N89-16005
Unclas

DETERMINATION OF THE RELATIVE RESISTANCE TO IGNITION OF SELECTED TURBOPUMP MATERIALS IN HIGH-PRESSURE, HIGH-TEMPERATURE, OXYGEN ENVIRONMENTS
VOLUME 3 Interim Report (NASA) 150 p 63/25 0185105

TEST REPORT
VOLUME III

DETERMINATION OF THE RELATIVE RESISTANCE TO IGNITION OF SELECTED TURBOPUMP MATERIALS IN HIGH-PRESSURE, HIGH-TEMPERATURE, OXYGEN ENVIRONMENTS

Lyndon B. Johnson Space Center
White Sands Test Facility
Post Office Drawer MM
Las Cruces, New Mexico 88001
AC 505 524-5011
TEST REPORT

DETERMINATION OF THE RELATIVE RESISTANCE TO IGNITION
OF SELECTED TURBOPUMP MATERIALS IN
HIGH-PRESSURE, HIGH-TEMPERATURE, OXYGEN ENVIRONMENTS

VOLUME III

Issued By
National Aeronautics and Space Administration
Johnson Space Center
White Sands Test Facility
Laboratories Test Office

Prepared By: Joel M. Stoltzfus
Lockheed-EMSCO

Prepared By: Frank J. Benz
NASA Laboratories Test Office

Approved By: David L. Pippens, Chief
NASA Laboratories Test Office
ABSTRACT

Advances in the design of the liquid oxygen, liquid hydrogen engines for the Space Transportation System call for the use of warm, high-pressure oxygen as the driving gas in the liquid oxygen turbopump. The NASA Lewis Research Center requested the NASA White Sands Test Facility (WSTF) to design a test program to determine the relative resistance to ignition of nine selected turbopump materials: Hastelloy X, Inconel 600, Invar 36, Monel K-500, Monel 400, nickel 200, silicon carbide, stainless steel 316, and zirconium copper. The materials were subjected to particle impact and to frictional heating in high-pressure oxygen.

In the particle impact tests, nickel 200, Monel 400, and silicon carbide were the most resistant to ignition; Monel K-500 and zirconium copper were slightly less resistant to ignition; and Hastelloy X, Invar 36, and stainless steel 316 were the least resistant to ignition. Inconel 600 was not tested.

In frictional heating tests of pairs of like materials, the ranking was generally upheld, with the materials ranked in order of decreasing resistance to ignition as follows: nickel 200, Inconel 600, Monel 400, Monel K-500, Hastelloy X, Invar 36, and stainless steel 316. Pairs of silicon carbide and zirconium copper failed mechanically at modest contact pressures and did not ignite.

In tests where pairs of different materials were rubbed together, the material rated less resistant to ignition in previous tests appeared to control the resistance to ignition of the pair.

Tests designed to determine the effects of oxygen pressure on the results of frictional heating appeared to indicate that the greater heat rates per unit area required to ignite metals at high pressures resulted from increased convective heat losses from the test samples.
This interim report addresses the test series that resulted from three test plans written at the NASA White Sands Test Facility in response to a request from the NASA Lewis Research Center to determine the relative compatibility of selected turbopump materials in gaseous oxygen. The first test plan, Determination of the Ignition Sensitivity of Selected Turbopump Metals in High Pressure, High Temperature, Oxygen Environments (TP-WSTF-324), proposed tests in which eight materials were impacted with particles in hot, high-pressure oxygen and nine materials were heated frictionally in high-pressure oxygen. The second test plan, TP-WSTF-324 ADDI, proposed tests in which pairs of different materials were rubbed together in high-pressure oxygen to induce frictional heating. The third test plan, Evaluation of Pressure Effects in the WSTF Friction Rubbing Test System (TP-WSTF-356), proposed tests to determine the effects of the test gas pressure on the results of frictional heating tests. Testing proposed in the first and third test plans has been completed, and six of the eight tests proposed in the second test plan have been completed.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOLUME I</td>
<td></td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vii</td>
</tr>
<tr>
<td>1.0 INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2.0 OBJECTIVES</td>
<td>2</td>
</tr>
<tr>
<td>3.0 PARTICLE IMPACT TESTS</td>
<td>2</td>
</tr>
<tr>
<td>3.1 BACKGROUND</td>
<td>3</td>
</tr>
<tr>
<td>3.2 TEST SYSTEM DESCRIPTION</td>
<td>4</td>
</tr>
<tr>
<td>3.3 TEST CONSIDERATIONS</td>
<td>7</td>
</tr>
<tr>
<td>3.3.1 Sample Preparation</td>
<td></td>
</tr>
<tr>
<td>3.3.2 Test Conditions</td>
<td></td>
</tr>
<tr>
<td>3.3.3 Test Procedure</td>
<td></td>
</tr>
<tr>
<td>3.4 PARTICLE IMPACT TEST RESULTS</td>
<td>10</td>
</tr>
<tr>
<td>3.4.1 Tests With Impact Plates</td>
<td></td>
</tr>
<tr>
<td>3.4.1.1 Types of Ignition Events Observed</td>
<td></td>
</tr>
<tr>
<td>3.4.1.2 Ignition Susceptibility of the Materials</td>
<td></td>
</tr>
<tr>
<td>3.4.1.3 Discussion of Test Results</td>
<td></td>
</tr>
<tr>
<td>3.4.2 Tests With Rupture Disks</td>
<td></td>
</tr>
<tr>
<td>3.4.2.1 Types of Ignition Events Observed</td>
<td></td>
</tr>
<tr>
<td>3.4.2.2 Ignition Susceptibility of the Materials</td>
<td></td>
</tr>
<tr>
<td>3.4.2.3 Discussion</td>
<td></td>
</tr>
<tr>
<td>4.0 FRICTIONAL HEATING TESTS</td>
<td>19</td>
</tr>
<tr>
<td>4.1 BACKGROUND</td>
<td>19</td>
</tr>
<tr>
<td>4.2 TEST SYSTEM DESCRIPTION</td>
<td>22</td>
</tr>
<tr>
<td>4.3 TEST CONSIDERATIONS</td>
<td>26</td>
</tr>
<tr>
<td>4.3.1 Sample Preparation</td>
<td></td>
</tr>
<tr>
<td>4.3.2 Test Conditions</td>
<td></td>
</tr>
<tr>
<td>4.3.3 Test Procedure</td>
<td></td>
</tr>
<tr>
<td>4.4 FRICTIONAL HEATING TEST RESULTS</td>
<td>29</td>
</tr>
<tr>
<td>4.4.1 Ignition Resistance of Pairs of Like Materials</td>
<td></td>
</tr>
<tr>
<td>4.4.1.1 General Comments Concerning the Data</td>
<td></td>
</tr>
<tr>
<td>4.4.1.2 Relative Resistance of the Test Materials to Ignition</td>
<td></td>
</tr>
<tr>
<td>4.4.1.3 Discussion of Test Results</td>
<td></td>
</tr>
<tr>
<td>4.4.2 Ignition Resistance of Pairs of Different Materials</td>
<td></td>
</tr>
<tr>
<td>4.4.2.1 General Comments Concerning the Data</td>
<td></td>
</tr>
<tr>
<td>4.4.2.2 Relative Resistance of the Test Materials to Ignition</td>
<td></td>
</tr>
<tr>
<td>4.4.2.3 Discussion of the Test Results</td>
<td></td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>4.4.3 Effect of Oxygen Pressure on the Ignition of Materials</td>
<td>56</td>
</tr>
<tr>
<td>4.4.3.1 General Comments Concerning the Data</td>
<td></td>
</tr>
<tr>
<td>4.4.3.2 Description of the Test Results</td>
<td></td>
</tr>
<tr>
<td>4.4.3.3 Discussion of the Test Results</td>
<td></td>
</tr>
<tr>
<td>5.0 CONCLUSIONS</td>
<td>58</td>
</tr>
<tr>
<td>LIST OF REFERENCES</td>
<td></td>
</tr>
<tr>
<td>DISTRIBUTION</td>
<td>60</td>
</tr>
<tr>
<td>APPENDIX A: Temperature Calibration of Particle Impact Tester</td>
<td>A-1</td>
</tr>
<tr>
<td>APPENDIX B: Estimation of Minimum Particle Velocity by a Dent-Block Comparison Test</td>
<td>B-1</td>
</tr>
<tr>
<td>VOLUME II</td>
<td></td>
</tr>
<tr>
<td>APPENDIX C: Data From Particle Impact Test</td>
<td>C-1</td>
</tr>
<tr>
<td>APPENDIX D: Data From Frictional Heating Tests on Pairs of Like Materials</td>
<td>D-1</td>
</tr>
<tr>
<td>VOLUME III</td>
<td></td>
</tr>
<tr>
<td>APPENDIX E: Data From Frictional Heating Tests on Pairs of Different Materials</td>
<td>E-1</td>
</tr>
<tr>
<td>VOLUME IV</td>
<td></td>
</tr>
<tr>
<td>APPENDIX F: Data From Frictional Heating Tests to Determine the Effect of Oxygen Pressure on the Pv Product Required for Ignition</td>
<td>F-1</td>
</tr>
</tbody>
</table>
APPENDIX E

Data From Frictional Heating Tests on Pairs of Different Materials

<table>
<thead>
<tr>
<th>TEST NUMBER</th>
<th>TEST MATERIAL</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ROTATING SAMPLE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>STATIONARY SAMPLE</td>
<td></td>
</tr>
<tr>
<td>252</td>
<td>Monel K-500</td>
<td>E-1</td>
</tr>
<tr>
<td>255</td>
<td>Monel K-500</td>
<td>E-9</td>
</tr>
<tr>
<td>256</td>
<td>Stainless Steel 316</td>
<td>E-17</td>
</tr>
<tr>
<td>257</td>
<td>Stainless Steel 316</td>
<td>E-25</td>
</tr>
<tr>
<td>258</td>
<td>Stainless Steel 316</td>
<td>E-33</td>
</tr>
<tr>
<td>259</td>
<td>Stainless Steel 316</td>
<td>E-41</td>
</tr>
<tr>
<td>260</td>
<td>Stainless Steel 316</td>
<td>E-49</td>
</tr>
<tr>
<td>261</td>
<td>Silicon Carbide</td>
<td>E-57</td>
</tr>
<tr>
<td>262</td>
<td>Silicon Carbide</td>
<td>E-65</td>
</tr>
<tr>
<td>263</td>
<td>Silicon Carbide</td>
<td>E-73</td>
</tr>
<tr>
<td>264</td>
<td>Silicon Carbide</td>
<td>E-81</td>
</tr>
<tr>
<td>265</td>
<td>Silicon Carbide</td>
<td>E-89</td>
</tr>
<tr>
<td>266</td>
<td>Silicon Carbide</td>
<td>E-97</td>
</tr>
<tr>
<td>267</td>
<td>Monel K-500</td>
<td>E-105</td>
</tr>
<tr>
<td>268</td>
<td>Monel K-500</td>
<td>E-113</td>
</tr>
<tr>
<td>272</td>
<td>Monel K-500</td>
<td>E-121</td>
</tr>
<tr>
<td>273</td>
<td>Nickel (EP)</td>
<td>E-129</td>
</tr>
<tr>
<td>274</td>
<td>Nickel (EP)</td>
<td>E-137</td>
</tr>
</tbody>
</table>
Normal Load (Lbf)

Time (seconds)
Time (seconds)

Revolution Per Minute

Time (seconds)

Torque Load (lbft)

Contamine a torque load and a normal load offset.

Time (seconds)

Filtered Coefficient of Friction

Contains a -2.0 load offset.
FRT#257: ZrCu-Stat.; 316 SS-Rot.

Time (seconds)

Revolutions Per Minute

-20000
-18000
-16000
-14000
-12000
-10000
-8000
-6000
-4000
-2000
0
-10 0 10 20 30 40 50 60 70 80 90
Time (seconds)

Chamber Oxygen Pressure (pa/ig)

FR1#257: ZrC-n-St4t. : 316 SS-Rot.
FRT#257: ZrCu-Stat.; 316 SS-Rot.

Filtered Coefficient of Friction

Time (seconds)

Contains a torque load and a normal load offset.

E-32

ORIGINAL PAGE IS OF POOR QUALITY
FRT#258: ZrCu-Stat.; 316 SS-Rot.

Revolutions Per Minute

Time (seconds)
FRT#258: ZrCu-Stat.; 316 SS-Rot.
FRT#258: ZrCu-Stat.; 316 SS-Rot.
FRT#258: ZrCu-Stat.; 316 SS-Rot.

Contains a -3.4 load offset.
Time (seconds)

Temperature (°F)

FRTR#259: ZRCU-Start: 316 SS-Rot.
FRT#259: ZrCu-Stat.; 316 SS-Rot.

Contains a torque load and a normal load offset.

Contains a -42.3 load offset.

Chamber Oxygen Pressure (PSIG)

Time (seconds)
Coefficient of Friction

Time (seconds)

FRT#260: Mon. 
K500-Stat.; 
316 SS-Rot.

OF POOR QUALITY
ORIGINAl FACE IS
Filtered Coefficient of Friction

Time (seconds)


Normal Load (Lbf)

Time (seconds)

Contains a -0.5 load offset.

Chamber Oxygen Pressure (PSIG)

Time (seconds)

Contains a +.7 load offset.

![Graph showing revolutions per minute over time in seconds.](image-url)

Temperature (°F)

Time (seconds)
Figure 26: Mon. K500-Stat. 316 SS-Rox.

time (seconds)

Torque Load (lb-ft)
FRT#263: INVAR-36-Stat.; SiC-Rot.

Chamber Oxygen Pressure (PSIG)

Time (seconds)
FRT#263: INVAR-36-Stat.; SiC-Rot.
Contaminates a torque load and a normal load effect.

Time (seconds)

Coefficient of Friction

FRT#263: INVAR-36-Stat.; SiC-Rot.

Contains a torque load and a normal load offset.
FRT#264: INVAR-36-Stat.; SiC-Rot.

Graph showing revolutions per minute over time (seconds) for INVAR-36-Stat. and SiC-Rot.
FRT#264: INVAR-36-Stat.; SiC-Rot.
FRT#264: INVAR-36-Stat.; SiC-Rot.

Contains a torque load and a normal load offset.
Time (seconds)

Revolutions Per Minute

FR1G265: INVAR-35-36-34.5 : 51C-Rot.
FRT#265: INVAR-36-Stat.; SiC-Rot.
FRT#266: Mon. K500-Stat.; SiC-Rot.

Normal Load (Lbf)

Time (seconds)

Contains a -5 slippage offset.
Time (seconds)

Temperature (°F)

FR#266: Mon. KA005-Stat.; SIC-Rot.
Torque Load (Lbf)

Time (seconds)

FRT#266: Mon., K500-Stat.; SiC-Rot.
Time (seconds)

Sample Wear (Inches)

FRT#267: Mon. K500-Stat.; SiC-Rot.

Contains a torque load and a normal load offset.
FRT#268: Mon. K500-Stat.; SiC-Rot.

Graph showing the relationship between Normal Load (Lbf) and Time (seconds). The graph indicates an increasing load over time, with a noticeable load offset at the beginning. The graph is marked as of poor quality.
FRT#268: Mon. K500-Stat.; SiC-Rot.

Chamber Oxygen Pressure (PSIG)

Time (seconds)
FRT#268: Mon. K500-Stat.; SiC-Rot.

Contains a +6.5 load offset.
Time (seconds)

Coefficient of Friction

Filtered Coefficient of Friction

Time (seconds)

Contains a torque load and a normal load offset.
Normal Load (Lbf)

Time (seconds)

Time (seconds)

Coefficient of Friction

Contains a torque load and a normal load offset.

Contains a -7.1 load offset.

Revolutions Per Minute

Time (seconds)

Chamber Oxygen Pressure (PSIG) vs. Time (seconds)

Sample Wear (Inches)

Time (seconds)

Filtered Coefficient of Friction

Time (seconds)

Contains a torque load and a normal load offset.

Graph showing revolutions per minute over time (in seconds).

Chamber Oxygen Pressure (PSIG)

Time (seconds)

Contains a -200 lb load offset.

Contains a torquing load and a normal load offset.