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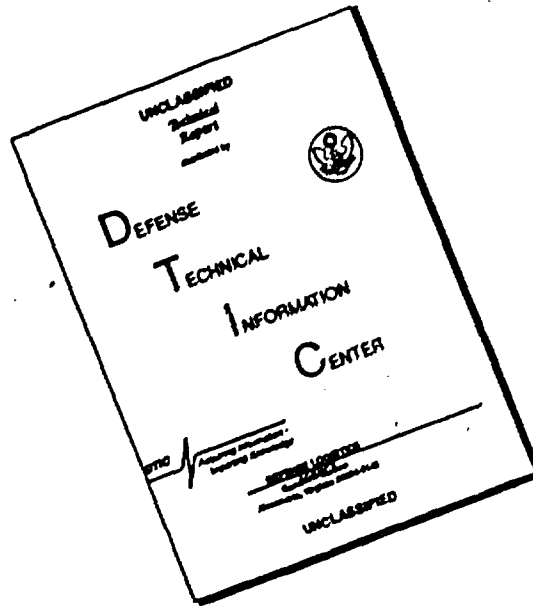
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**THERMOPHYSICAL PROPERTIES OF SOME CANDIDATE
SUPERORBITAL HEAT SHIELD AND INSULATION MATERIALS**

Prepared By

Materials Applications Division
AF Materials Laboratory
Deputy Cmdr/Research & Engineering

6 June 1963

Task 738103

Aeronautical Systems Division
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

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Aeronautical Systems Division
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

Technical Memorandum
ASRCE TM-63-16

Materials Applications Division
Air Force Materials Laboratory
Deputy Cmdr/Research & Engineering

THERMOPHYSICAL PROPERTIES OF SOME CANDIDATE
SUPERORBITAL HEAT SHIELD AND INSULATION MATERIALS

I. PURPOSE:

The purpose of this memorandum is to present a concise summary of the most useful thermophysical properties of some candidate heat shield materials for the thermal protection of superorbital lift reentry vehicles.

II. FACTUAL DATA

1. The following materials properties reports and compendia were searched for pertinent data:

- (a) WADC TR58-476
- (b) ASD TR62-215
- (c) TPRC Data Book Vol. 1, 2, & 3
- (d) DMIC Memo 141
- (e) WADC TR57-476
- (f) ASD TR62-765
- (g) DMIC Memo 177

III. CONCLUSIONS

1. The data sheets (Appendix I) constitute Information Processing Section's first compilation in this specific area, and it is intended to be the most complete summary of the data in published unclassified reports and data compendia.

2. In evaluating the reliability of the data, we suggest that the source reference be noted and that they have the following order, the most reliable first:

- (a) TPRC Data Book
- (b) DMIC Memo 141 & 177
- (c) ASD & WADC Technical Reports

3. The emissivity data, while the best available, is probably the least reliable of the data presented.

IV. RECOMMENDATIONS:

It is recommended that this initial review be continued and updated as may be warranted by the availability of new and/or more refined data.

COORDINATION:


Edward Dugger, ASRCE-32

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PREPARED BY:


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PUBLICATION REVIEW

This report has been reviewed and is approved.



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AF Materials Laboratory

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TERMO-PROPERTIES - SUPERCRITICAL HEAT TREAT & IRRADIATION MATERIALS

Ref.	Material	Density g/cm ³	Condition	M. P.	Thermal Conductivity Watts/cm °K	ρTC/ hr °K °K ²	Q	Temp	Electrical Resistivity Ω-cm	Sensitivity %	Temp	Specific Heat BTU/lb. °F	Temp	Linear Thermal Expansion % 0-1000°C	Temp.
MSC TR64-76 Vol. I	Graphite gr 4M	109				15.0		2000 Ω-cm							
"	Carbon (most probably per reference)	110		7100°K		16.0		5000 Ω-cm							
"	Graphite Acheson Type 3087	101.7	Extruded Bulk-crystalline			16.0		5000 Ω-cm	0.001 Ω-cm			0.5	5000°K	1.00	1000°K
"	Graphite Acheson Type 308		Extruded Bulk-crystalline			15		5000 Ω-cm	0.001 Ω-cm			0.75	5000°K	0.80	1000°K
"	Graphite Acheson Type 307AD	101	Extruded Bulk-crystalline			20		5000 Ω-cm	0.001 Ω-cm			0.75	5000°K	0.97	1000°K
ASD TR64-214	Polycrystalline Graphite	112.5 to 138.5		6600°K	1.5 (gr) 0.165 (gr)	200 (gr) 30 (gr)		5000 Ω-cm				0.68	500	2.7 (°C) (gr)	2500
TPMC TR64-113	Graphite 208	99.6			0.381 Watts/0.165 cm ²			1000 Ω-cm							
"	Graphite Type 307C	100.6			0.381			1000 Ω-cm							
"	Graphite Acheson Type 307AD				0.381			1000 Ω-cm							
"	Graphite (Pure filament)				0.381			1000 Ω-cm							
MSC TR64-111	Oxides	0.510 g/cm ³		1700°K		50		1000 Ω-cm							
"	Tantalum	0.600 g/cm ³		5250°K	0.114	50		1000 Ω-cm							
"	Chromium	0.700 g/cm ³		4500°K	0.100	50		1000 Ω-cm							
"	Scandium	0.700 g/cm ³		4500°K	0.100	50		1000 Ω-cm							
"	Zirconium	0.600 g/cm ³		6100°K	1.251	12		1000 Ω-cm							
"	Radium	0.700 g/cm ³		4500°K		21		1000 Ω-cm							
MSC TR64-107	Metals														
"	Aluminum	2.70 g/cm ³		2000°K	0.170	15		1000 Ω-cm							
"	Beryllium Oxide	2.70 g/cm ³		2800°K	0.170	15		1000 Ω-cm							
"	Calcium Oxide	3.30 g/cm ³		2800°K	0.170	15		1000 Ω-cm							
"	Barium Oxide	5.60 g/cm ³		2800°K	0.170	15		1000 Ω-cm							
"	Strontium Oxide	4.60 g/cm ³		2800°K	0.170	15		1000 Ω-cm							
"	Yttrium Oxide	5.00 g/cm ³		2800°K	0.170	15		1000 Ω-cm							
"	Lanthanum Oxide	6.10 g/cm ³		2800°K	0.170	15		1000 Ω-cm							
"	Europium Oxide	6.80 g/cm ³		2800°K	0.170	15		1000 Ω-cm							
"	Barium Oxide	5.60 g/cm ³	polycrystalline	900°K		12.5		1000 Ω-cm							
"	Strontium Oxide	4.60 g/cm ³		900°K		17.0		1000 Ω-cm							
ASD TR64-25	Polybenz Oxazine 60512	1.90 g/cm ³		550°K		25.0		1000 Ω-cm							

Figures indicated by asterisk from TR64
 Figures indicated by (1) from TR64-76
 Symbols A, measured parallel to line of processing (rolling, extruding, etc.)
 Symbols (1) measured parallel to line of processing (rolling, extruding, etc.)

TERMO-PROPERTIES - SUPERHOT HEAT TREAT & IRRADIATION MATERIAL

Ref.	Material	Density g/cm ³	Condition	M. P.	Thermal Conductivity W/m ² /m °C	κ W/m °C	Temp.	Electrical Resistivity	Reactivity	Temp	Specific Heat J/g °C	Temp	Linear Thermal Expansion % - 0-2000°C	Temp
BALC 7850-476 Vol. III	Hafnium Oxide HfO ₂	68.6 g/cm ³		2780R	0.95	0.90	1000R	0.86 ⁽¹⁾		1500 ⁽¹⁾	0.09 ⁽¹⁾	400 ⁽¹⁾	0.0	500R
					0.0099 ^a		2000R	0.15 ⁽¹⁾		4000 ⁽¹⁾	0.15 ⁽¹⁾	400 ⁽¹⁾	1.48	500R
	Thorium Oxide ThO ₂	68.6 g/cm ³		670R	0.95	0.90	1271.2R	0.59 Total		1250R	0.07 ⁽¹⁾	500 ⁽¹⁾	0.0	500R
					0.014 ^a	2.8	300R	0.62 Total		2000R	0.08 ⁽¹⁾	500 ⁽¹⁾	1.40	150R
	Uranium Dioxide UO ₂	68.6 g/cm ³		960R	0.014 ^a	2.8	1700R				0.070	100R	1.0	50R
					0.0099 ^a	1.0	1400, 1100, 3500R				0.098	2500R	1.70	2500R
	Zirconium Oxide ZrO ₂	560 g/cm ³		5370R	0.0099 ^a	1.0	1000R				0.134	1000R	6.14x10 ⁻⁴ °C ⁻¹	10 to 1500 ⁽¹⁾
						1.2L	1475.2R				0.144	3000R		10 to 1500 ⁽¹⁾
	Chromium Oxide Cr ₂ O ₃	417 g/cm ³		3000R							0.148	1000R		
											0.210	2000R		
	Hafnium Carbide HfC	790 g/cm ³		7500R	0.2 ⁽¹⁾	17.5 ⁽¹⁾	1800 ⁽¹⁾	0.99 ⁽¹⁾		1500 ⁽¹⁾				
							4000 ⁽¹⁾	0.85 ⁽¹⁾		1500 ⁽¹⁾				
	Niobium Carbide NbC	674 g/cm ³		5300R				0.65 ⁽¹⁾		900 ⁽¹⁾	0.089 ⁽¹⁾	400 ⁽¹⁾	0.0	500R
								0.20 ⁽¹⁾		4000 ⁽¹⁾	0.128 ⁽¹⁾	3000 ⁽¹⁾	0.76	2500R ^a install 2500R ^a install
	Tantalum Carbide TaC	900 g/cm ³		7100R				0.40 ⁽¹⁾		1000 ⁽¹⁾			0.0	500R
								0.28 ⁽¹⁾		4000 ⁽¹⁾			0.90	200R
	Titanium Carbide TiC	507 g/cm ³		6100R	0.041 ^a	10.0	1000R	0.6 ⁽¹⁾		1000 ⁽¹⁾	0.146	1000R	0.0	500R
						2.5	1393.8R	0.4 ⁽¹⁾		4000 ⁽¹⁾	0.22	2500R	1.70	500R
	Tungsten Carbide WC	975.8 g/cm ³		9600R				0.6 ⁽¹⁾		1000 ⁽¹⁾	0.09 ⁽¹⁾	500 ⁽¹⁾	0.0	500R
						29.0 ⁽¹⁾	1500 ⁽¹⁾	0.4 ⁽¹⁾		4000 ⁽¹⁾	0.08 ⁽¹⁾	4000 ⁽¹⁾	0.70	500R
	Uranium Carbide U ₃ C ₂	795 g/cm ³		4740R		10.0	600R							500R
A-D-7850-705	Vanadium Carbide	5.42 g/cm ³			21.6	20.3	1500R	0.68		1500 ⁽¹⁾	0.180	500R	4.10x10 ⁻⁴ °C ⁻¹	0-1500 ⁽¹⁾
							1500R	0.28		4000 ⁽¹⁾	0.39	500R		0-1500 ⁽¹⁾
BALC 7850-476 Vol. II	Sirconium Boride SiB ₂	580 g/cm ³		4000R		7.5	500R	0.4 ⁽¹⁾		1000 ⁽¹⁾			0.0	400R
						16.0 ⁽¹⁾	3000 ⁽¹⁾	0.55 ⁽¹⁾		3000 ⁽¹⁾			1.0	300R
BALC 7850-476 Vol. II	Sirconium Carbide SiC	400 g/cm ³		4600R				0.45 ⁽¹⁾		4000 ⁽¹⁾			0.0	500R
								0.35 ⁽¹⁾		4000 ⁽¹⁾			0.0	500R
	Hafnium Boride HfB ₂	700 g/cm ³		6100R		11.9 ⁽¹⁾	1500 ⁽¹⁾	0.4 ⁽¹⁾		1000 ⁽¹⁾	0.08 ⁽¹⁾	1500 ⁽¹⁾	0.5x10 ⁻⁴ °C ⁻¹	1000R
						23.0 ⁽¹⁾	3000 ⁽¹⁾	0.7 ⁽¹⁾		4000 ⁽¹⁾	0.120 ⁽¹⁾	4000 ⁽¹⁾		0-4000 ⁽¹⁾
	Niobium Boride NbB ₂	690 g/cm ³		4700R										
	Tantalum Boride TaB ₂	680 g/cm ³		4800R										
	Tungsten Boride WB ₂	15.2 g/cm ³			21.4	21.4	1500R	0.5		1000R	0.08	500R	4.10x10 ⁻⁴ °C ⁻¹	0-4000 ⁽¹⁾
							4000R	0.5		4000 ⁽¹⁾	0.30	500R		0-4000 ⁽¹⁾
BALC 7850-476 Vol. II	Vanadium Boride VB ₂	580 g/cm ³		4700R										
	Titanium Nitride TiN	330 ⁽¹⁾		5300 ⁽¹⁾		11.0	1000R	0.45 ⁽¹⁾		1000 ⁽¹⁾	0.146	500R		500R
		330 g/cm ³		5000R	0.088 ^a	3.0	1000R	0.30 ⁽¹⁾		4000 ⁽¹⁾	0.22	500R		500R
							1353.8R	0.177 ^a						
	Praseodymium Nitride PrN	895 g/cm ³		5000R		2.95	500R							
	Silicon Nitride Si ₃ N ₄	344 g/cm ³		5100R	0.059 ^a	6.7	1000R	0.098		500R	0.134	500R	0.0	500R
							1361.7R	0.134		3000R	0.16	500R	1.16	1500R
						5.3	2500R							
BALC 7850-705	Tantalum Nitride TaN	13.4 g/cm ³						0.70		1000R	0.09	500R	2.1x10 ⁻⁴ °C ⁻¹	0-1000 ⁽¹⁾
								0.68		4000 ⁽¹⁾	0.09	500R		0-1000 ⁽¹⁾
BALC 7850-85	Beryllium Carbide Be ₂ C	154 g/cm ³		3400R		0.85	1200R				0.19	2000R		
	Boron Carbide B ₄ C	254 g/cm ³		4400R		14.0	2500R				0.294	500R	0.0	500R
	Silicon Carbide SiC	301 g/cm ³		4710R		8	3000R				0.08	500R	0.0	500R
								0.04 Total		400-3000R	0.08	500R	0.0	500R
	Boron Nitride BN	137 g/cm ³		5600R		16	2500R	0.65 Total		4500R	0.07 ⁽¹⁾	4000 ⁽¹⁾	0.0	500R
						7	2500R	0.44 ⁽¹⁾		4000 ⁽¹⁾	0.14 ⁽¹⁾	4000 ⁽¹⁾		500R
	Al ₂ O ₃ -Cr ₂ O ₃	100 to 200 g/cm ³		> 3700R		Nonzero to 3.5	2100R							500R
														500R
	Yttrium Oxide Y ₂ O ₃	505.8 g/cm ³		3600R		5.5	600R							1000R
						1.70	2000R							
						2.5	1200R				0.16	500R	0.0	500R
						1.9	3000R				0.2	500R	0.0	500R

Figures indicated by asterisk from TPIC.
 Figures indicated by (1) from 7850-705.
 Figures indicated by (2) from BALC Report 177.
 Figures indicated by (3) from BALC 7850-85.