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Dynamic High-Temperature Tensile Characterization of an Iridium Alloy



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Outline

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- **Dynamic high-temperature tensile characterization of a DOP-26 iridium alloy**
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- **Summary**
- **Acknowledgments**

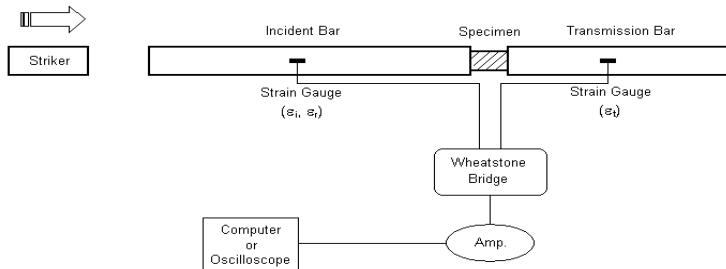
Background



Periodic Table of the Elements

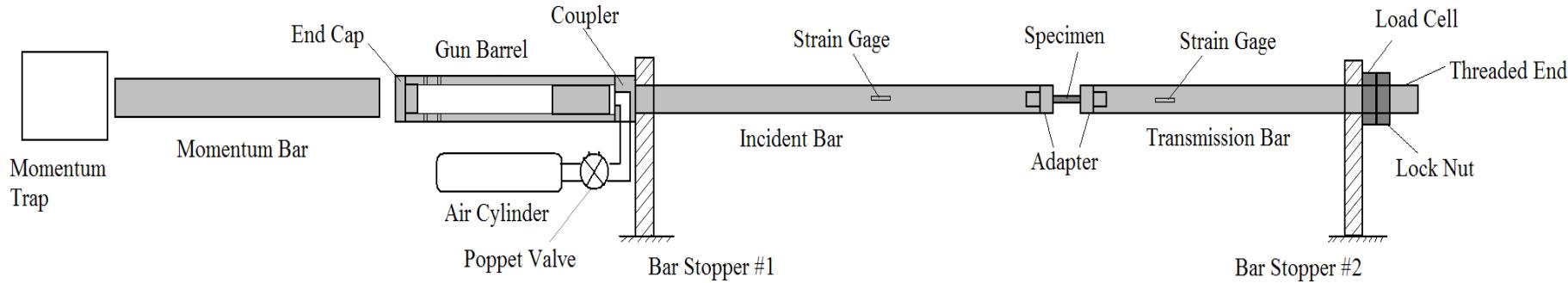
77	Iridium	192.22
Periodic Table of the Elements		
55	Ca	Boron
56	Ba	57-71
57	Hf	Tantalum
58	Ta	72
59	W	73
60	Ru	74
61	Os	75
62	Ir	76
63	Pt	77
64	Au	78
65	Hg	79
66	Tl	80
67	Pb	81
68	Bi	82
69	Po	83
70	At	84
71	Rn	85
72	Fr	86
73	Ra	87
74	Hf	88-103
75	Ta	104
76	W	105
77	Ru	106
78	Os	107
79	Ir	108
80	Pt	109
81	Au	110
82	Hg	111
83	Tl	112
84	Pb	113
85	Bi	114
86	Po	115
87	At	116
88	Rn	117
89	Fr	118
90	Ra	119
91	Hf	120
92	Ta	121
93	W	122
94	Ru	123
95	Os	124
96	Ir	125
97	Pt	126
98	Au	127
99	Hg	128
100	Tl	129
101	Pb	130
102	Bi	131
103	Po	132
104	At	133
105	Rn	134
106	Fr	135
107	Ra	136
108	Hf	137
109	Ta	138
110	W	139
111	Ru	140
112	Os	141
113	Ir	142
114	Pt	143
115	Au	144
116	Hg	145
117	Tl	146
118	Pb	147
119	Bi	148
120	Po	149
121	At	150
122	Rn	151
123	Fr	152
124	Ra	153
125	Hf	154
126	Ta	155
127	W	156
128	Ru	157
129	Os	158
130	Ir	159
131	Pt	160
132	Au	161
133	Hg	162
134	Tl	163
135	Pb	164
136	Bi	165
137	Po	166
138	At	167
139	Rn	168
140	Fr	169
141	Ra	170
142	Hf	171
143	Ta	172
144	W	173
145	Ru	174
146	Os	175
147	Ir	176
148	Pt	177
149	Au	178
150	Hg	179
151	Tl	180
152	Pb	181
153	Bi	182
154	Po	183
155	At	184
156	Rn	185
157	Fr	186
158	Ra	187
159	Hf	188
160	Ta	189
161	W	190
162	Ru	191
163	Os	192
164	Ir	193
165	Pt	194
166	Au	195
167	Hg	196
168	Tl	197
169	Pb	198
170	Bi	199
171	Po	200
172	At	201
173	Rn	202
174	Fr	203
175	Ra	204
176	Hf	205
177	Ta	206
178	W	207
179	Ru	208
180	Os	209
181	Ir	210
182	Pt	211
183	Au	212
184	Hg	213
185	Tl	214
186	Pb	215
187	Bi	216
188	Po	217
189	At	218
190	Rn	219
191	Fr	220
192	Ra	221
193	Hf	222
194	Ta	223
195	W	224
196	Ru	225
197	Os	226
198	Ir	227
199	Pt	228
200	Au	229
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202	Tl	231
203	Pb	232
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211	Ta	240
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215	Ir	244
216	Pt	245
217	Au	246
218	Hg	247
219	Tl	248
220	Pb	249
221	Bi	250
222	Po	251
223	At	252
224	Rn	253
225	Fr	254
226	Ra	255
227	Hf	256
228	Ta	257
229	W	258
230	Ru	259
231	Os	260
232	Ir	261
233	Pt	262
234	Au	263
235	Hg	264
236	Tl	265
237	Pb	266
238	Bi	267
239	Po	268
240	At	269
241	Rn	270
242	Fr	271
243	Ra	272
244	Hf	273
245	Ta	274
246	W	275
247	Ru	276
248	Os	277
249	Ir	278
250	Pt	279
251	Au	280
252	Hg	281
253	Tl	282
254	Pb	283
255	Bi	284
256	Po	285
257	At	286
258	Rn	287
259	Fr	288
260	Ra	289
261	Hf	290
262	Ta	291
263	W	292
264	Ru	293
265	Os	294
266	Ir	295
267	Pt	296
268	Au	297
269	Hg	298
270	Tl	299
271	Pb	300
272	Bi	301
273	Po	302
274	At	303
275	Rn	304
276	Fr	305
277	Ra	306
278	Hf	307
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281	Ru	310
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285	Au	314
286	Hg	315
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288	Pb	317
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317	Ir	346
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319	Au	348
320	Hg	349
321	Tl	350
322	Pb	351
323	Bi	352
324	Po	353
325	At	354
326	Rn	355
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329	Hf	358
330	Ta	359
331	W	360
332	Ru	361
333	Os	362
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335	Pt	364
336	Au	365
337	Hg	366
338	Tl	367
339	Pb	368
340	Bi	369
341	Po	370
342	At	371
343	Rn	372
344	Fr	373
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373	Pb	402
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375	Po	404
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390	Pb	419
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393	At	422
394	Rn	423
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397	Hf	426
398	Ta	427
399	W	428
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403	Pt	432
404	Au	433
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406	Tl	435
407	Pb	436
408	Bi	437
409	Po	438
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415	Ta	444
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417	Ru	446
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424	Pb	453
425	Bi	454
426	Po	455
427	At	456
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431	Hf	460
432	Ta	461
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434	Ru	463
435	Os	464
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443	Po	472
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462	Rn	491
463	Fr	492
464	Ra	493
465	Hf	494
466	Ta	495
467	W	496
468	Ru	497
469	Os	498
470	Ir	499
471	Pt	500
472	Au	501
473	Hg	502
474	Tl	503
475	Pb	504
476	Bi	505
477	Po	506
478	At	507
479	Rn	508
480	Fr	509
481	Ra	510
482	Hf	511
483	Ta	512
484	W	513
485	Ru	514
486	Os	515
487	Ir	516
488	Pt	517
489	Au	518
490	Hg	519
491	Tl	520
492	Pb	521
493	Bi	522
494	Po	523
495	At	524
496	Rn	525
497	Fr	526
498	Ra	527
499	Hf	528
500	Ta	529
501	W	530
502	Ru	531
503	Os	532
504	Ir	533
505	Pt	534
506	Au	535
507	Hg	53

Kolsky Bar (Split Hopkinson Bar) Techniques



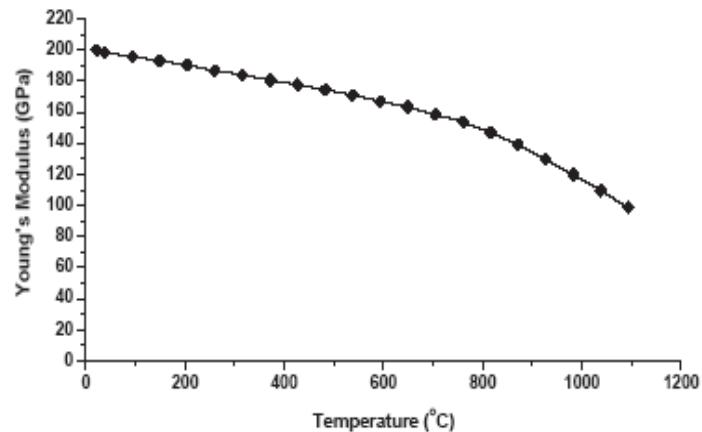
$$\dot{\varepsilon} = \frac{u_1 - u_2}{l_0} = \frac{C_b}{l_0} (\varepsilon_i - \varepsilon_r - \varepsilon_t) \rightarrow \varepsilon = \int_0^t \dot{\varepsilon}(\tau) d\tau$$

$$\sigma = \frac{F_1 + F_2}{2A_0} = \frac{E_b A_b}{2A_0} (\varepsilon_i + \varepsilon_r + \varepsilon_t) \rightarrow \sigma \sim \varepsilon$$



High-Temperature Kolsky Bar Principles

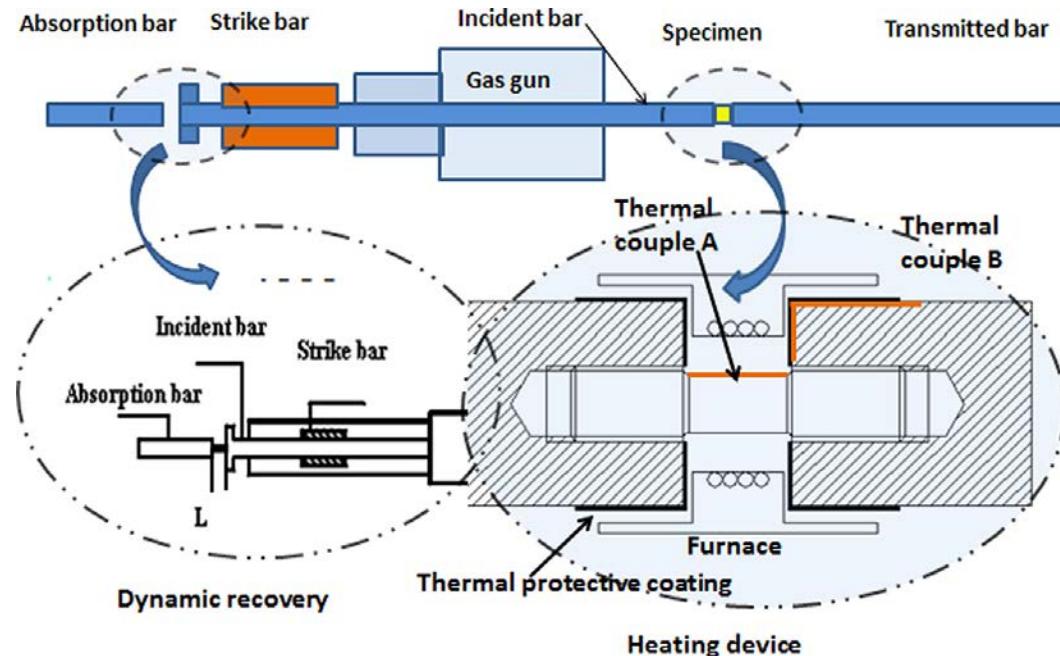
- Avoid “hot” pressure bars
 - Heat specimen individually
 - Hot Specimen/Cold Bars
 - Heat transfer
 - Specimen temperature drops
 - Bar temperature increases – thermal gradient in the bars
- Good for high-temperature Kolsky compression bar tests
 - Frantz et al. (1984)
 - Lennon and Ramesh (1998)
 - Apostol et al. (2003)
 - Song et al. (2012, 2014)
- Not applicable to Kolsky tensile bar tests



Cold Contact Time (CCT) is the time during which the “hot” specimen stays in contact with the “cold” pressure bars until being dynamically loaded

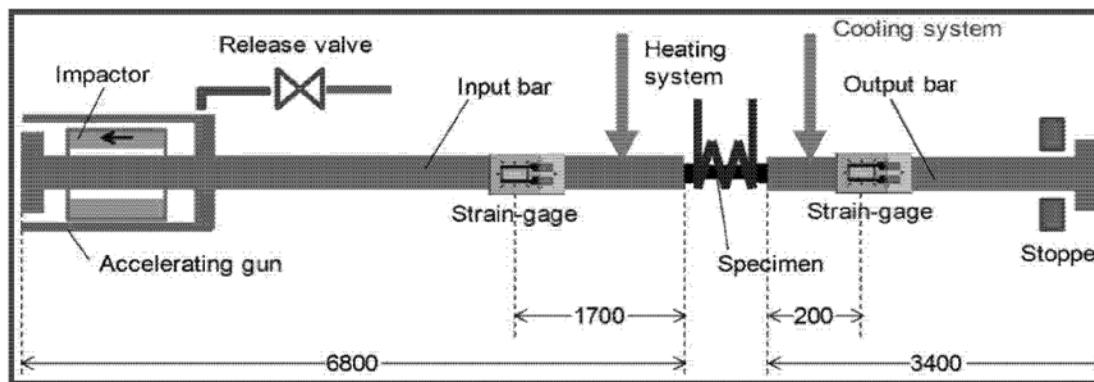
High-Temperature Kolsky Tensile Bar Tests

Su et al. (2013)



$T < 600C$

Scapin et al. (2014)



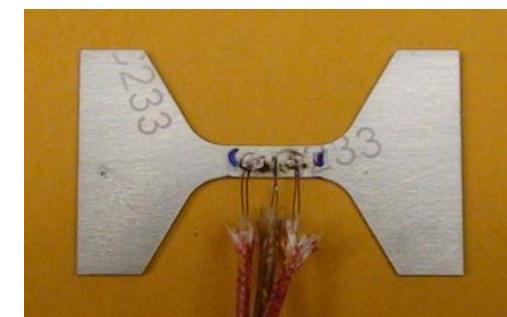
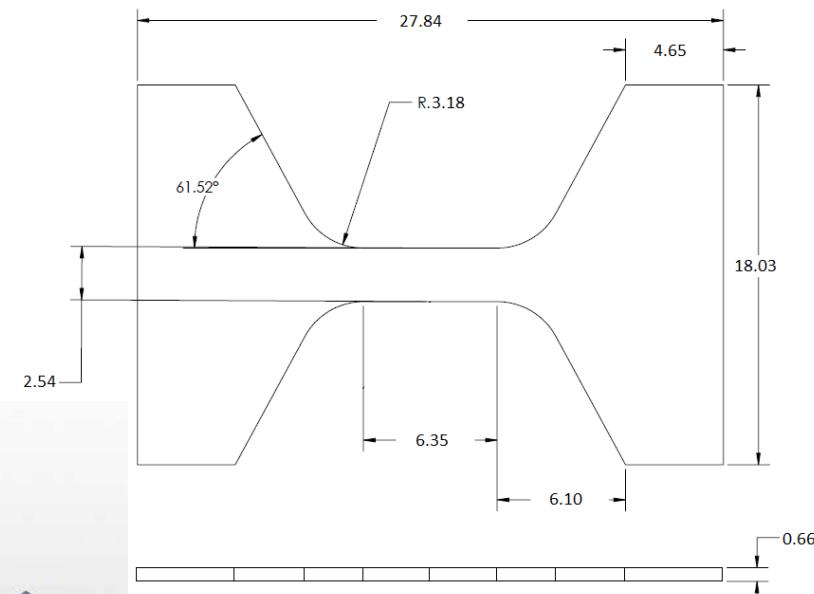
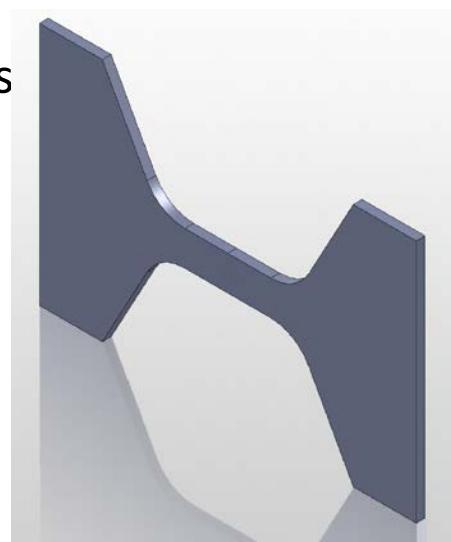
Challenges in High-Temperature Kolsky Tensile Bar Tests of Iridium

- DOP-26 iridium alloy: only 660-um-thick thin sheet

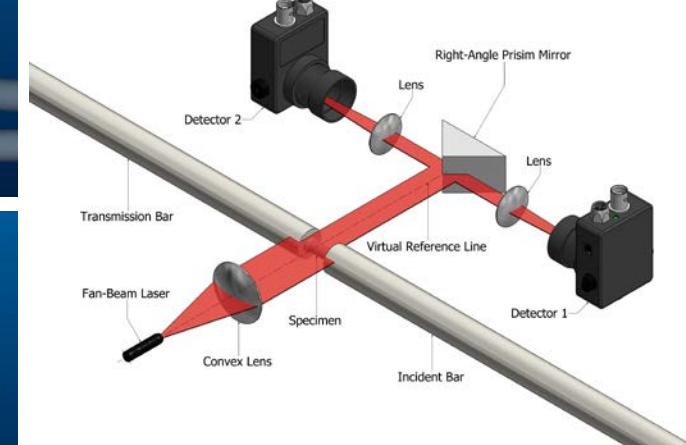
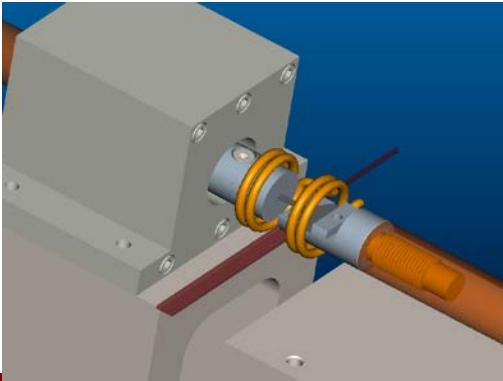
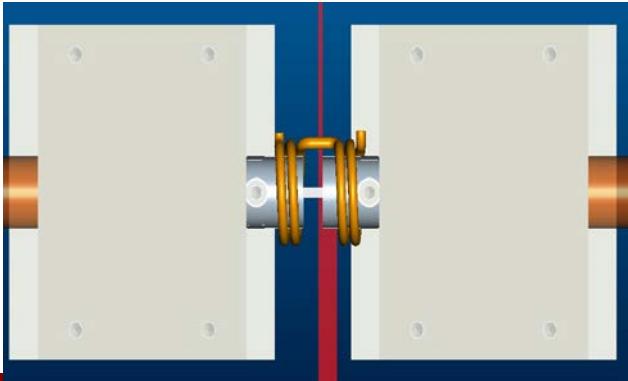
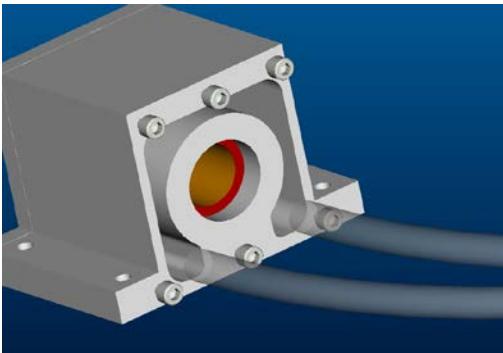
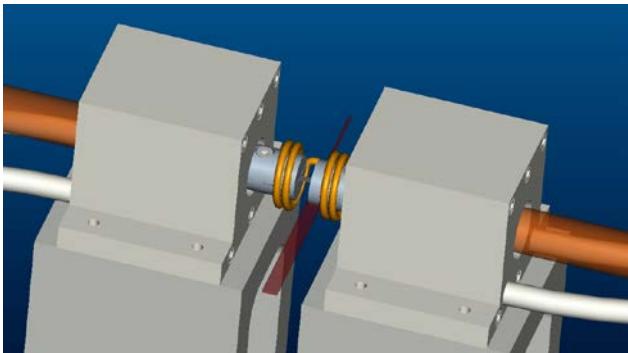
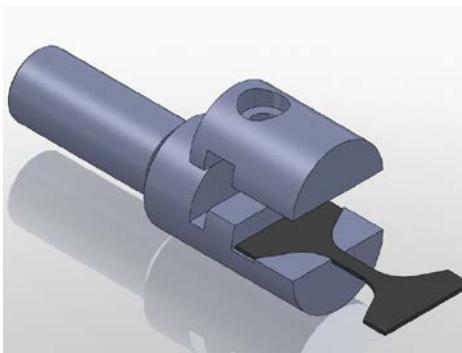
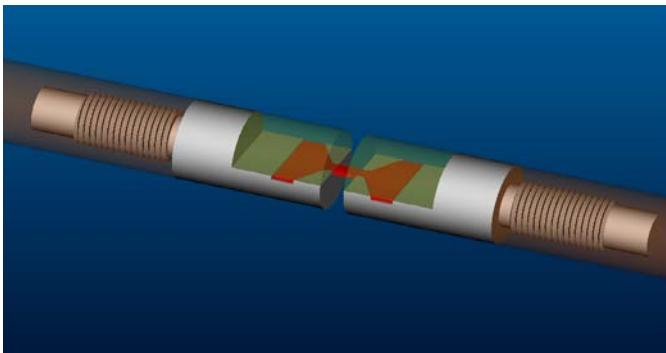
- Special grips/fixtures
 - Specimen geometry design
 - Small cross-sectional area
 - Small transmitted force

- Ultra-high temperatures

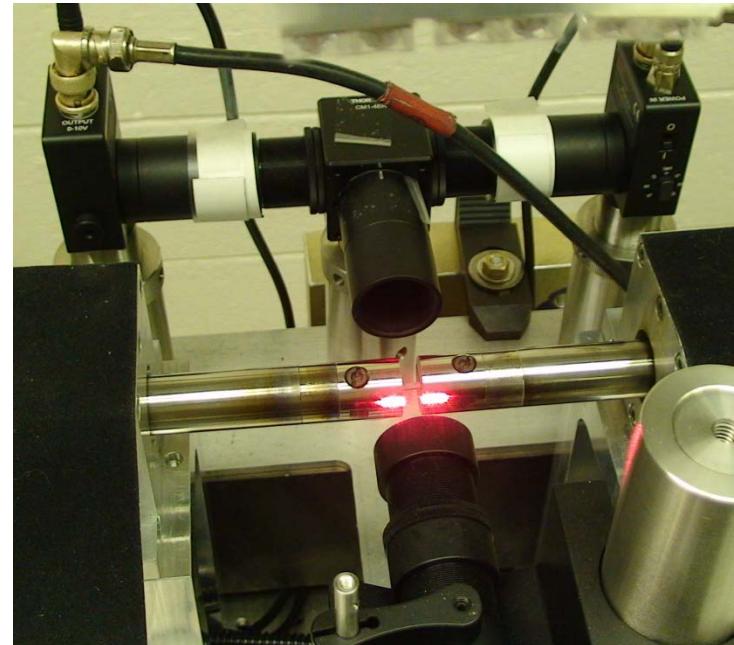
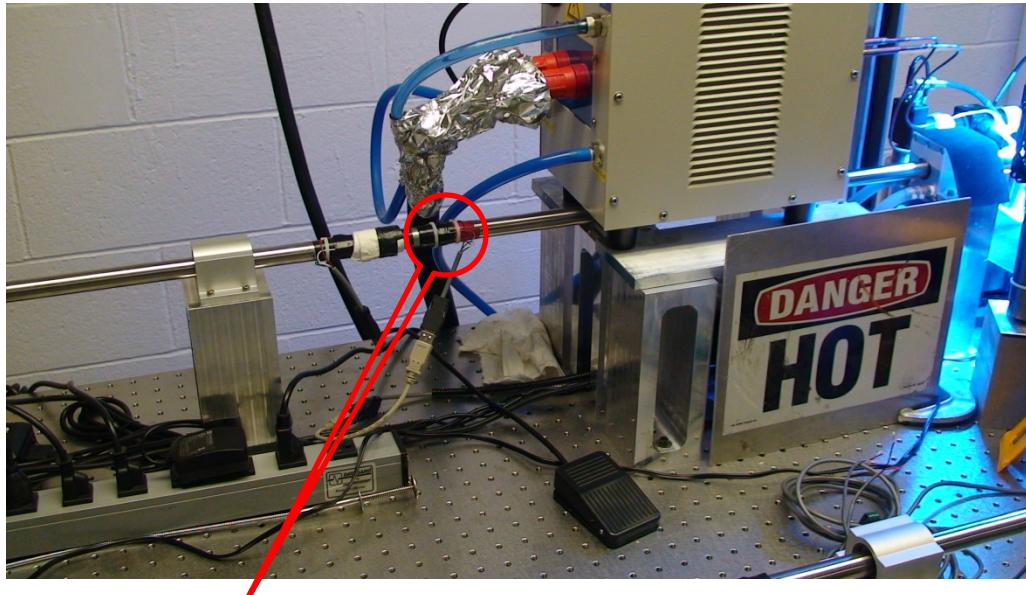
- 750 and 1030C
 - Hot specimen/cool bars
 - Thermal expansion
 - Possible buckling



High-Temperature Kolsky Tensile Bar Tests



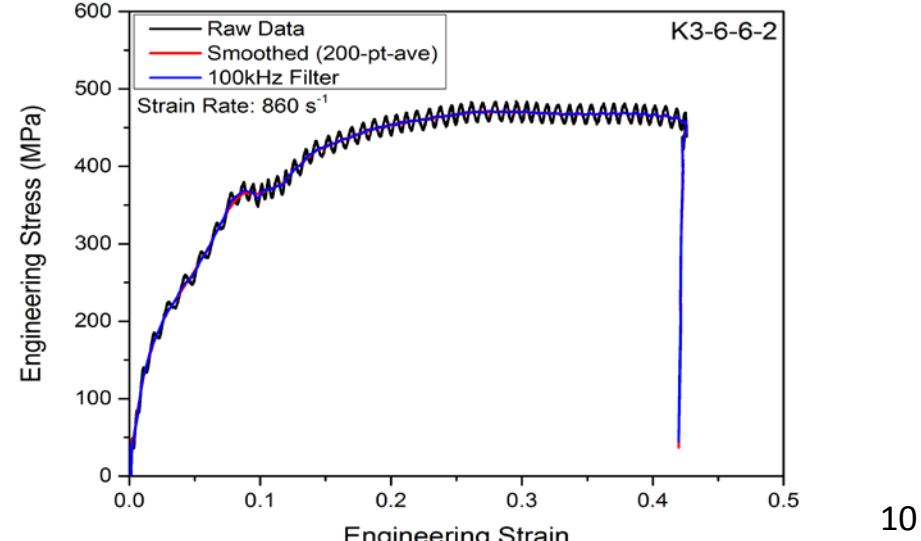
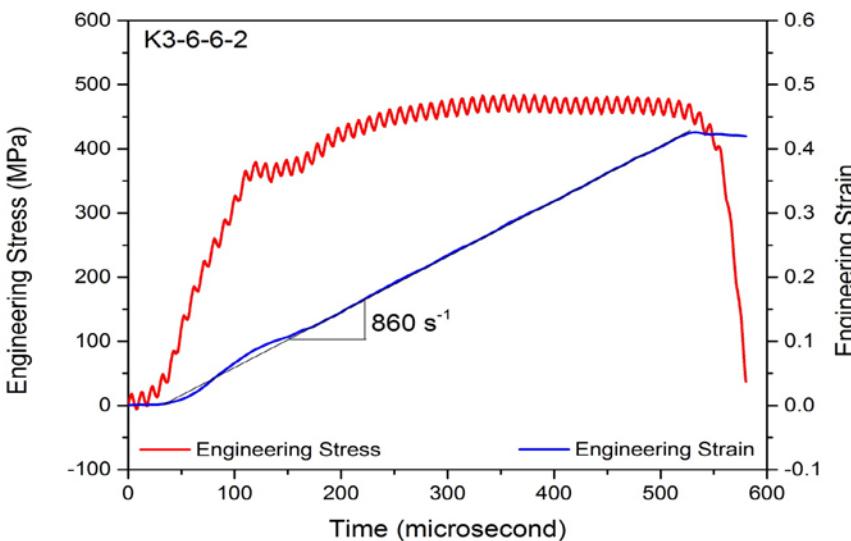
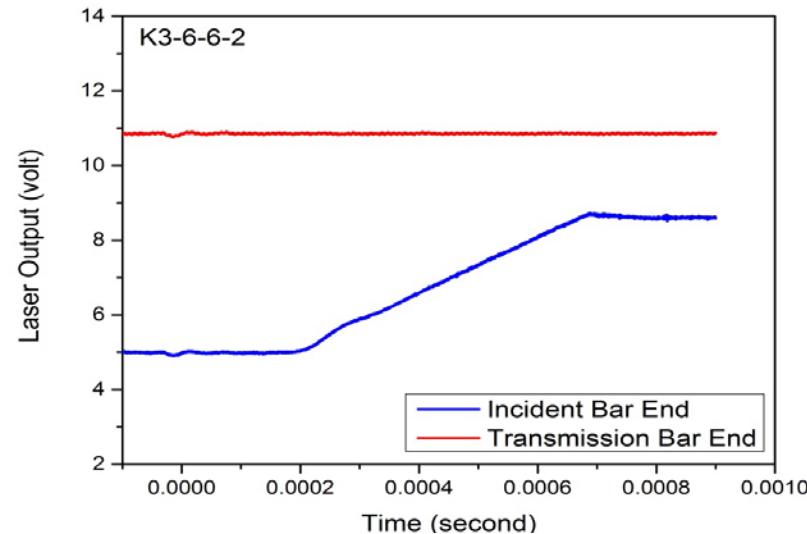
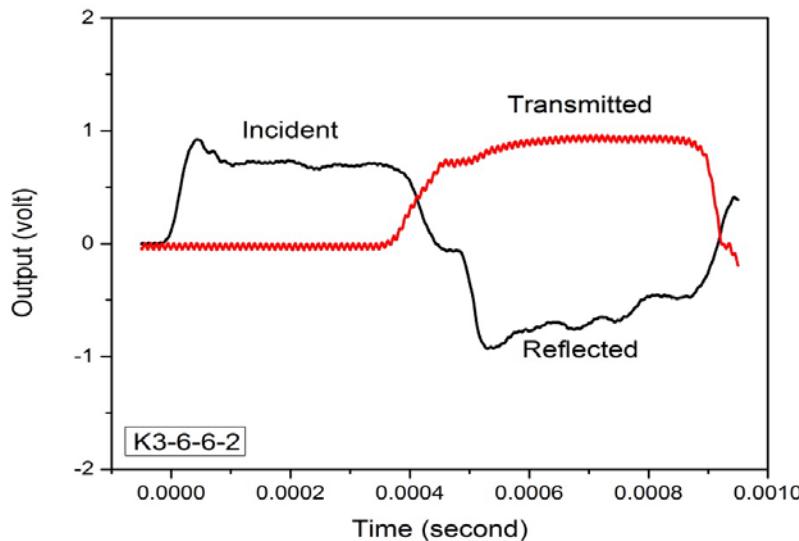
Stress and Strain Measurements



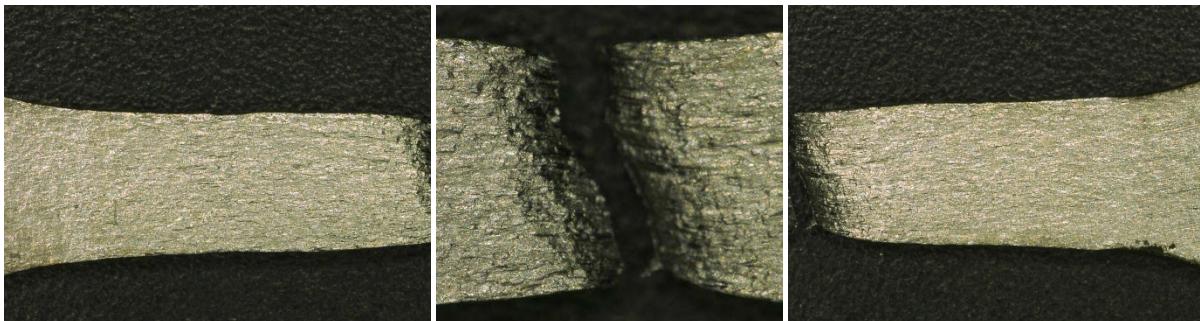
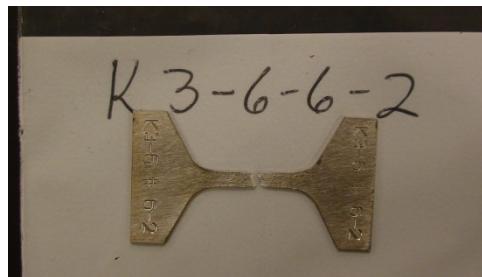
Semiconductor strain gages – specimen stress measurement
(GF: 139 vs. 2 for regular foil strain gage)



Typical Dynamic High-Temperature Tensile Test

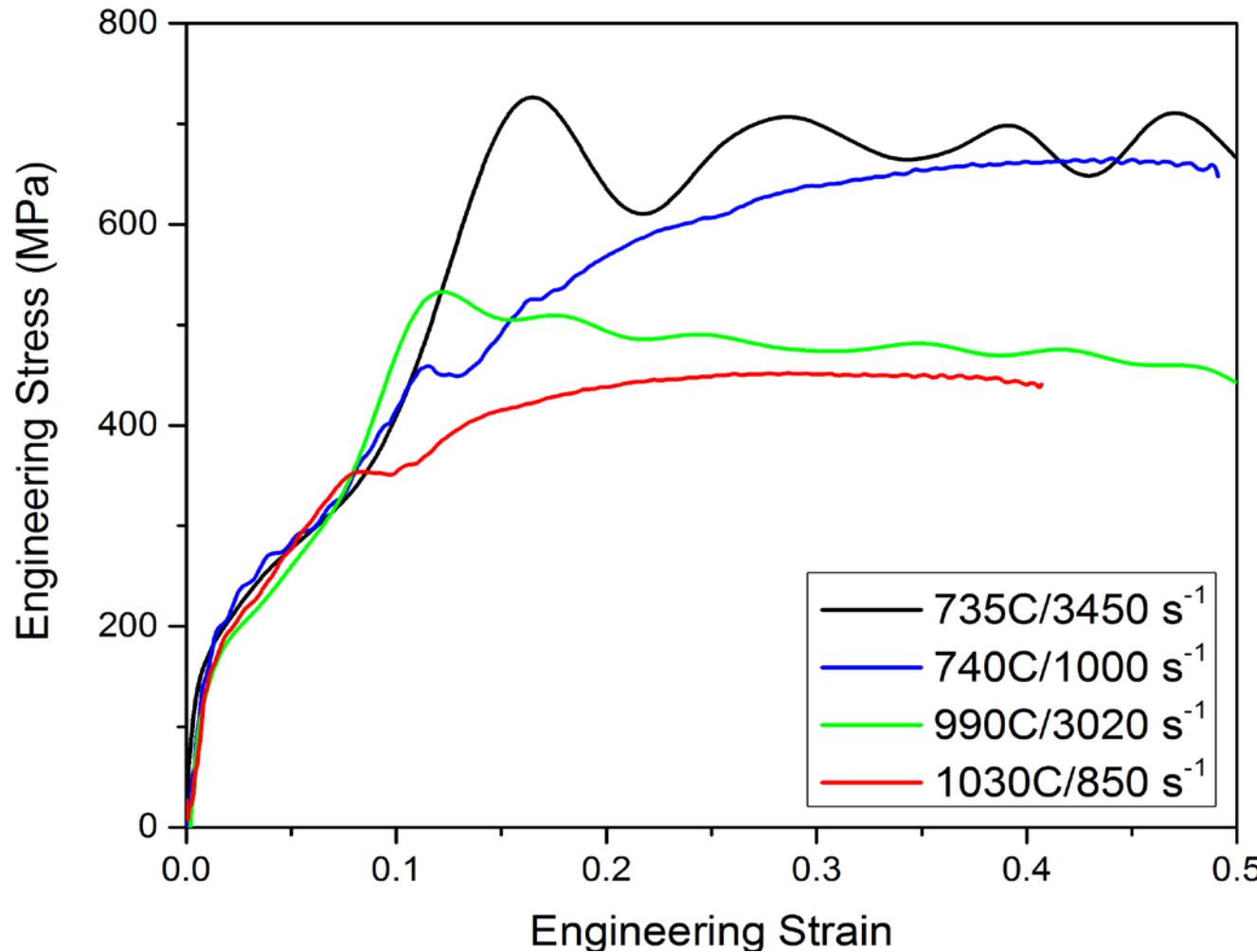


Specimen During and After Dynamic High-Temperature Test

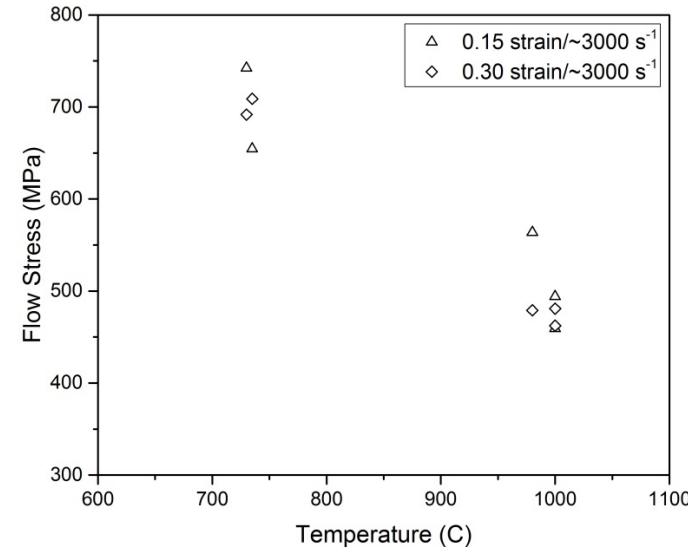
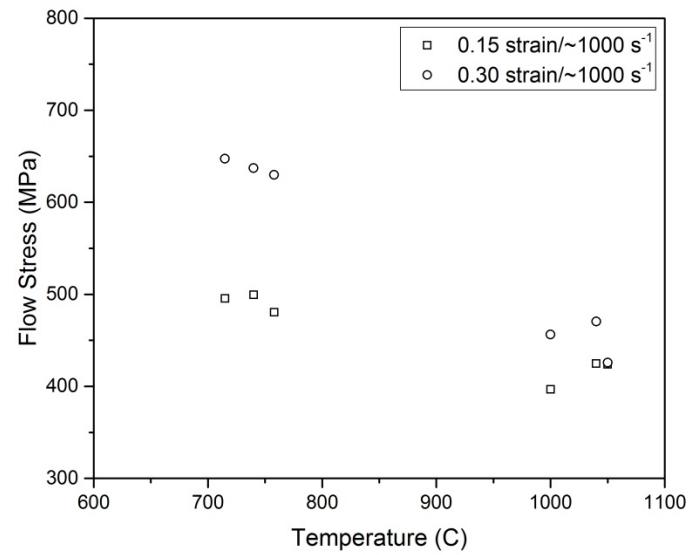
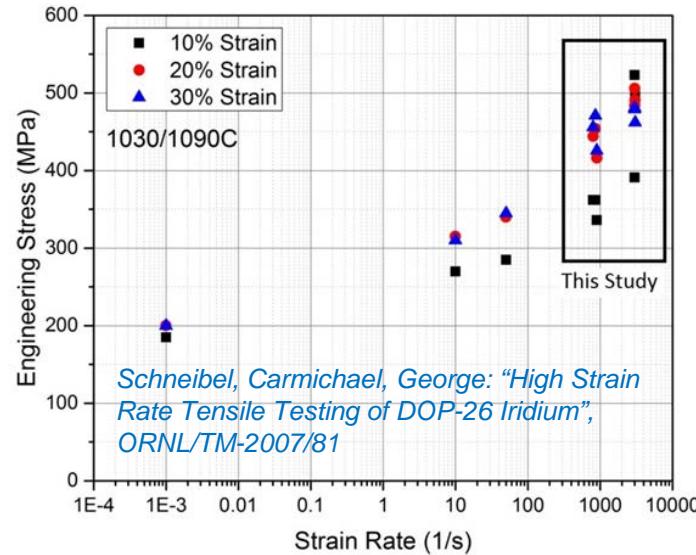
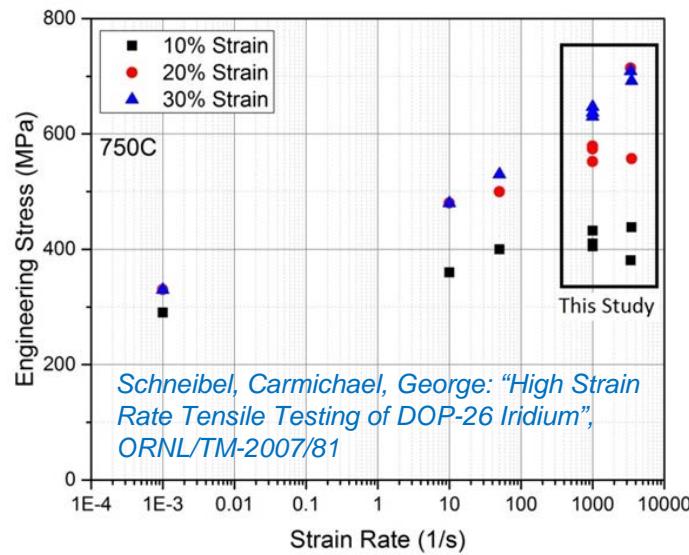


		K3-6-2	
		Initial Measurements	After Measurements
		(in.)	(mm)
0.03590	0.9119		* 1.3406
0.03495	0.8877		Break
0.03495	0.8877		* 1.3467
0.03495	0.8877		1.3606
0.03485	0.8852		1.2579
0.03505	0.8903		
** One or both indentations were difficult to detect. Measurement value is suspect			
Average			
0.03511	0.89175		
		3.5725	5.3058
			0.485

Engineering Tensile Stress-Strain Curves at Different Strain Rates and Temperatures



Strain-Rate and Temperature Effects



Summary and Acknowledgement

- Kolsky tension bar (split Hopkinson tension bar) techniques have been properly modified to characterize Iridium in tension at high temperatures
- DOP-26 iridium alloy has been dynamically characterized in tension at different strain rates and temperatures
- The DOP-26 iridium has shown significant strain rate and temperature effects
 - *Flow stress increases with increasing strain rate but decreases with increasing temperature*
- *This work was sponsored by U.S. DOE Office of Space and Defense Power Systems (NE-75).*
 - **Ryan Bechtel, U.S. Department of Energy**