Radiation Damage Assessment & Back-up Option, N.Simos

Carbon-based materials (either graphite of different grades or carbon-carbon composites) have been used in a variety of applications especially reactors and accelerators. Neutron-induced irradiation effects on these materials have been accumulated and provide a basis of expectation for the applicability of these materials to different environments, such as accelerator targets and collimating materials. The need, however, for materials that can withstand high intensity proton bunches has led the accelerator community to look closer into the special properties of the carbon-carbon composites. Recent experimental studies at BNL have confirmed that carbon-carbon composites are superior to graphite in the way they respond to shock induced by energetic proton bunches. Figure 1 demonstrates the ability of CC-composite to minimize the mechanical shock as compared to graphite. The experimental data of Figure 1 resulted from a 24 GeV proton pulse of intensity $4x10^{12}$ protons impinging on 1-cm diameter graphite and CC-composite rod targets. Therefore, and as initial assessment, the choice of material for the LHC collimators is on the right track given that the LHC collimators are expected to experience the effect of misguided pulses that will, in turn, induce shock stresses. The chances for the CC-composite surviving a misguided beam are much higher than those of graphite due to the fact that CC-composite exhibits higher strength combined with much lower thermal expansion coefficient. This is true, provided that the material does not experience extensive degradation of its key properties due to irradiation from intercepted protons.

This is an open question for the LHC collimators regarding the longevity of the baseline material and its ability to maintain the properties for which it was chosen. Irradiation studies at BNL on materials such as INVAR, which exhibits thermal expansion properties similarly attractive as those of the CC-composites, showed that there is significant degradation of that key property with small levels of irradiation. Figure 2 shows the dramatic effect that irradiation may have on such material. The primary reason why this is pointed out is that special alloys or composites may be more susceptible to irradiation that pure counterparts. This basically stems from the way these alloys or composites are made.

These uncertainties associated with the material choice (CC-composite and/or graphite) are in the process of being addressed through an extensive irradiation study that is under way at BNL. Specifically, an array of “smart” composites and other materials have been irradiated at the BNL accelerator facility in March of 2004. These include carbon-carbon composite (3-dimensional weaved structure that is slightly different than the LHC 2-D choice), graphite (IG-43 grade from Japan), AlBeMet (a special Beryllium/Aluminium alloy that combines properties of both materials, see Table 1), and titanium alloy known as “gum metal” that combines high strength with low thermal expansion.

The above materials, amongst others, will be post-irradiation tested in the Fall of 2004 for mechanical and physical property changes due to proton irradiation. The tests will assess changes in the material strength, thermal expansion coefficient and conductivity. The irradiation-induced changes in the CC-composite and the graphite will be of special interest both to BNL and subsequently to the LHC in that it will provide a direct comparison of the two materials. While more is known about irradiation of graphite [APT Materials Handbook, TPO-P00-MDD-X-

00001, LANL, 20001], different grades may exhibit different response. Thus, information relevant to the LHC regarding graphite as a back-up option will become available as a result of the BNL study. The other two materials (AlBeMet and “gum metal”) may have some applicability to the LHC collimators either as baseline material for collimators (AlBeMet) in the event that both CC-composite and graphite are eliminated (highly unlikely) or as back-bone collimator structure (“gum metal”) to eliminate potential structural distortions induced by the thermal loads and help maintain the high tolerances of the jaws.

Therefore, as a way forward that allows for a back-up option to be considered can be envisioned as follows:

- Maintain the CC-composite as the material of choice for the LHC collimators until upcoming experimental results (BNL studies) indicate that there might be issues associated with such choice

- Consider Graphite as the best possible alternative and perform system studies for collimation efficiency, accident scenarios, activation, etc., using graphite as the baseline (the whole exercise may have already been done!)

- Maintain contact with BNL regarding the upcoming post-irradiation assessment of these two key candidates

- Re-examine the ability to maintain collimator tolerances in the event the experimental studies indicate significant effects on the thermal expansion and look into alternative materials to support the collimator jaws.

- Re-examine the ability of the compression springs to withstand radiation and hold onto the design compression load. Loss of compression due to spring hardening will have a profound effect on the overall heat removal process and may change the system performance dramatically

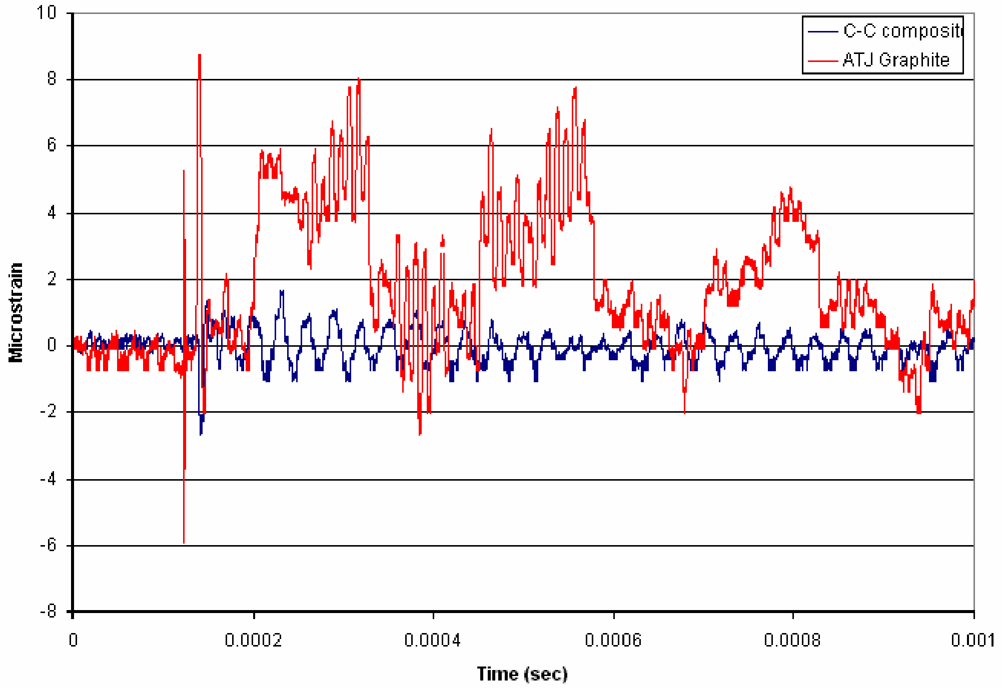


Figure 1: Graphite (ATJ) and Carbon-Carbon Composite Response to 24 GeV Protons (BNL Experiment E951)

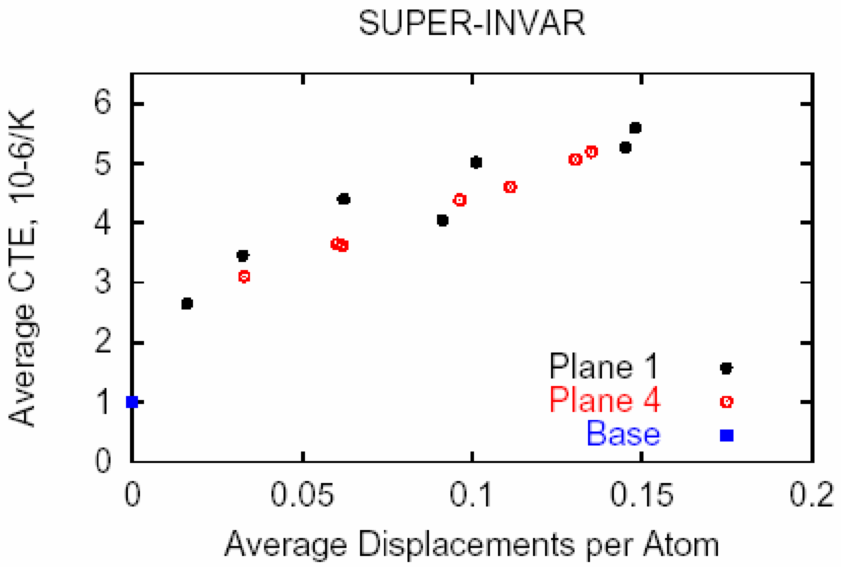
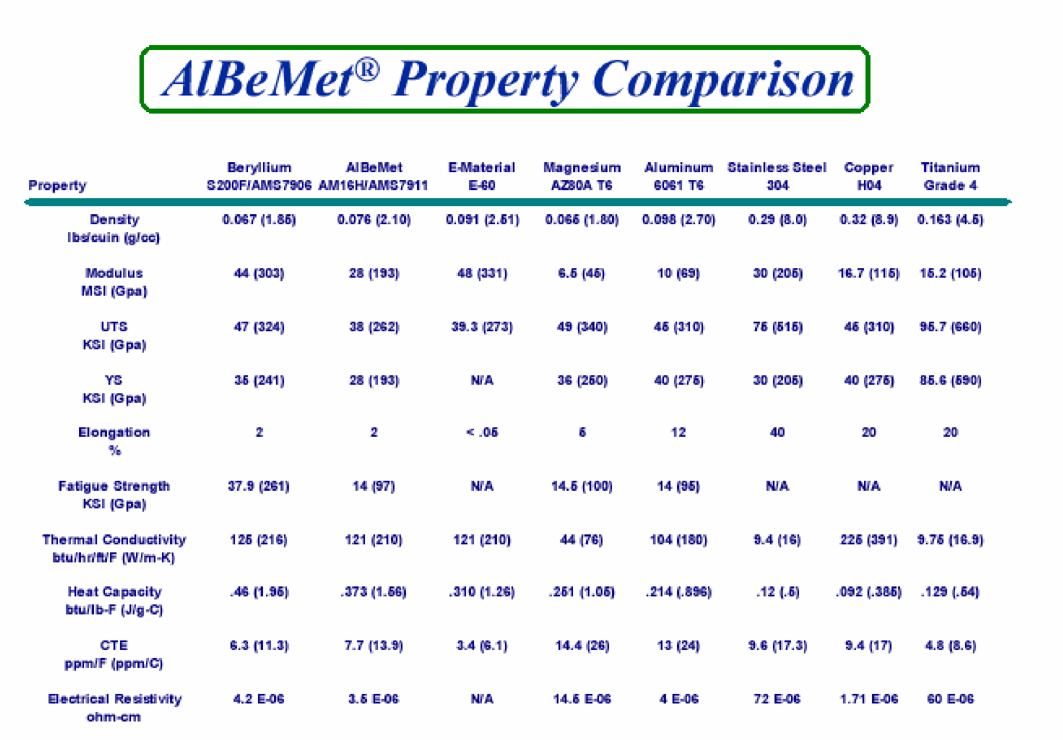


Figure 2: Irradiation effects on Thermal Expansion Coefficient (CTE) of Super-Invar (BNL Experiment E951-Irradiation Phase I)

Table 1: Comparative Properties of the AlBeMet composite/alloy cuurently under study for irradiation effects



AlBeMet® Property Comparison

Property	Beryllium S200F/AMS7906	AlBeMet AM16H/AMS7911	E-Material E-60	Magnesium AZ80A T6	Aluminum 6061 T6	Stainless Steel 304	Copper H04	Titanium Grade 4
Density lbs/cuin (g/cc)	0.067 (1.85)	0.076 (2.10)	0.091 (2.51)	0.066 (1.80)	0.098 (2.70)	0.29 (8.0)	0.32 (8.9)	0.163 (4.5)
Modulus MSI (Gpa)	44 (303)	28 (193)	48 (331)	6.5 (45)	10 (69)	30 (205)	16.7 (115)	15.2 (105)
UTS KSI (Gpa)	47 (324)	38 (262)	39.3 (273)	49 (340)	45 (310)	75 (515)	45 (310)	95.7 (660)
YS KSI (Gpa)	35 (241)	28 (193)	N/A	36 (250)	40 (275)	30 (205)	40 (275)	85.6 (590)
Elongation %	2	2	< .05	6	12	40	20	20
Fatigue Strength KSI (Gpa)	37.9 (261)	14 (97)	N/A	14.5 (100)	14 (95)	N/A	N/A	N/A
Thermal Conductivity btu/hr/ft/F (W/m-K)	125 (216)	121 (210)	121 (210)	44 (76)	104 (180)	9.4 (16)	226 (391)	9.75 (16.9)
Heat Capacity btu/lb-F (J/g-C)	.46 (1.95)	.373 (1.56)	.310 (1.26)	.251 (1.05)	.214 (.896)	.12 (.5)	.092 (.385)	.129 (.54)
CTE ppm/F (ppm/C)	6.3 (11.3)	7.7 (13.9)	3.4 (6.1)	14.4 (26)	13 (24)	9.6 (17.3)	9.4 (17)	4.8 (8.6)
Electrical Resistivity ohm-cm	4.2 E-06	3.5 E-06	N/A	14.5 E-06	4 E-06	72 E-06	1.71 E-06	60 E-06