes at temperature, oil quenched and double temper at 600°F.

AISI 4340 - Austenitized at 1650°F for 45 minutes at temperature, oil quenched and double temper at 800°F.
### TABLE V

The Effect of Surface Decarburization on Charpy Impact Energy

<table>
<thead>
<tr>
<th>Material (a)</th>
<th>Decarb Depth (b)</th>
<th>Energy Absorbed ft. lbs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>300-K</td>
<td>0.000</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td>0.012</td>
<td>15.5</td>
</tr>
<tr>
<td></td>
<td>0.018</td>
<td>12.3</td>
</tr>
<tr>
<td>R-270</td>
<td>0.000</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>0.012</td>
<td>14.3</td>
</tr>
<tr>
<td></td>
<td>0.018</td>
<td>13.3</td>
</tr>
</tbody>
</table>

(a) Heat treated according to the program given with Table IV.

(b) Depth determined from control samples.
As shown in Figure 3, increased amount of decarburization reduces the spring-back. Decarburization did not seem to produce any undesirable surface conditions such as orange-peel, strain lines on the bent specimen surface.

**Stress-Corrosion** - The effect of surface decarburization on stress-corrosion is being studied on three ultra-high strength steels heat treated to various strength levels. U-bend specimens were prepared and exposed in a one molar solution of sodium chloride. Specimen failure data indicate that surface decarburization tends to prevent stress-corrosion attack. Specimens of all three steels without any decarburization have failed.

**Tensile Loading of Center Notched Specimens** - Center notch 3 in. wide sheet specimens were prepared, heat treated in a manner to prevent any decarburization in the notch root, and were tested at three levels of surface decarburization. Results given in Table VI show a definite improvement in fracture toughness and percent shear fracture commensurate with increased depth of decarburization. The effects of decarburization on fatigue and biaxial strength of these steels are also being investigated.
Photograph of samples of 300-M showing the effect of surface decarburization on spring-back after deformation. The front sample has 0.012 in. surface decarburization and the rear sample has no surface decarburization. Both samples have the same core hardness of 54 HRC. The surface decarburized sample has a surface hardness of 51 HRC.
TABLE VI

Effect of Surface Decarburization\(^{(a)}\) on the Fracture Toughness\(^{(b)}\) and Fracture Appearance of Low Alloy Steels

<table>
<thead>
<tr>
<th>Material</th>
<th>Decarb Depth</th>
<th>(G_0) ksi</th>
<th>(\Sigma_{\text{net}}) ksi</th>
<th>Per cent Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rocoloy 270</td>
<td>0.000</td>
<td>127</td>
<td>67.5</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>0.012</td>
<td>197</td>
<td>87.2</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>0.018</td>
<td>476</td>
<td>135.0</td>
<td>30</td>
</tr>
<tr>
<td>300-M</td>
<td>0.000</td>
<td>233</td>
<td>96.0</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>0.012</td>
<td>539</td>
<td>144.0</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>0.018</td>
<td>808</td>
<td>176.0</td>
<td>65</td>
</tr>
<tr>
<td>AISI 4340</td>
<td>0.000</td>
<td>682</td>
<td>173.0</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>0.012</td>
<td>816</td>
<td>191.0</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>0.018</td>
<td>773</td>
<td>183.0</td>
<td>100</td>
</tr>
</tbody>
</table>

\(a\) Surface decarburization depth determined using metallographic and microhardness tester.

\(b\) Visual examination revealed no decarburization at the root of the notch.
This program comes to a conclusion on September 30. Hence, no further experimental work has been planned for the next reporting period. A final report will be issued in October.

Respectfully submitted,

G. K. Bhat
Project Leader

Approved:

H. L. Anthony III
Director of Research
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