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Margaret V. Whalen
and Michael V. Nathal

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Lewis Research Center
Cleveland, Ohio

Summary

Resistojets for the space station require long life and multipropellant capability. The choice of available materials to meet these requirements is limited. Dispersion-strengthened platinum was selected to be studied for use as a resistojet material. Past results indicated that dispersion-strengthened platinum should be sufficiently inert in candidate propellant environments and should be capable of operating at moderate temperatures for extended periods of time.

A series of propellant compatibility tests was conducted with platinum strengthened with either yttria or zirconia. The data presented include the results of 1000-hr tests in carbon dioxide (CO_2), hydrogen (H_2), ammonia (NH_3), nitrogen (N_2), steam, hydrazine (N_2H_4), and methane (CH_4); and 2000-hr tests in H_2 and NH_3.

The platinum samples were tested at 1400 °C in CO_2, H_2, NH_3, N_2, steam, and N_2H_4; at 500 °C in CH_4; and at 800 °C in N_2H_4. The mass-loss results indicated material life, extrapolated from experimental mass-loss data, in excess of 100 000 hr in all environments except steam and N_2H_4, where material life was $\geq 45\,000$ hr. Generally, on the basis of mass loss, there were no compatibility concerns in any of the environments considered. Optical and scanning electron microscopy were used to determine the effect of propellants on the material surface and to evaluate material stability as a function of resistance to grain growth. The propellant interaction varied from little or no reaction with H_2 and CH_4 to evidence of void formation and pitting of samples tested in NH_3 and N_2H_4. Material stability when measured as a function of grain growth did not appear to be a problem.

Introduction

Resistojet propulsion systems have the potential for reduced propellant requirements, reduced propellant resupply servicing, and reduced cost, when compared to existing systems. In addition, they have long thruster life, low power consumption, and low spacecraft contamination. These potential benefits make resistojets attractive for space station auxiliary propulsion systems. The resistojet for the space station must be capable of both long life and multipropellant operation. Meeting these requirements is limited by available materials. Thus, evaluation of potential materials will have direct application to the development of multipropellant resistojets.

Two major considerations for candidate materials are the life-limiting problem of creep and the compatibility of these materials with potential space station propellants. Creep and grain growth can occur when a material is operated at high temperatures for extended periods of time. Grain growth can result in the formation of voids, physical distortions, and unacceptable reduction in the creep-strength of the material.

Platinum and alloy-strengthened platinum were considered for biowaste resistojets during the Manned Orbital Research Laboratory program of the early 1970's (refs. 1 to 3). Platinum was assumed to be compatible with candidate propellants, and it was chosen for its excellent corrosion resistance and particularly for its oxidation resistance (ref. 4). Pure platinum, although corrosion resistant, was found to lack adequate high-temperature strength. Alloying platinum with rhodium improved the material strength; however, compatibility problems were encountered because rhodium is not as corrosion resistant as platinum.

Another material developed during this period as a high-temperature, high-strength material for biowaste resistojets was platinum-0.6 percent thoria. The compatibility of this material with carbon dioxide (CO_2) was verified, but no other data were available (ref. 5). Platinum-thoria alloy is no longer manufactured, but the experience gained in producing it was used in developing platinum materials strengthened with either zirconia or yttria for use in high-temperature oxidizing environments where corrosion resistance is necessary.

Preliminary work showed promise for the use of dispersion-strengthened platinum for space station resistojets (ref. 6). This report presents the results of compatibility tests on dispersion-strengthened platinum. The tests were conducted on tube samples representative of the resistojet heater element, which is the hottest resistojet component. A summary of the results of the 1000-hr compatibility tests in CO_2, methane (CH_4), hydrogen (H_2), and ammonia (NH_3) is included (ref. 7), together with new data on 1000-hr tests in nitrogen (N_2), steam, and decomposed hydrazine (N_2H_4), and 2000-hr tests in H_2 and NH_3. The material evaluation included mass-loss measurements, use of optical and scanning electron microscopy (SEM), grain growth evaluation, and use of auger electron spectroscopy (AES). The mass-loss results were used

to estimate thruster life in each propellant, the photomicrographs were used to determine if any material deterioration had occurred and also to examine the materials for evidence of grain growth, and the AES was used to examine the materials for contamination from the various propellants.

Material Characteristics

The space station resistojet requirements for 10 000-hr life and multipropellant capability are demanding of any material. A material with these capabilities would reduce the thruster maintenance and replacement costs and would enable thruster operation with both oxidizing and reducing propellants that may be on board the space station. Platinum strengthened with yttria or zirconia has the potential to meet these requirements.

Platinum has been recognized for its corrosion resistance in severe environments at high temperatures (≥ 1200 °C) (refs. 8 and 9). However, pure platinum has limited strength and creep resistance at these high temperatures. Dispersion strengthening of platinum was found to significantly increase the high-temperature strength of the material. The process of dispersion strengthening involves strengthening a metal by incorporating a fine, insoluble material uniformly throughout the metal. The dispersoid is nearly insoluble in the metal and very stable at temperatures up to the metal melting point. In addition to increased strength, dispersion-strengthened platinum has greater resistance to grain growth than pure platinum.

Two types of dispersion-strengthened platinum materials are currently available. One is dispersion strengthened with yttria (Y_2O_3) and the other with zirconia (ZrO_2). Since the oxide content is less than 1 percent by weight in both the materials, the physical and room-temperature mechanical properties of platinum are not significantly changed by addition of these oxides. However, as described earlier in this section, there is improvement in the high-temperature strength, the creep resistance, and the stability of the material as measured by grain growth (refs. 8 and 9).

Apparatus

Material compatibility tests were conducted in six test cells. The test cells were of two basic configurations, with the major difference being the technique used for maintaining cell pressure. Differences were the result of safety requirements and facility ventilation capabilities. Figure 1 shows a diagram of a test cell arrangement. The tests using CO_2, steam, and N_2 were run in cells in which flow was controlled by needle valves and exiting gases were drawn to roughing pumps. The CO_2 and N_2 tests were run in the same cell. Each of these cells was fabricated from quartz tubing and was typically 3.81 cm in diameter by 20.3 cm in length. Silicon rubber

O-rings were used to seal the CO_2 test chamber, and Teflon O-rings were used to seal the N_2 and steam test cells.

The H_2, NH_3, N_2H_4, and CH_4 tests were run in similar test cells. The chambers were stainless steel with quartz viewing windows. These cells were typically 15.2 cm in diameter by 30.5 cm in length. The H_2 test cell was sealed with copper gaskets, the NH_3 and N_2H_4 cells with nickel-plated copper gaskets, and the CH_4 cell with Teflon gaskets. In the H_2, NH_3, and N_2H_4 tests, needle valves both upstream and downstream of the cells were used for flow control. Roughing pumps were used only to purge the system, and the exiting gases were vented to the atmosphere. For the CH_4 test, flow was controlled by needle valves, and exiting gases were drawn to a roughing pump, as for the CO_2, steam, and N_2 tests.

All samples were coiled platinum-yttria or platinum-zirconia tubes, except those tested in N_2H_4 at 1400 °C, which were straight lengths of tubes because of a lack of material. The samples were coiled from 0.0203-cm-o.d., 0.025-cm-wall tubing, with about a 43.2-cm length required for each coil. Samples for the 1400 °C N_2H_4 tests were 15.2 cm lengths of the same tubing. The platinum-yttria material required a 30-min anneal at 1000 °C prior to coiling The platinum-zirconia was ductile enough in the drawn condition to coil without cracking.

The samples were resistively self-heated by a 100-A, 100-V dc power supply. The power was applied to the samples through stainless steel or copper support rods, depending on the gas environment. Sample temperatures were measured by using a two-color optical pyrometer in all tests except those in CH_4. Since the CH_4 tests were run at temperatures outside the pyrometer range, a calibrated Chromel-Alumel thermocouple was attached to a center coil for temperature measurement. The accuracy of the two-color pyrometer was 1 percent of full scale, and the thermocouple was accurate to about ± 20 °C, based on calibration.

Procedure

The samples were cleaned, and their pretest mass was measured by using an analytical balance with an accuracy of ± 1 mg. Prior to the test, each cell was evacuated and purged with N_2 twice, then evacuated again. The samples were tested in a flowing gas environment at a cell pressure of about 1.39×10^5 N/m^2 (20 psia). The cells were brought to operating pressure by closing the gas outlet valve and introducing gas into the chamber. Then, the outlet gas valve was opened and adjusted to maintain the pressure. The gas flow in the decomposed N_2H_4 tests was about 300 standard cubic centimeters per minute (SCCM) to maintain stable operation of the thermal gas generator. The N_2H_4 was decomposed from a liquid to a gas by flowing it through a thermal gas generator. The resulting gas was a mixture of ammonia, hydrogen, nitrogen, and small amounts of water and aniline. The gas flow was about 100 SCCM in all other

tests. All samples were tested at 1400 °C, except those in CH_4 and a sample in N_2H_4. The CH_4 tests were run at 500 °C so that solid carbon formation was minimized. Additionally, a test in decomposed N_2H_4 was operated at 800 °C to determine if the surface reaction was reduced. Each test was run for at least 1000 hr. Two tests in H_2 and NH_3 were extended to determine the effect of longer exposure. Tables I and II summarize test conditions for platinum-yttria and platinum-zirconia, respectively.

Several techniques were used in the evaluation of the compatibility of these materials with the various candidate propellants. Sample mass loss over the period was used as a compatibility indicator. The mass of each sample was measured before and after testing. The mass loss was used to extrapolate thruster life for each propellant environment, which was based on a failure criterion of 10 percent gross mass loss for a sample. This criterion is more stringent than standards accepted by other industries (ref. 10).

The effect of propellant interaction with platinum-yttria and platinum-zirconia was evaluated. Optical and scanning electron microscopes were used to examine the test sample surfaces and cross sections before and after testing. The photographs allowed evaluation of propellant interaction at the material surface and determination of changes in relative grain size.

Auger electron spectroscopy was used to determine the material surface composition only in the 1000-hr tests in CO_2, H_2, NH_3, and CH_4. This technique allowed elemental characterization of the surface of the sample. A brief discussion of the results of this evaluation is included in the following section. Further details are available in reference 7.

Results and Discussion

These experiments were intended to determine the compatibility of dispersion-strengthened platinum with a variety of potential resistojet propellants. The mass-loss and material-analysis results that follow include data on both platinum-yttria and platinum-zirconia.

Mass-Loss Results

A summary of initial sample masses and mass-loss percentages is presented in table III. The mass-loss values are for 1000 hr of exposure to the indicated environment, except that the values for the last H_2 and NH_3 tests are for 2000 hr of testing.

The platinum-yttria samples had losses in 1000-hr tests ranging from 0.006 percent in CH_4 to 0.206 percent in N_2H_4. The mass losses in the 2000-hr tests were 0.110 percent in NH_3 and 0.136 percent in H_2. The results of the N_2H_4 tests at 1400 and 800 °C confirmed that operating temperature has a major impact on service life; the mass loss of 0.010 percent for the 800 °C test was more than an order of magnitude lower than that for the 1400 °C N_2H_4 test. Although these tests

TABLE I.—SUMMARY OF PLATINUM-YTTRIA TEST CONDITIONS

Propellant	Operating temperature, °C	Operating time, hr	Current,[a] A	Voltage,[a] V
CO_2	1400	1000	30	6.8
H_2			45	7.5
NH_3			44	7.5
N_2			40	7.0
Steam			41	9.0
N_2H_4			67	5.5
CH_4	500		21	1.8
N_2H_4	800		25	2.8
H_2	1400	2000	46	7.0
NH_3	1400	2000	52	6.2

[a]Test average.

TABLE II.—SUMMARY OF PLATINUM-ZIRCONIA TEST CONDITIONS

Propellant	Operating temperature, °C	Operating time, hr	Current,[a] A	Voltage,[a] V
CO_2	1400	1000	39	6.3
H_2			49	7.0
NH_3			48	7.5
Steam			46	9.0
N_2H_4			69	5.5
CH_4	500		19	1.2

[a]Test average.

TABLE III.—DISPERSION-STRENGTHENED PLATINUM MASS-LOSS RESULTS

Propellant[a]	Platinum-yttria		Platinum-zirconia	
	Initial mass, g	Mass loss, percent	Initial mass, g	Mass loss, percent
CO_2	9.0194	0.033	13.1955	0.012
H_2	12.6589	.049	13.2124	.023
NH_3	12.5982	.052	13.0632	.050
N_2	11.0635	.094	-------	-----
Steam	13.0695	.089	11.5133	.221
N_2H_4	4.5987	.206	4.1238	.155
CH_4 at 500 °C	12.6384	.006	11.696	.000
N_2H_4 at 800 °C	10.7323	.010	-------	-----
H_2[b]	11.2678	.136	-------	-----
NH_3[b]	10.9983	.110	-------	-----

[a]All samples tested at 1400 °C, except where noted otherwise.
[b]2000-hr test.

were run at 3.66 N/m^2, the mass loss was consistent with vacuum evaporation of platinum (ref. 10). This indicates that evaporation may be a loss mechanism, rather than any corrosive attack by the propellants.

The mass-loss results presented were used to extrapolate thruster life (table IV). Previously reported data estimated lifetimes of platinum-yttria samples exposed to CO_2, H_2, NH_3, and CH_4 at 300 000, 200 000, 200 000, and 1 500 000 hr, respectively (ref. 7). The 1000-hr tests in N_2, steam, N_2H_4 at 1400 °C, and N_2H_4 at 800 °C resulted in thruster life estimates of 106 000, 110 000, 48 000, and 970 000 hr, respectively. The 2000-hr tests in H_2 and NH_3 gave life estimates of 148 000 and 182 000 hr.

All platinum-zirconia samples were tested for 1000 hr in each environment. The mass losses for these samples ranged from no measurable loss in CH_4 to a 0.221-percent loss in the steam environment. The next largest mass loss occurred in the sample tested in N_2H_4, which lost 0.155 percent of its original mass. Mass losses in CO_2, H_2, and NH_3 were 0.012, 0.023, and 0.050 percent, respectively.

The life estimates of platinum-zirconia previously reported for CO_2, H_2, NH_3, and CH_4 were 800 000, 200 000, 400 000, and >1 500 000 hr, respectively. The sample tested in CH_4 showed no measurable mass loss. Both the platinum-zirconia and the platinum-yttria samples tested in CH_4 were tested at a much lower temperature (500 °C) than the other samples to minimize methane decomposition and the resulting carbon deposition.

The life estimates of platinum-zirconia for the steam and N_2H_4 tests were 45 000 and 64 000 hr, respectively. The platinum-zirconia coiled tube sample tested in steam had the lowest life estimate. Both straight tube samples tested at 1400 °C in N_2H_4 exhibited low life estimates. The mass loss of these samples may have been lower in a coiled configuration because of the possibility of redeposition of metal on facing sections and on cooler sections of the sample. Regardless of this possibility, the life estimates of 48 000 hr for the platinum-yttria and 64 000 hr for the platinum-zirconia samples

TABLE IV.—ESTIMATED THRUSTER LIFE

| Propellant[a] | Estimated thruster life | |
	Platinum-yttria	Platinum-zirconia
CO_2	300×10^3	800×10^3
H_2	200	400
NH_3	200	200
N_2	106	----------
Steam	110	45
N_2H_4	48	64
CH_4 at 500 °C	1500	>1500
N_2H_4 at 800 °C	970	----------
N_2[b]	148	----------
NH_3[b]	182	----------

[a]All samples tested at 1400 °C, except where noted otherwise.
[b]2000-hr test.

exceeded the anticipated 10 000-hr life requirement for the space station resistojet by at least a factor of four.

The mass-loss and life calculations did not take into account redeposition of the base metal or deposit of contaminates, such as carbon, on the sample surface. On the basis of the information from the AES surface analyses, which are discussed further in the subsection to follow, surface contaminates generally totaled an order of magnitude less than the observed mass losses, and therefore could be considered negligible. After testing, only the test cell used for the steam test had evidence of redeposited metal; all other test cells were clean. These factors indicated that the life estimates based on mass loss were realistic. However, void formation and pitting which occurred in the N_2H_4 and NH_3 tests reduced these estimates, as discussed in the following subsection.

Surface-Analysis Results

After testing, the material was examined for surface contamination, deterioration, and grain growth. Auger electron spectroscopy (AES) and AES with depth profiling were used to examine the possibility of surface contamination. These techniques gave the approximate atomic percent of constituents at the surface and at specified depths below the material surface. The samples tested in CO_2, H_2, NH_3, and CH_4 were evaluated by this technique. The contaminants that were found on each sample included carbon, H_2, N_2, and oxygen (O_2). The samples tested in H_2 and NH_3 generally had lower levels of surface contaminants than the samples tested in CH_4 and CO_2. The CO_2 and CH_4 environments produced higher levels of carbon, and the CO_2 also showed evidence of silicon. The source of the carbon was suspected to be hydrocarbon oils from the pumps used to maintain the cell pressure, and the silicon source appeared to be the O-rings used to seal these test cells. The other test cells used roughing pumps only for evacuation and purging, and used either Teflon, copper, or nickel-plated copper gaskets for sealing.

The AES for both platinum-yttria and platinum-zirconia indicated that the samples had surface layers of contamination which extended to depths of about 200 Å. Profiling to greater depth did not reveal any significant reaction. These results indicated that any reactions between the platinum and the propellants tended to occur at the material surface.

The surface deterioration was also evaluated qualitatively by examining the material surface and cross section before and after testing. Cross-sectional views obtained with an optical microscope were also used to evaluate grain growth.

A photomicrograph showing the cross section of the platinum-yttria prior to any treatment is shown in figure 2. The material had a fine grain structure. The platinum-yttria tubing required an anneal before the sample could be coiled to the test configuration. Figure 3 shows the surface and cross section of the platinum-yttria sample after a 30-min anneal, at 1000 °C in vacuum. The surface photograph (fig. 3(a)) shows the initial surface roughness and longitudinal grain pattern resulting from the extruding process. The cross-

sectional view (fig. 3(b)) provides grain size information for comparison with other samples. Note that some grain growth occurred during the annealing treatment.

Figures 4 and 5 show the platinum-yttria surfaces after 1000 hr at 1400 °C in CO_2, H_2, NH_3, N_2, steam, and N_2H_4; at 500 °C in CH_4; and at 800 °C in N_2H_4. Figure 6 shows the platinum-yttria surface after 2000 hr at 1400 °C in H_2 and NH_3, respectively. The sample exposed to CO_2 showed evidence of a deposit, which was most probably the carbon that was found by the AES experiments. The surface of the N_2, steam, and both H_2 samples had a similar appearance, with a grain structure running parallel to the extrusion direction. The grain structure on these unetched surfaces is indicative of grain-boundary grooving, which is commonly observed in metals exposed to high temperatures in inert environments. The sample tested at 500 °C in CH_4 appeared unchanged (fig. 5(a)). The samples at 1400 °C exposed to NH_3 and decomposed N_2H_4 showed a roughened surface with pitting over the entire exposed area (figs. 4(c) and (f)). The pitting observed raised concerns about how much of the material was affected, and what effect this pitting had on the material strength. A sample tested in N_2H_4, but run at the lower temperature of 800 °C (fig. 5(b)), showed no evidence of the surface pitting that was so prominent in the 1400 °C test.

Surface and cross-sectional photographs of the extruded platinum-zirconia tube prior to testing are presented in figure 7. The platinum-zirconia samples, which did not require annealing prior to fabricating the coiled samples, had a finer grain structure in the as-drawn condition than the platinum-yttria.

Surface photographs of platinum-zirconia samples tested at 1400 °C in CO_2, H_2, NH_3, steam, and N_2H_4, and at 500 °C in CH_4 are shown in figure 8. In general, these samples exhibited features similar to the platinum-yttria material. The platinum-zirconia sample exposed to CH_4 (fig. 8(f)) appeared similar to the untested sample; however, there was a coating over the material surface that had darkened the color of the sample and that appeared thicker at the center coils. This coating was found by the AES analysis to be carbon.

Cross-sectional photomicrographs of platinum-yttria tested at 1400 °C in CO_2, H_2, NH_3, N_2, steam, and N_2H_4; at 500 °C in CH_4; and at 800 °C in N_2H_4 appear in figures 9 and 10. The cross sections of samples after 2000 hr in H_2 and NH_3 are shown in figure 11. The platinum-yttria samples tested at 500, 800, and 1400 °C exhibited similar grain size and very little, if any, difference from the annealed sample (fig. 3(b)). Since this grain size was greater than that of the as-drawn platinum-yttria sample, but was approximately the same as that of the sample after the short anneal, this evidence implies that most of the grain growth occurred during the 1000 °C, 30-min anneal. The 2000-hr exposure in H_2 showed no reaction, but there appeared to be slight grain growth. This observed grain growth, which may have been due to sample variability, was not considered significant.

The pitting that appeared in the cross section of the sample

tested in CO_2 was found to be bubbles in the mounting epoxy and so unrelated to the testing. The platinum-yttria samples exposed to CO_2, H_2, N_2, steam, and CH_4 showed no evidence of corrosion or deterioration. The cross-sectional views of the two NH_3 samples (figs. 9(c) and 11(b)) and the N_2H_4 sample run at 1400 °C (fig. 9(f)) show that the pitting evident in the surface photograph extended well into the material. In each sample the corrosion was uniform across the tube thickness, with no evidence of accelerated attack at the grain boundaries. After 1000 hr at 1400 °C in NH_3, the reaction zone, or the depth of pitting in the material, extended through about one-third the wall thickness. Exposing a similar sample to the same environment for 2000 hr resulted in a reaction zone extending approximately halfway through the wall thickness. On the basis of a study of this reaction zone by M.V. Nathal, M.V. Whalen, and D.P. Pank at NASA Lewis Research Center, the estimated time for the attack to grow through the entire wall thickness was approximately 5000 hr at 1400 °C; at 1300 and 1000 °C, lifetimes were estimated at about 15 000 and 40 000 hr, respectively. The 1400 °C N_2H_4 sample showed results similar to the NH_3 sample. Figure 10(b), the cross section of the N_2H_4 sample operated at 800 °C, showed no evidence of corrosion in either the cross-sectional or surface views. These results indicate that platinum-yttria may be acceptable for operation in NH_3 or N_2H_4 at lower temperatures. The platinum-yttria samples exposed to CO_2, H_2, N_2, steam, and CH_4 showed no evidence of corrosion or deterioration.

Photomicrographs showing cross sections of the platinum-zirconia samples exposed to CO_2, H_2, NH_3, steam, N_2H_4, and CH_4 are presented in figure 12. The CH_4 sample, which was tested at 500 °C, showed a finer grain size than the samples tested at 1400 °C. This can be explained by the fact that the platinum-zirconia samples did not receive an annealing treatment prior to testing. As a comparison, a platinum-zirconia sample was annealed for 30 min at 1000 °C. This test resulted in some slight grain growth similar to that of the annealed platinum-yttria, as shown in figure 13. Thus in the case of the platinum-zirconia samples, some grain growth occurred during the exposures at 1400 °C, but the 500 °C exposure was too low for grain growth to occur. If a prior annealing treatment had been performed, all significant grain growth would have occurred during the annealing process rather than during the test, as in the platinum-yttria cases. The platinum-zirconia samples tested in CO_2, H_2, steam, and CH_4, as in the platinum-yttria samples, showed no corrosion or deterioration. The samples exposed to NH_3 and N_2H_4 showed a reaction zone extending through about half the cross section. The reaction zone of the platinum-yttria sample exposed to N_2H_4 was about the same thickness. The samples tested in NH_3 showed a thicker zone for the platinum-zirconia sample. However, further testing by Nathal, Whalen, and Pank indicated that these differences were due to experimental scatter, most likely due to temperature control.

The results of the NH_3 and N_2H_4 tests for both materials

were interesting in that the mass loss measured in these tests was much lower than necessary to form the volume of voids seen in the cross-sectional views. Measurement of the tube diameter before and after testing indicated an increase in outside diameter of as much as 10 percent. This evidence indicates that the void formation actually caused swelling of the material, rather than being indicative of a loss of material due to corrosion. A suspected mechanism for the void formation involves diffusion of hydrogen and nitrogen atoms into the platinum. The dissociation of NH_3 into H_2 and N_2 occurs by a process with an intermediate step in which atomic hydrogen and nitrogen are formed (refs. 11 to 13). The dissociation reaction occurs at the platinum surface, which is acting as a catalyst. Some of the atomic hydrogen and nitrogen can then diffuse into the platinum before combining to form H_2 and N_2 gas in the test chamber. These atoms can then coalesce into gas bubbles within the platinum and thus cause the swelling of the tubes. This type of reaction has been observed previously (refs. 12 and 13), where NH_3 gas was used for internal nitridation of steels. Additionally, no void formation was observed in experiments run by Nathal, Whalen, and Pank in H_2, N_2, or H_2/N_2 mixtures, because the gas molecules do not dissociate at temperatures near 1400 °C and because the molecules cannot diffuse into the platinum to any significant extent. Again, the extent of this void formation can be reduced if operation at lower temperatures is acceptable, as confirmed by the tests at 800, 1000, and 1300 °C. Further testing to determine the influence of these voids on the mechanical properties of platinum is recommended before use of NH_3 and N_2H_4 propellants at high temperatures.

Concluding Remarks

The compatibility of dispersion-strengthened platinum with potential space station resistojet propellants was evaluated. A series of 1000-hr tests of platinum-yttria and platinum-zirconia exposed to gas environments of CO_2, H_2, NH_3, N_2, steam, and N_2H_4 at 1400 °C; CH_4 at 500 °C; and N_2H_4 at 800 °C was completed. Tests for 2000 hr at 1400 °C in H_2 and NH_3 were also performed.

The test sample and operating temperature were representative of a resistojet heating element. The life estimates extrapolated from the mass losses occurring in these tests indicated that platinum-yttria and platinum-zirconia samples would withstand a minimum of 45 000 hr in any of the environments tested; however, the void formation in the NH_3 and N_2H_4 samples suggests lower lifetimes. These estimates are greater than four times the expected space station life requirement. The grain growth occurring in the platinum-yttria samples was slight and appears to have occurred during the anneal prior to sample fabrication. The platinum-zirconia

samples showed some grain growth. Annealing may result in grain growth similar to that of the platinum-yttria samples. The grain growth was not considered a problem; however, the effects, if any, on the performance of a resistojet should be evaluated.

The results indicated that platinum-yttria and platinum-zirconia are compatible with CO_2, H_2, N_2, steam, and CH_4 under the conditions presented here. The reaction found in both materials at 1400 °C when exposed to NH_3 and decomposed N_2H_4 can be reduced by lowering the operating temperature. Both platinums should be acceptable for space station resistojets using CO_2, H_2, N_2, steam, and CH_4. The propellants NH_3 and N_2H_4 may also be acceptable if the resistojet operating temperature is lowered.

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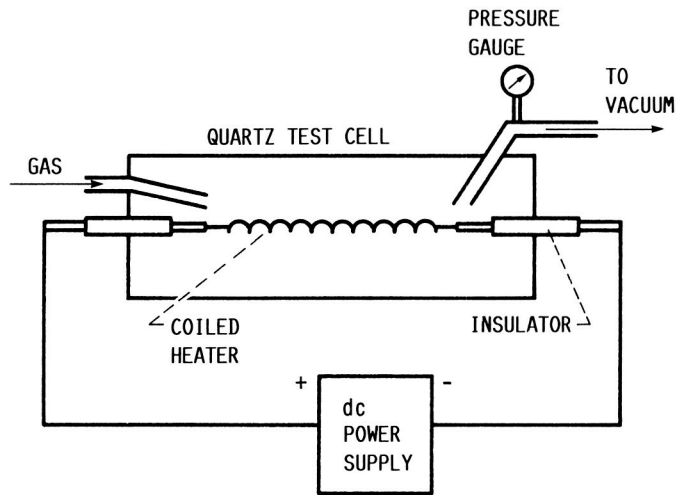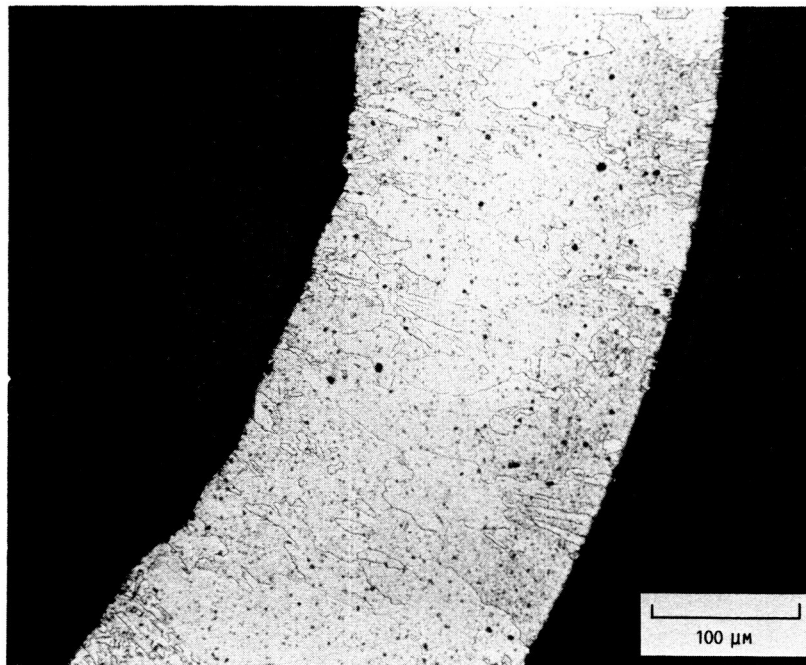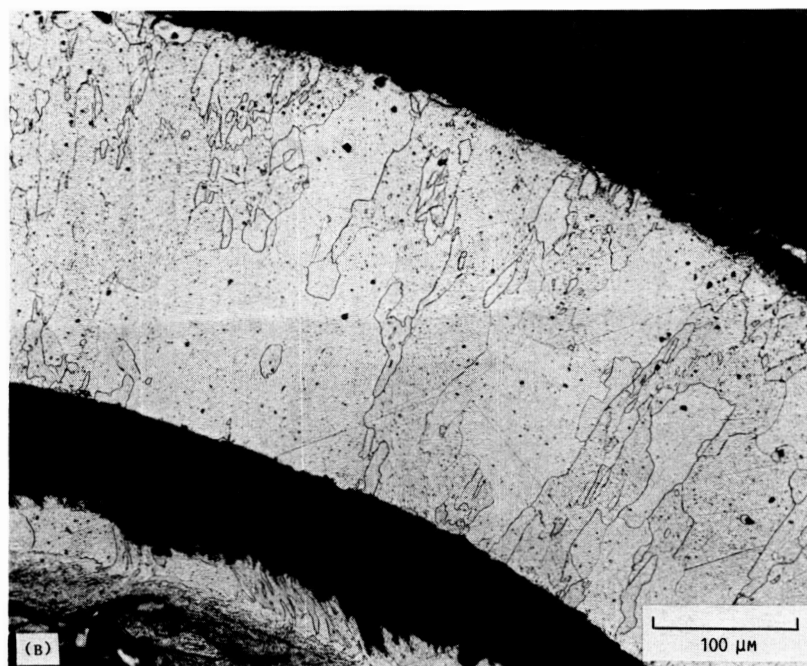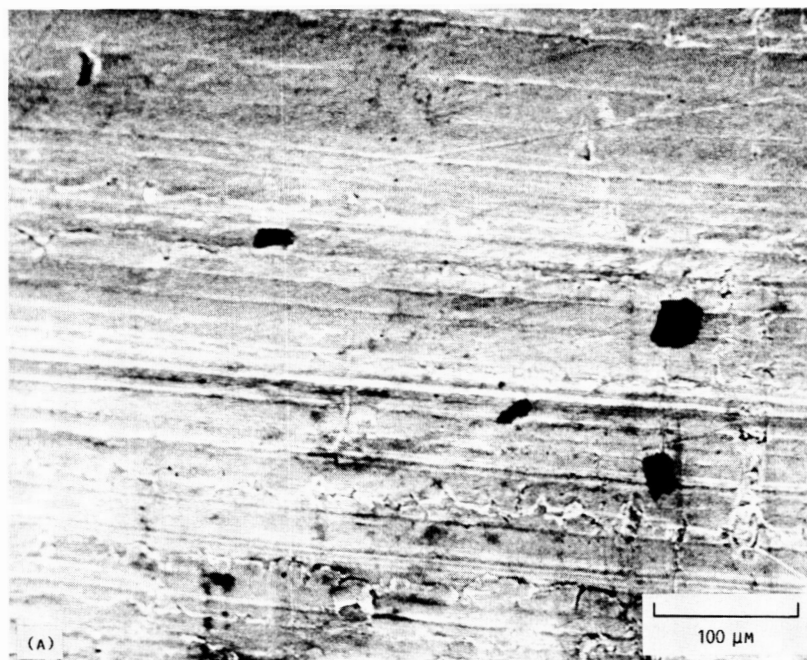
Figure 1.—Material test apparatus.

Figure 2.—Cross section of extruded, untreated platinum-yttria.
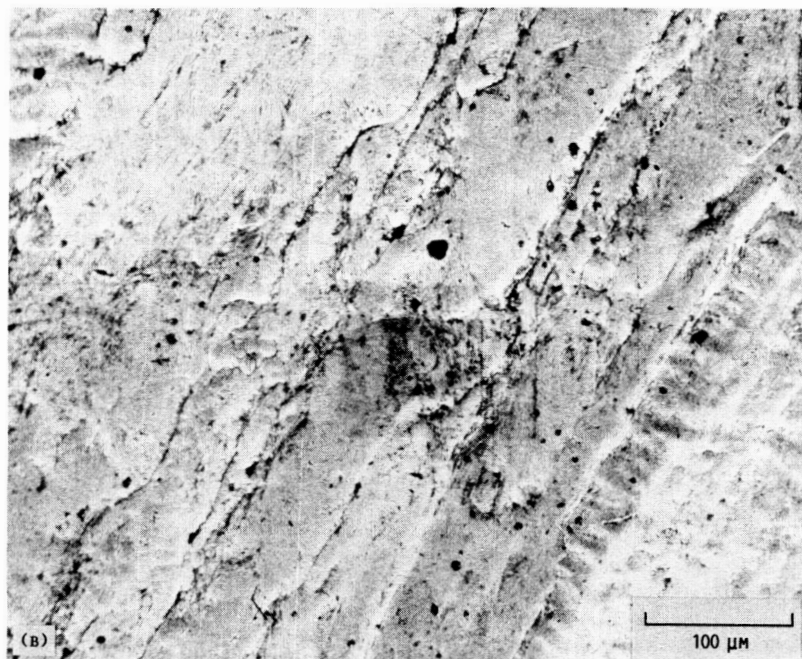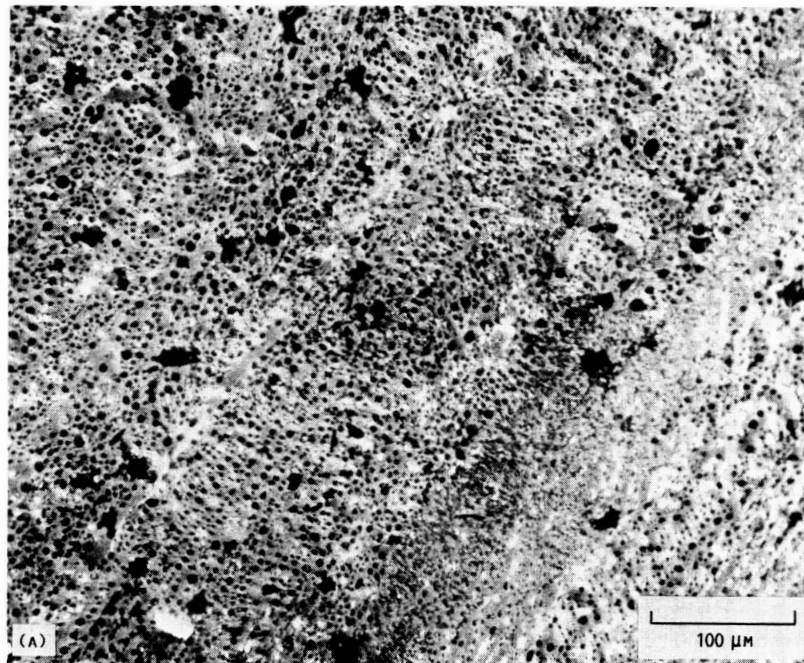
7

(a) Surface.
(b) Cross section.

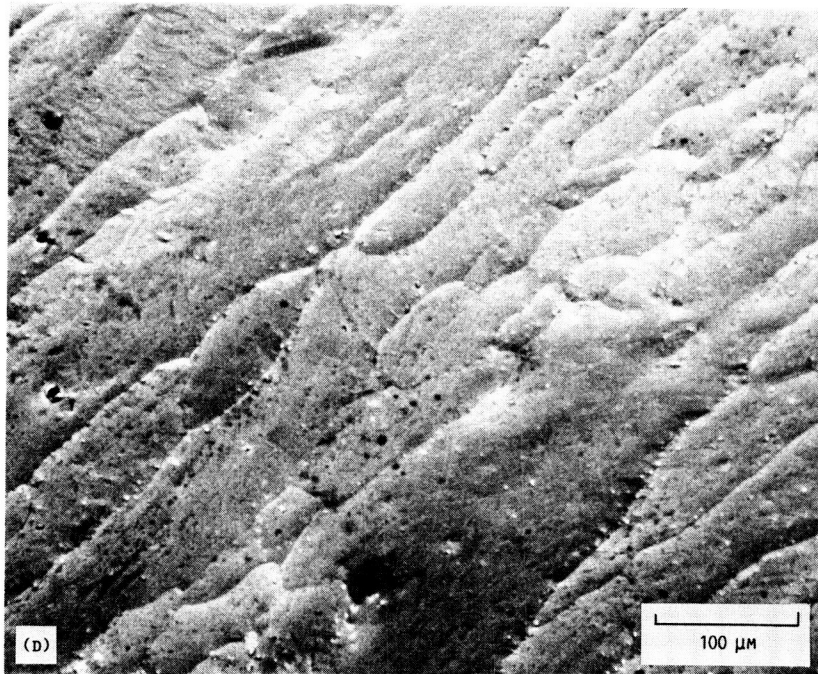Figure 3.—Platinum-yttria sample after 30-min vacuum anneal at 1000 °C.

(a) CO_2.
(b) H_2.

Figure 4.—Platinum-yttria surface after 1000 hr at 1400 °C.
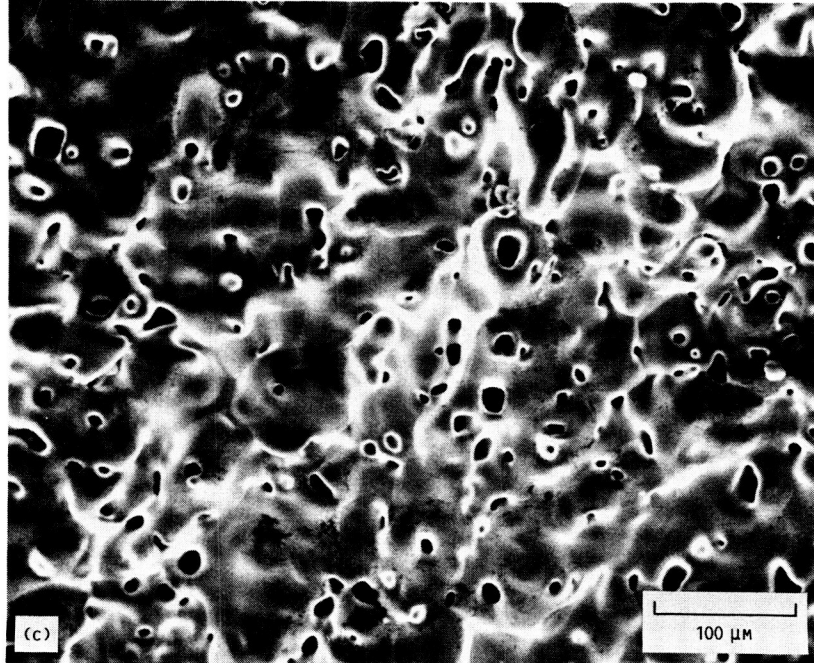
(c) NH₃.

(d) N₂.

Figure 4.—Continued.

10
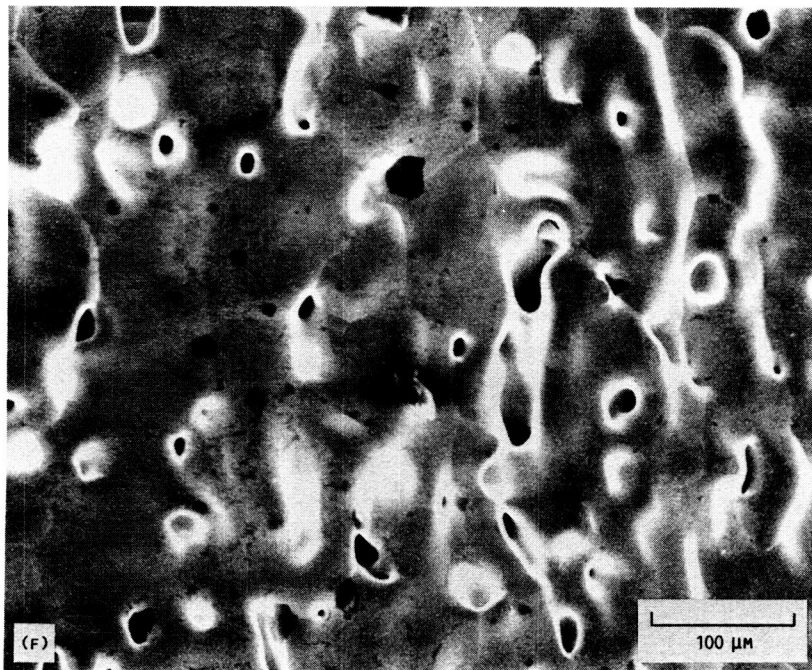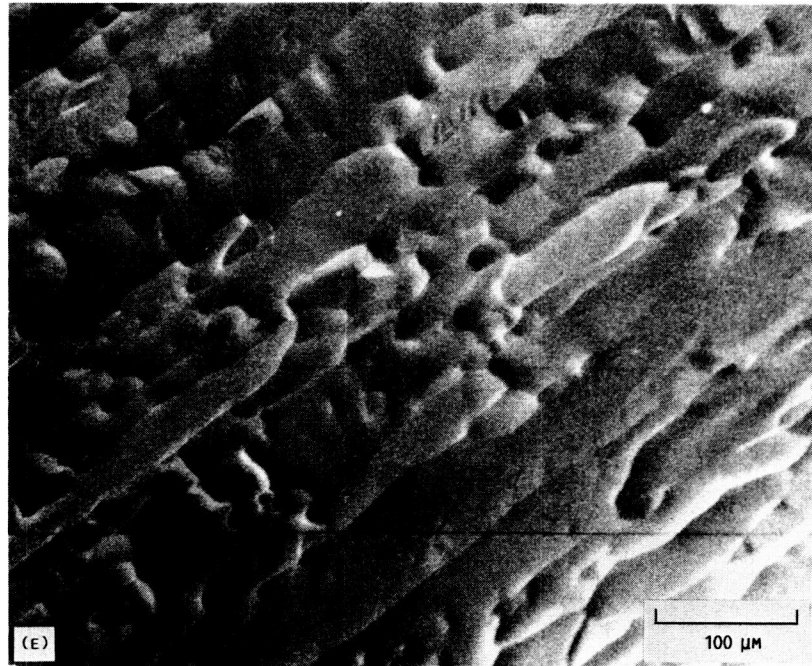
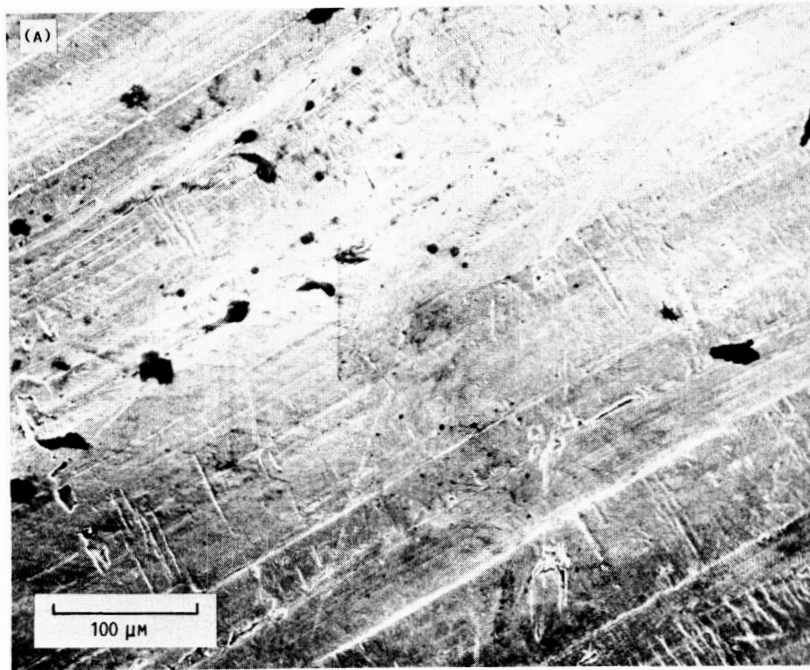(e) Steam.
(f) N_2H_4.

Figure 4.—Concluded.
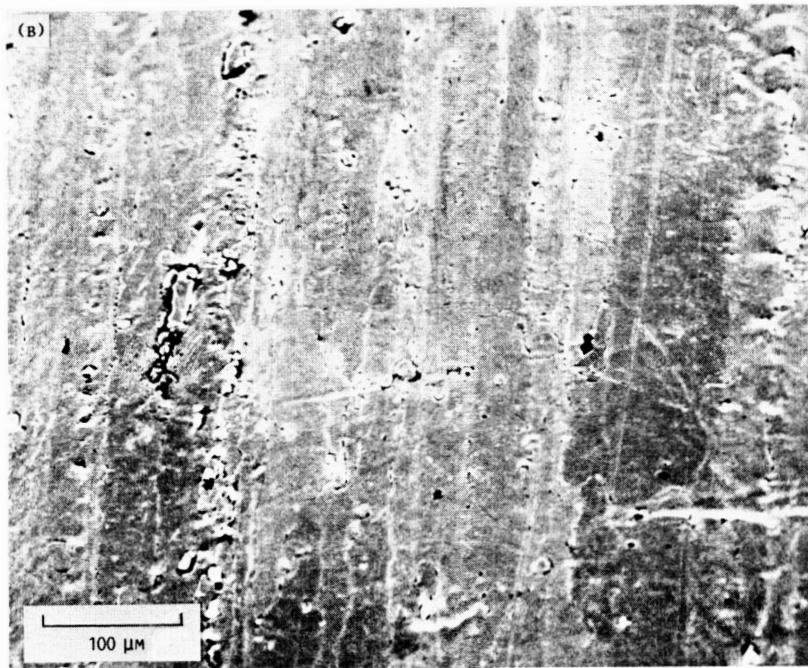
(a) At 500 °C in CH_4.
(b) At 800 °C in N_2H_4.

Figure 5.—Platinum-yttria surface after 1000 hr.
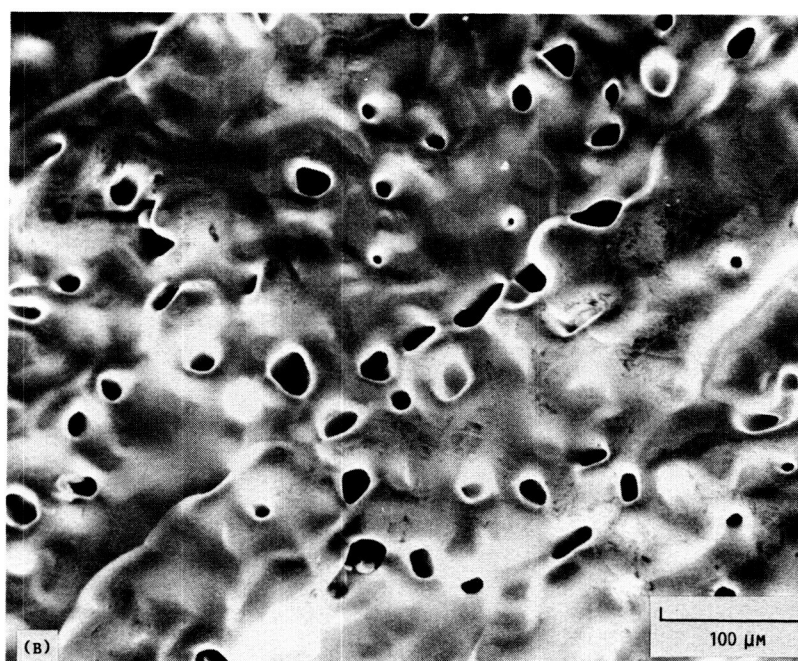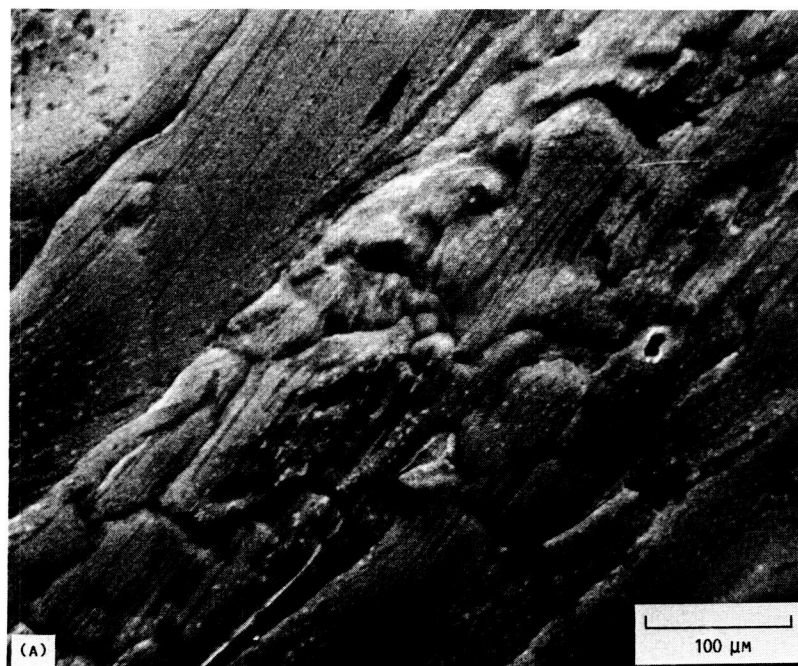
(a) H_2.
(b) NH_3.
Figure 6.—Platinum-yttria surface after 2000 hr at 1400 °C.
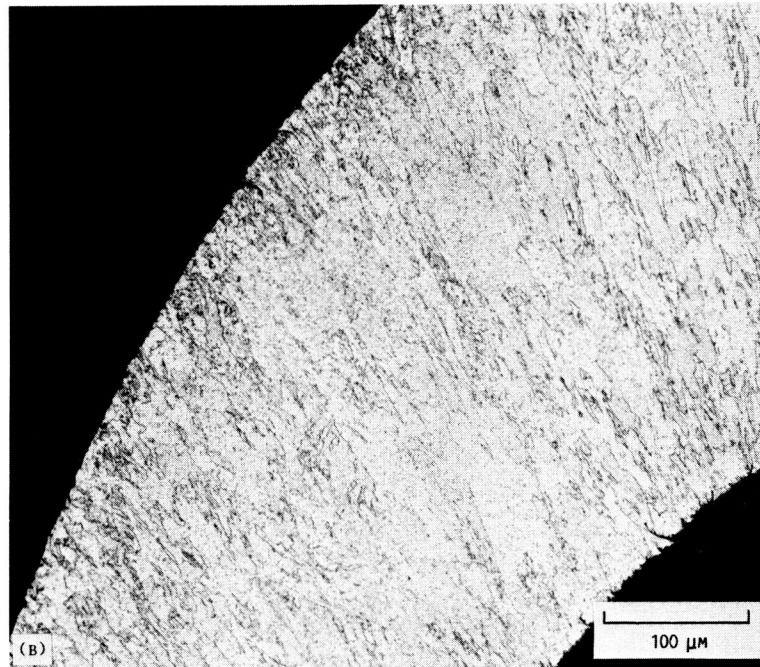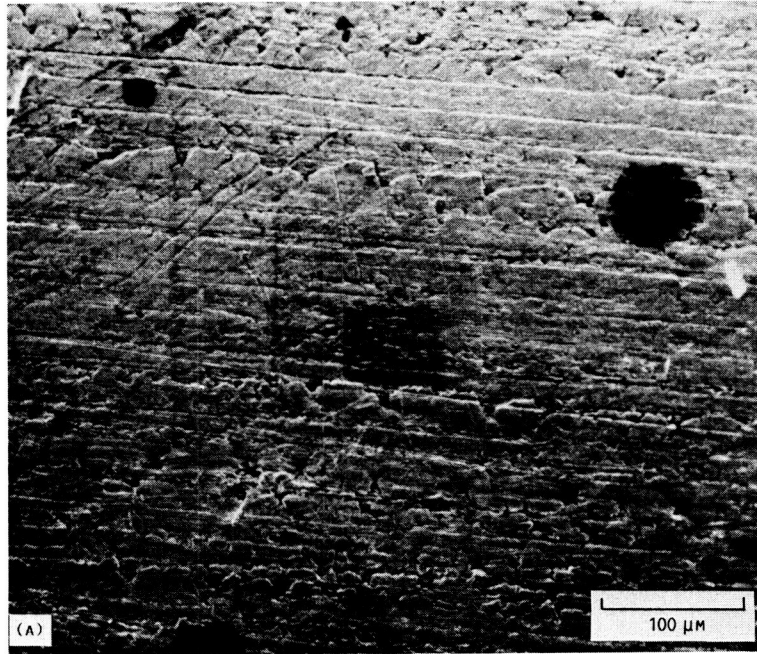
(a) Surface.
(b) Cross section.

Figure 7.—Platinum-zirconia sample before testing.
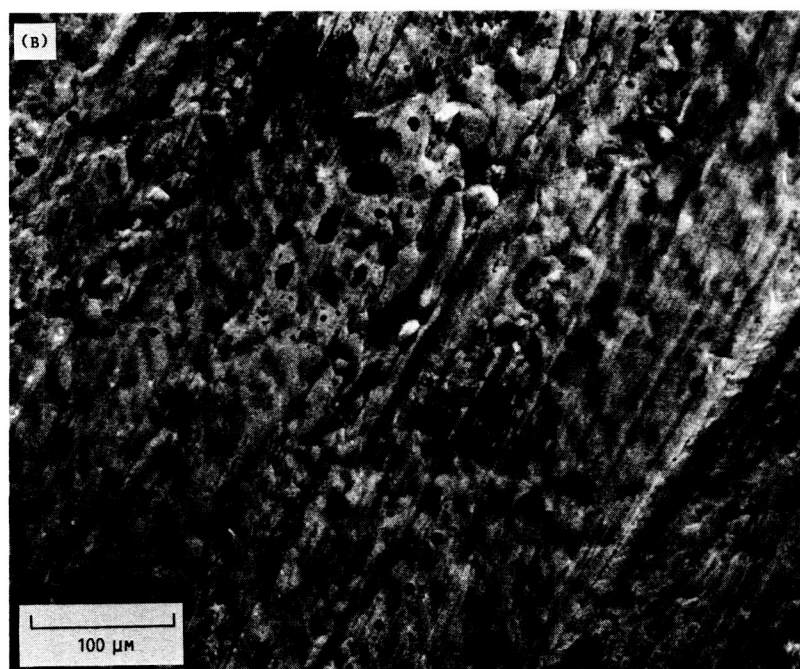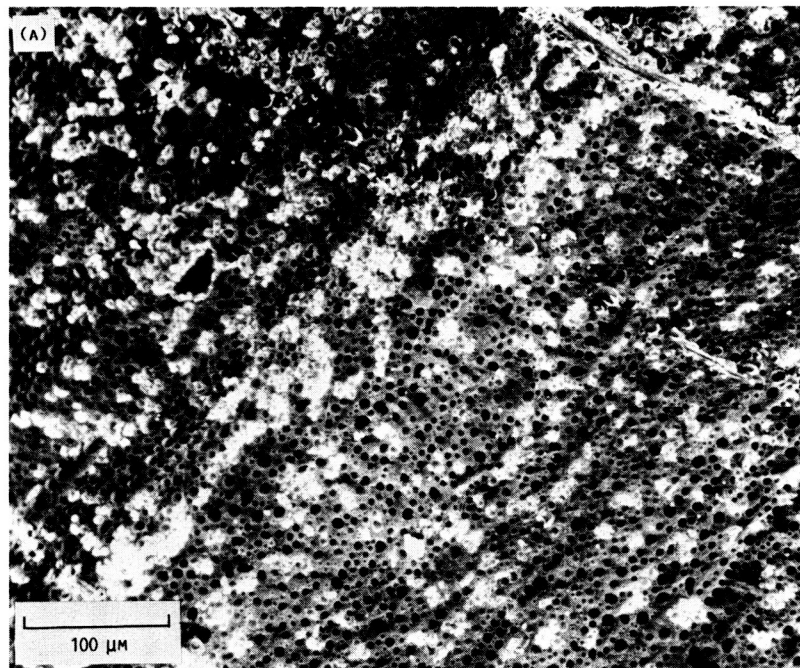
(a) CO_2.
(b) H_2.

Figure 8.—Platinum-zirconia surface after 1000 hr. All tests at 1400 °C, except CH_4 at 500 °C.
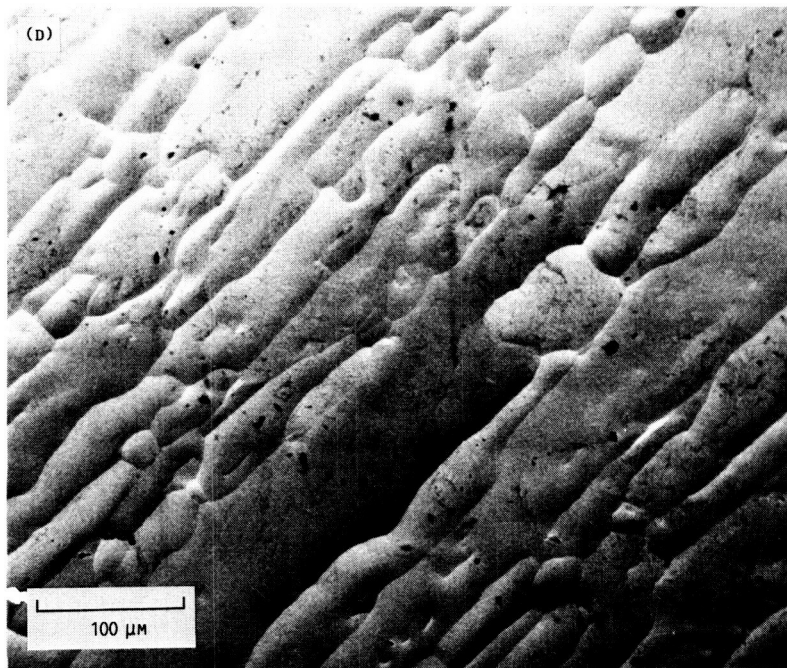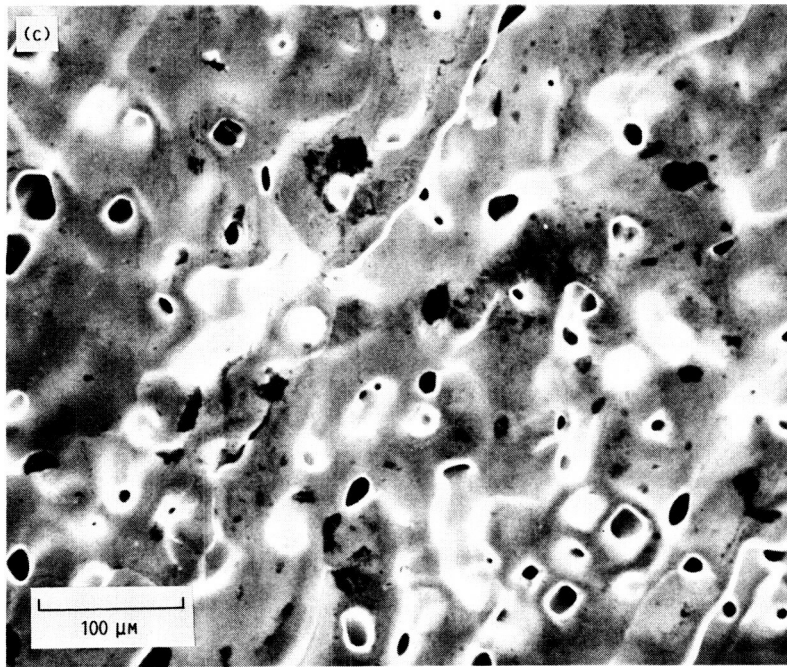
(c) NH_3.
(d) Steam.

Figure 8.—Continued.
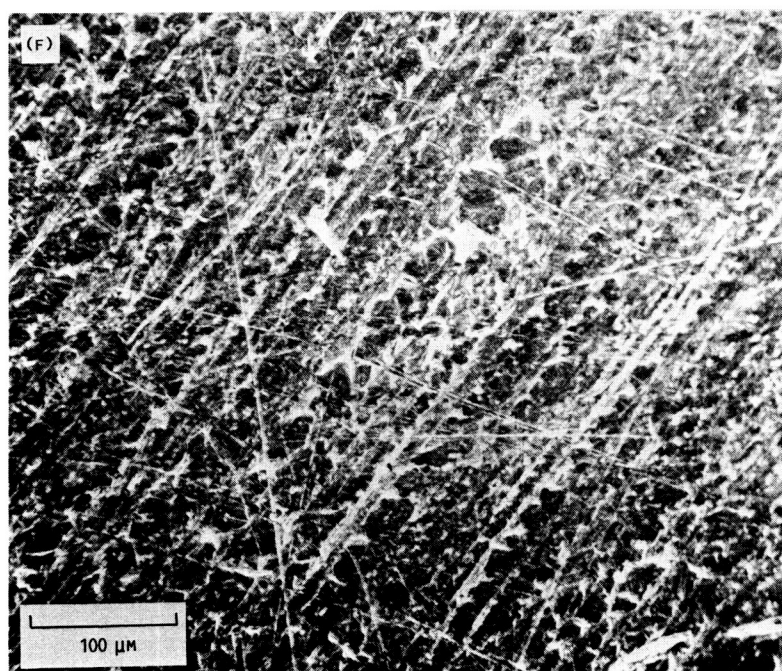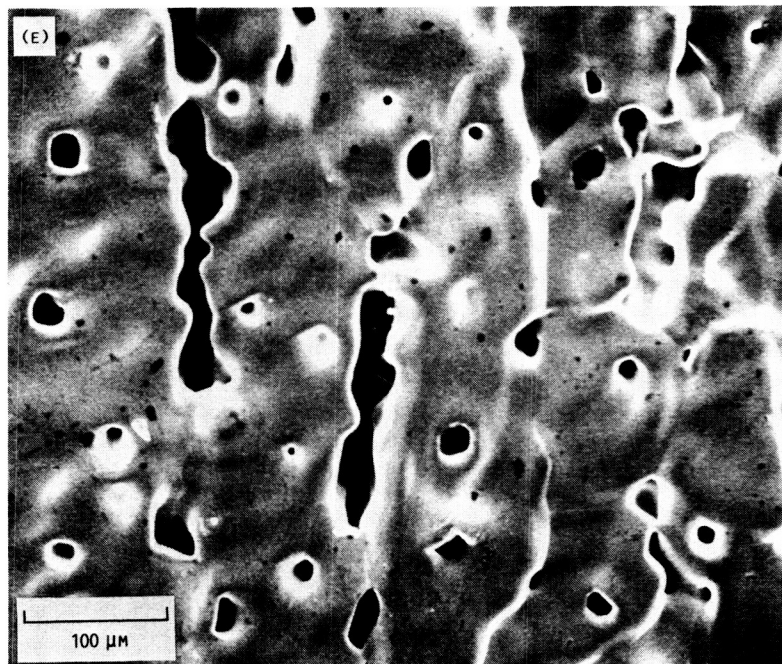
(e) N_2H_4.
(f) CH_4.

Figure 8.—Concluded.
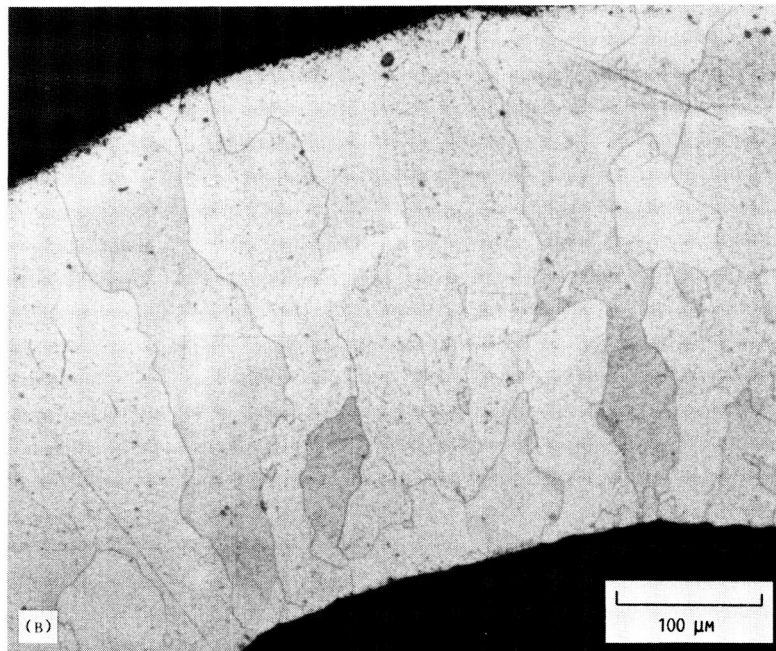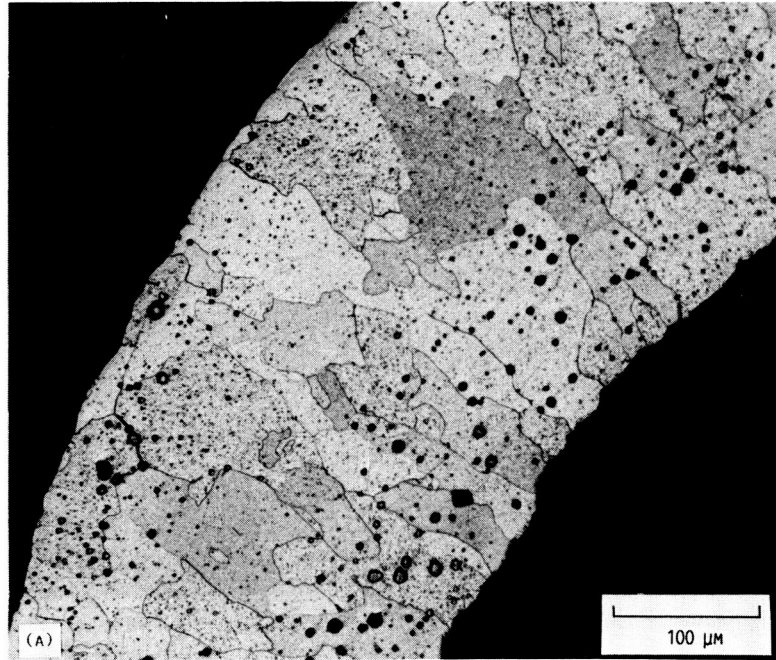
(a) CO_2.
(b) H_2.

Figure 9.—Platinum-yttria cross section after 1000 hr at 1400 °C.
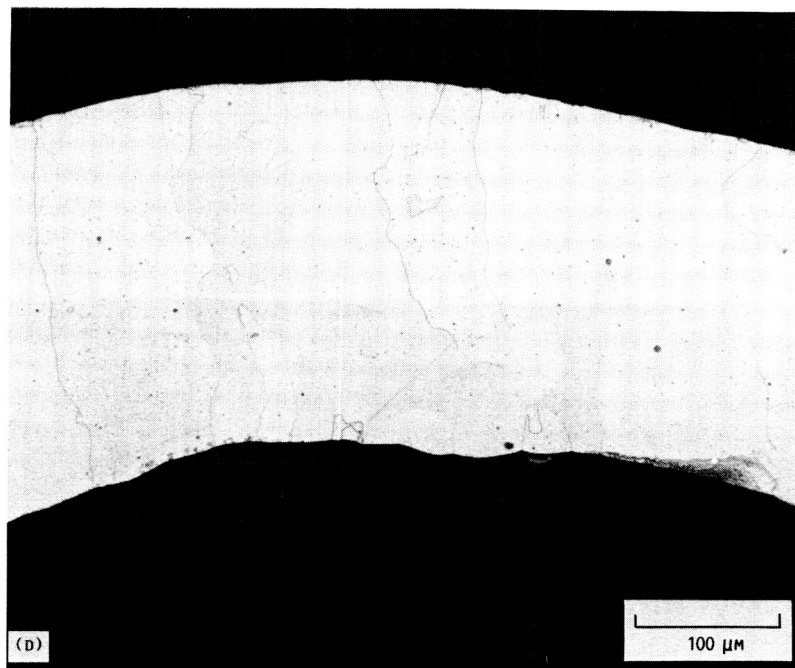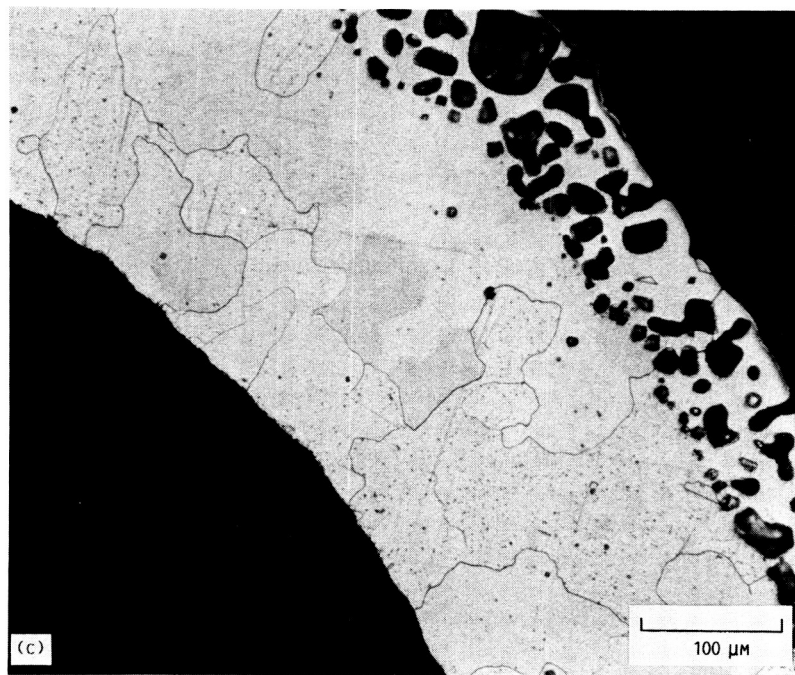
(c) NH₃.
(d) N₂.

Figure 9.—Continued.
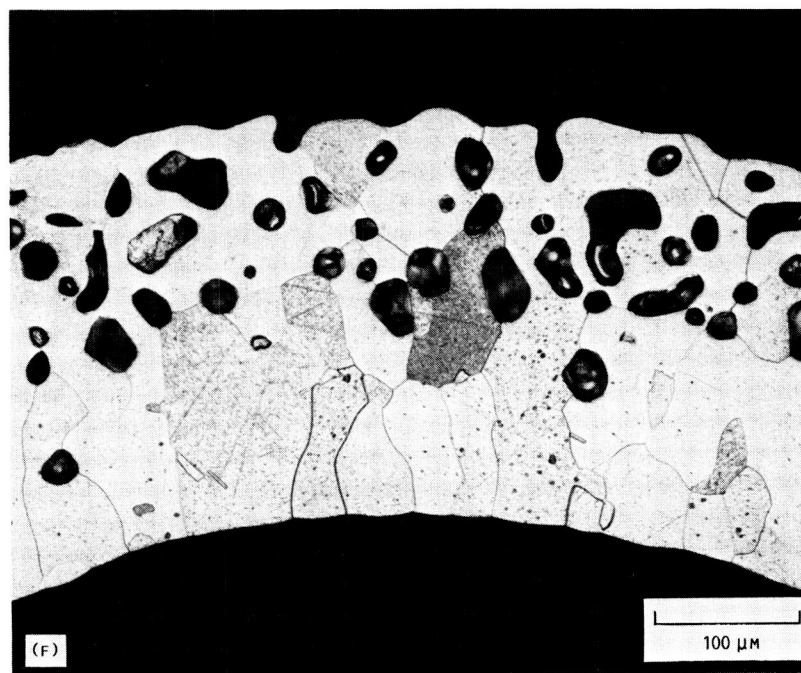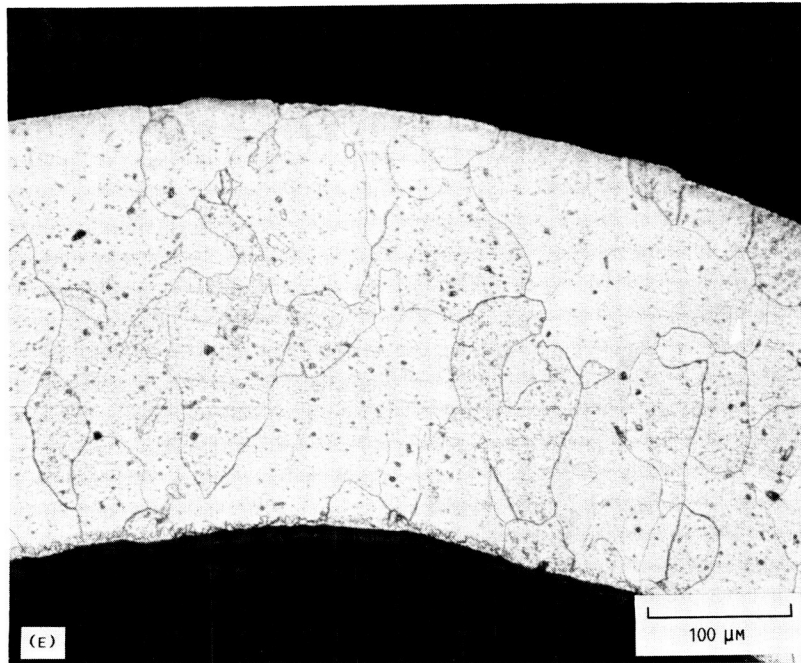
(e) Steam.

(f) N_2H_4.

Figure 9.—Concluded.
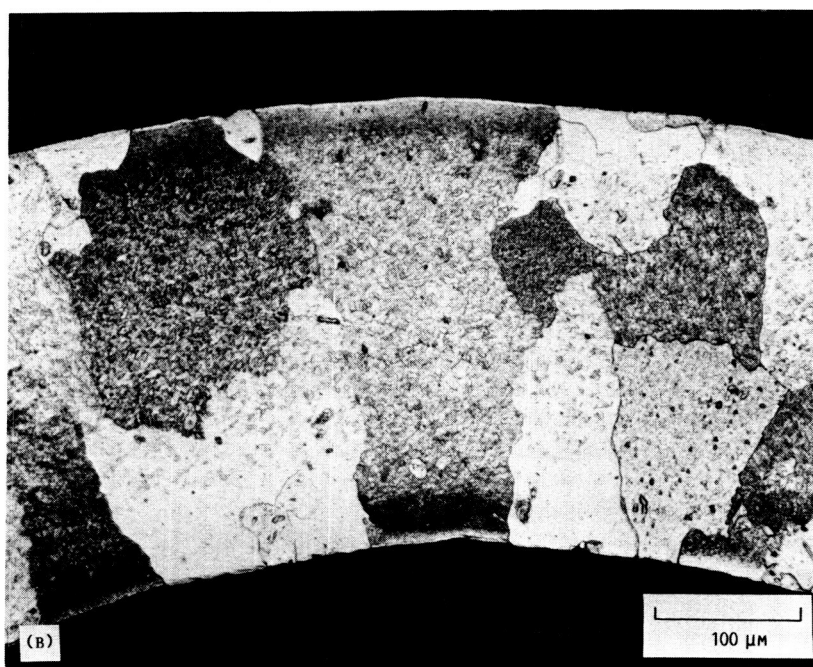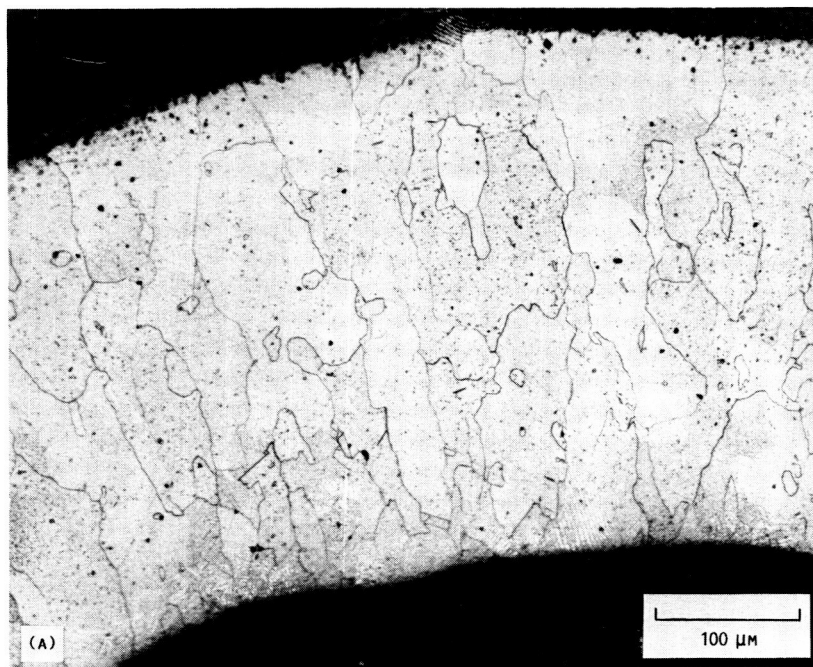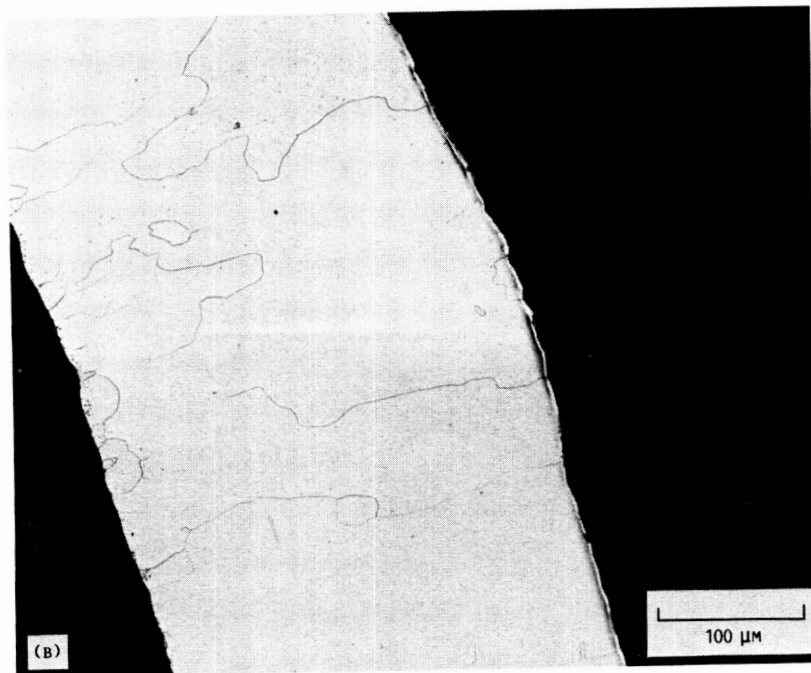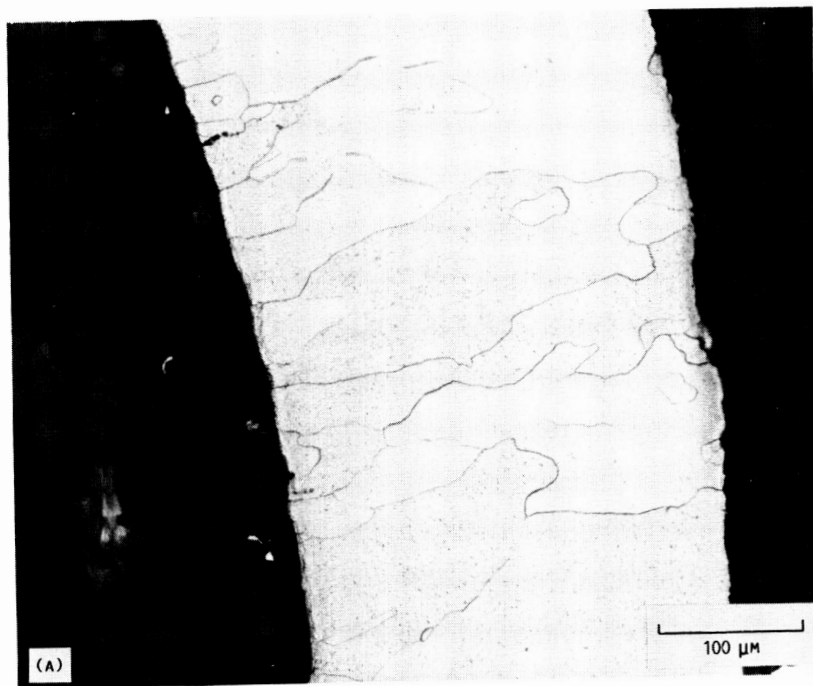
(a) At 500 °C in CH_4.
(b) At 800 °C in N_2H_4.

Figure 10.—Platinum-yttria cross section after 1000 hr.
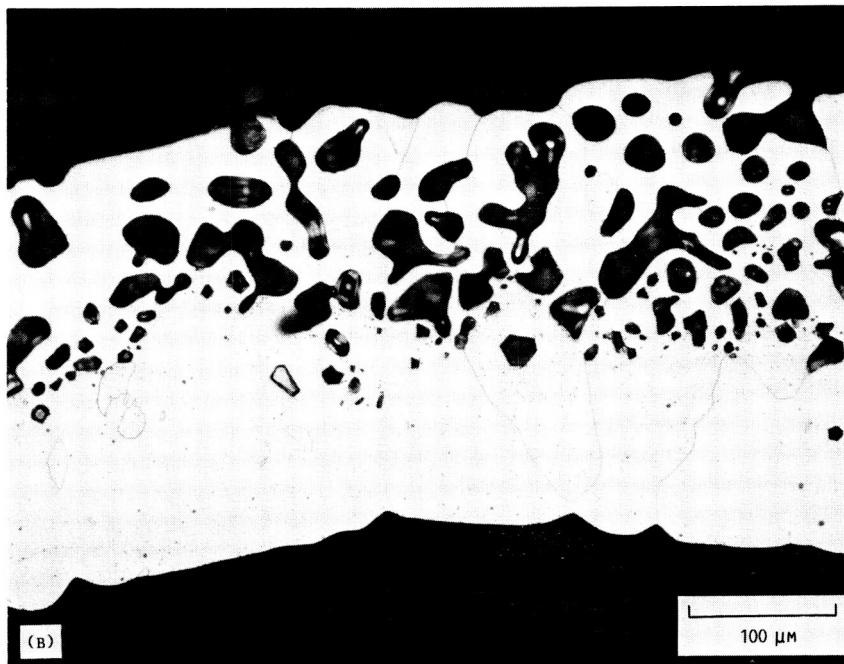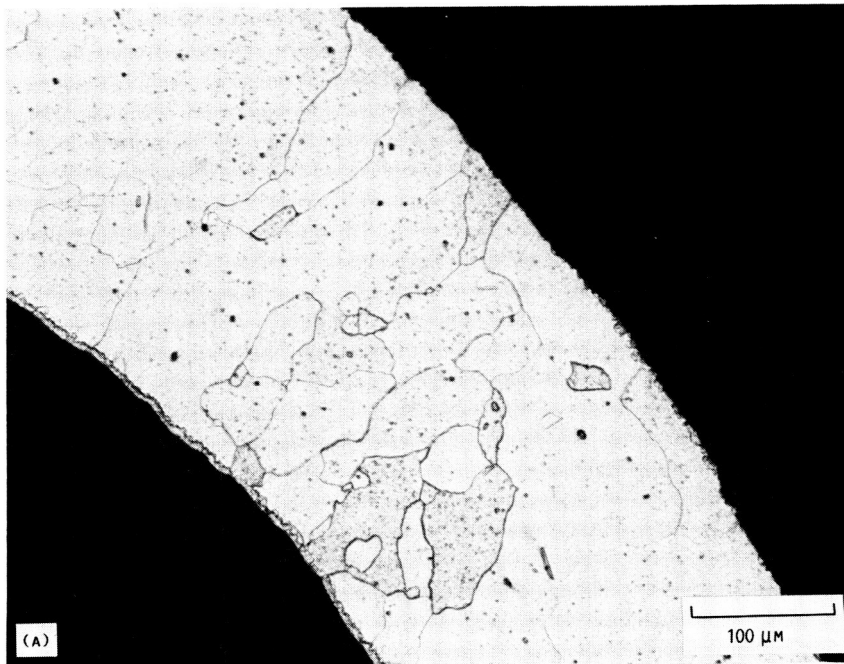
(a) H_2.
(b) NH_3.

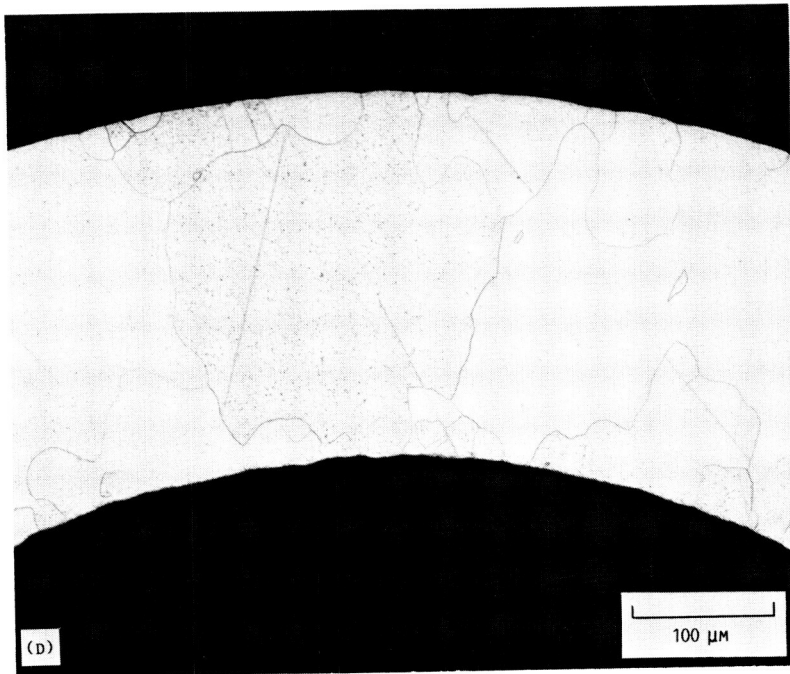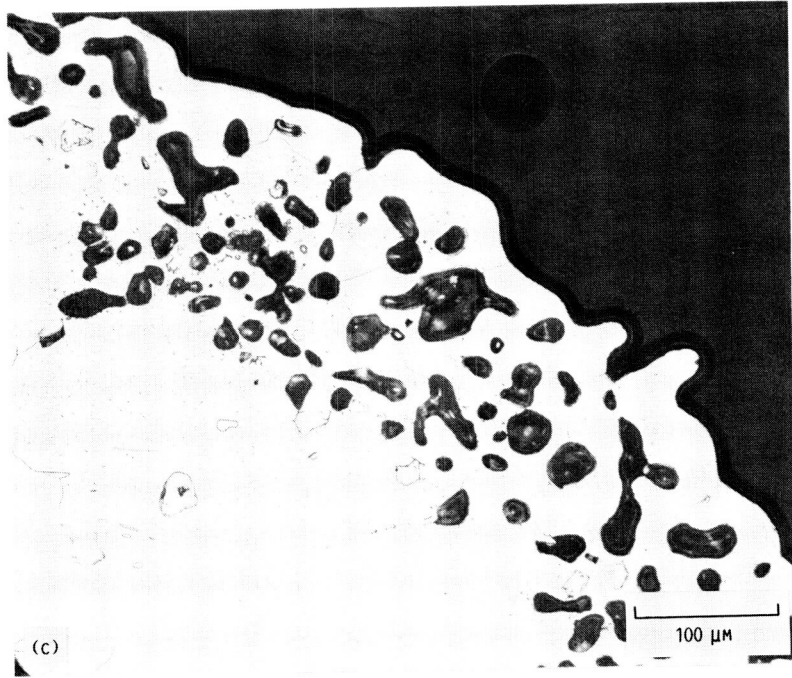Figure 11.—Platinum-yttria cross section after 2000 hr at 1400 °C.
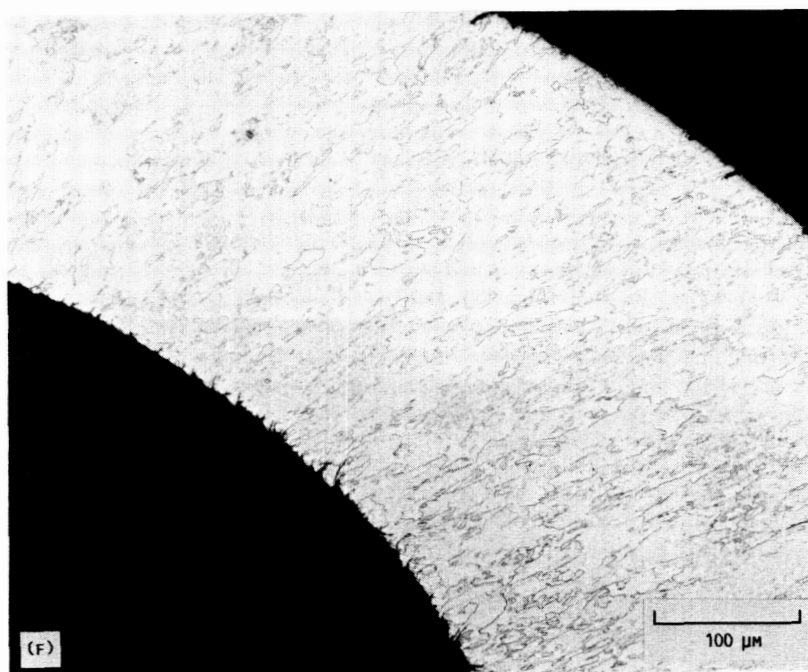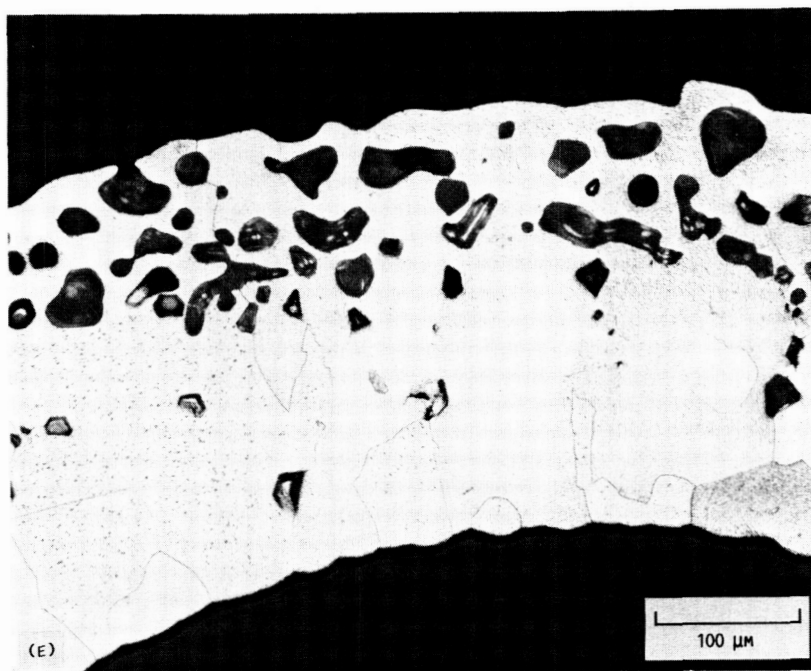
(a) CO_2.
(b) H_2.

Figure 12.—Platinum-zirconia cross section after 1000 hr. All tests at 1400 °C, except CH_4 at 500 °C.

23

(c) NH$_3$.
(d) Steam.

Figure 12.—Continued.
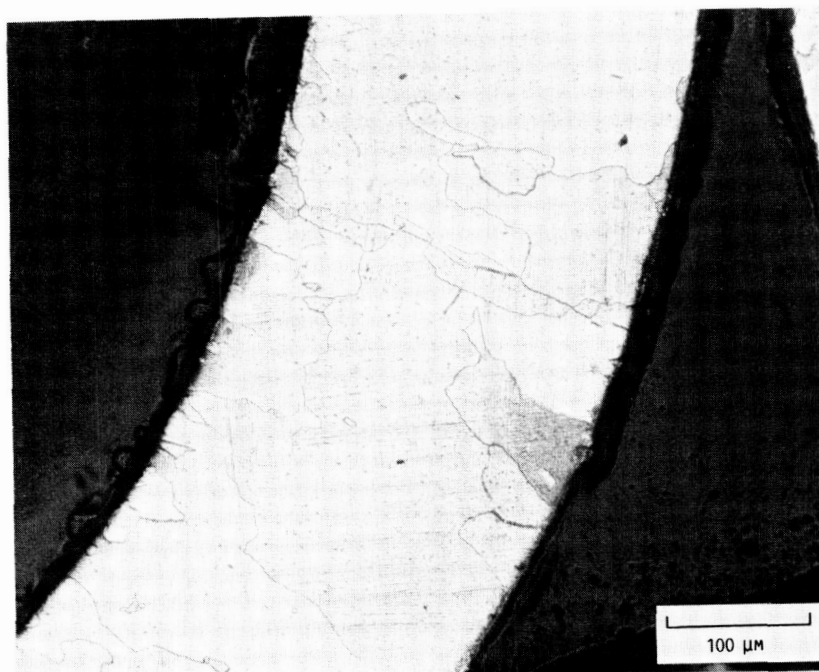
(e) N_2H_4.
(f) CH_4.

Figure 12.—Concluded.

Figure 13.—Platinum-zirconia sample after 30-min vacuum anneal at 1000 °C.

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15. Supplementary Notes

16. Abstract

Resistojets for the space station require long life and multipropellant capability. The choice of available materials to meet these requirements is limited. Dispersion-strengthened platinum was selected to be studied for use as a resistojet material. Past results indicated that dispersion-strengthened platinum should be sufficiently inert in candidate propellant environments and should be capable of operating at moderate temperatures for extended periods of time. A series of propellant compatibility tests was conducted with platinum strengthened with either yttria or zirconia. The data presented include the results of 1000-hr tests in carbon dioxide (CO_2), hydrogen (H_2), ammonia (NH_3), nitrogen (N_2), steam, hydrazine (N_2H_4), and methane (CH_4); and 2000-hr tests in H_2 and NH_3. The platinum samples were tested at 1400 °C in CO_2, H_2, NH_3, N_2, steam, and N_2H_4; at 500 °C in CH_4; and at 800 °C in N_2H_4. The mass-loss results indicated material life, extrapolated from experimental mass-loss data, in excess of 100 000 hr in all environments except steam and N_2H_4, where material life was $\geq 45\,000$ hr. Generally, on the basis of mass loss, there were no compatibility concerns in any of the environments considered. Optical and scanning electron microscopy were used to determine the effect of propellants on the material surface and to evaluate material stability as a function of resistance to grain growth. The propellant interaction varied from little or no reaction with H_2 and CH_4 to evidence of void formation and pitting of samples tested in NH_3 and N_2H_4. Material stability when measured as a function of grain growth did not appear to be a problem.

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