Talon Composites, LLC

A Delaware Limited Liability Company

Use of Talbor®, a Metal Matrix composite, as a Neutron Shielding Material.

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The following is a list of topics of interest related to engineering neutron shielding attributes pertinent to Talbor composites.

Introduction

Talbor is a patented metal matrix composite (MMC) composed of an Aluminum base alloy and Boron Carbide ceramic reinforcement. The Talbor material is a desirable material for use as a Neutron absorber in dry and wet environments, including BWR's and PWR's. Talbor composites are fabricated using powder metallurgy (P/M) techniques and are available in wrought and plate compositions as extrusion billets/forging stock and casting ingots. The amount of ceramic (B4C) reinforcement in Talbor composites can very between 1-40 vol.% for P/M products. The volume % of reinforcement is custom tailored to the B-10 Areal density needed. Talbor composites have been fabricated using 6XXX, 7XXX, 2XXX, 11XX and 5XXX series aluminum base alloys. The advantages of Talbor composites compared to standard absorption higher specific strength, better fatigue resistance, improved wear characteristics and lower density. Talbor composites materials can be extruded, forged, rolled, stamped, machined or cast similar to that of aluminum alloys. Process parameters for all the above mentioned forming methods have been predefined through research and trial-and-error to facilitate end-user ease of processing.

Designation

Talbor composites are identified by a combination of a letter(s) and a number. The letter(s) refers to the base alloy composition while the number designates the vol.% of ceramic reinforcement. An identification key can be found in the table below:

Material Designations for Talbor™ Boron Carbide Composites

Aluminum Alloy	Talbor Designation
1100	N
5XXX	C
6092	H
7093	E

Example: Talbor H-21 is 6092 + 21w% Boron Carbide particulate

Talbor Nuclear Grade Materials:

The Talbor is based on 1100 & 6092 series aluminum reinforced with various amounts of B_4C. This material is specifically designed to satisfy the needs of the nuclear shielding industry. This product exhibits very good ductility even at high vol.% of reinforcement. This product is currently fabricated using P/M methods; however, more cost effective fabrication means such as melt stirring are currently being developed. The Talbor is available with boron carbide content up to 40-vol.%. Since the particle size of the B_4C used in Talbor is significantly smaller (on average) compared to competitor products, and the particle distribution is extremely homogeneous, Talbor has a higher areal density of the B_{10} neutron-absorbing isotope then any other B_4C reinforced competitors product. These attributes allow Talbor to claim 90% safety efficiency compared to 75% safety efficiency for competing products. This means that the required neutron attenuation can be achieved with a thinner and ultimately lighter material than any currently available on the market. The nuclear -series material does not exhibit significant gains from heat treatment. This composite material is also **Weldable** using conventional techniques. The Talbor nuclear series composites are available in a variety of shapes and sizes including 3”-14” diameter extrusion billets, up 10” wide rolling planks, rolled sheet, forging blanks and a variety of extruded cross-sections plus tubing up to 3” in diameter. Special shapes and sizes are available upon request.

Engineering Parameters

Density

Talbor composites exhibit a lower density than comparable aluminum alloys when B_4C is used as the reinforcement. The weight savings associated with the lower density can be substantial. At 15 vol.% B_4C the composite material is ~1% lighter than a 6XXX series aluminum alloy. In addition, since the strength and stiffness are increased compared to base aluminum, less material needs to be used to provide equivalent strength. This combination of lower density and higher strength can result in potential weight savings of over 40% compared to conventional aluminum. The density of the Talbor composite material is strictly governed by the density of the base alloy and vol.% of ceramic as calculated by the “rule-of-mixtures”. An example calculation is shown below:

To calculate the theoretical density of E20:

Density of E (7093) base alloy: 2.878g/cm^3
Density of B_4C reinforcement: 2.520g/cm^3

80% of the composite is the base alloy and 20% of the composite is ceramic therefore:
Density of composite is equal to: (.80 x 2.878) + (.20 x 2.520) = 2.806 g/cm^3

Summary tables show the density of various Talbor composites.

Density Values for Relevant Materials

	Density	
Material	**g/cm^3**	**lb/in^3**
B_4C	2.52	0.091
SiC	3.21	0.116
Al_2O_3	3.92	0.142
6061 Al	2.71	0.098
Titanium	4.51	0.163
Steel (4030 Cr-Mo)	7.83	0.283
Talbor H20	2.66	0.097
Talbor HS20	2.80	0.102

Mechanical Strength (UTS, Yield, % Elongation)

The strength of the composite material is a function of 3 things: (1) the strength of the base alloy, (2) the strength of the ceramic, and (3) bonding between the matrix and the ceramic. In general, the strength of the composite increases in proportion to the volume fraction of the ceramic up to a certain point above which additional ceramic content reduces the UTS and yield strength of the composite. This cross over point is different for each combination of alloy and ceramic, but generally occurs at 20-vol.% or above. As the amount of ceramic increases in the composite, the ductility of the composite is also reduced. A summary table on page 23 shows the mechanical properties of various Talbor composites. The ductility of Talbor can be improved through heat treatment; however, the increase in ductility is often accompanied by a decrease in strength. In general, the specific strength (strength/density) of Talbor is greater than that of steel or titanium. This makes Talbor products attractive candidates for demanding applications.

Specific Strength

Specific strength represents the ultimate tensile strength divided (or normalized) by the density. The specific strength values for Talbor composites are superior to steel and conventional aluminum alloys and in some case titanium. The high specific strength makes the Talbor composites ideally suited for high strength, weight critical application. The graph below gives a comparison of the specific strength of Talbor compared to conventional materials.

Talbor Mechanical Properties:

Talbor® Wrought Materials Minimum Test Data

(English Units)

Material	Reinforcement and v%	Density Lb/Cu In)	Tensile Modulus (Msi)	Yield Strength (ksi)	Ultimate Strength (ksi)	Strain at Failure (%)	Thermal Expansion (ppm/°F)	Thermal Conduct. (BTU/Ft °F)
6092 T-6	——	0.098	9.9	50	60	8.5	13.1	100
6092	B4C / 5%	0.0973	11.3	52	60	8.00	12.5	100
T-6P	B4C / 10%	0.0971	12.2	54	62	5.00	11.7	96
	B4C / 15%	0.0968	13.4	56	64	4.00	10.6	90
B4C Series	B4C / 20%	0.0966	14.7	58	66	3.00	9.7	87
Nuclear	B4C / 25%	0.0963	16.1	60	68	2.00	9.0	84
	B4C / 30%	0.0961	17.5	62	70	1.00	8.3	78
	B4C / 35%	0.0958	19.1	65	72	0.75	7.9	72
6092	SiC / 5%	0.0986	11.1	54	62	8.00	12.5	104
T-6P	SiC / 10%	0.0995	12.2	56	64	6.00	11.7	106
	SiC / 15%	0.1005	13.3	58	66	5.00	10.6	107
SiC Series	SiC / 20%	0.1015	14.6	60	68	4.50	9.7	108
	SiC / 25%	0.1025	15.9	63	71	3.00	9.0	108
	SiC / 30%	0.1034	17.4	65	73	1.50	8.3	109
	SiC / 35%	0.1044	18.9	67	76	1.00	7.9	109
	SiC / 40%	0.1054	20.6	68	78	0.80	7.6	110

Talbor® Wrought Materials Minimum Test Data

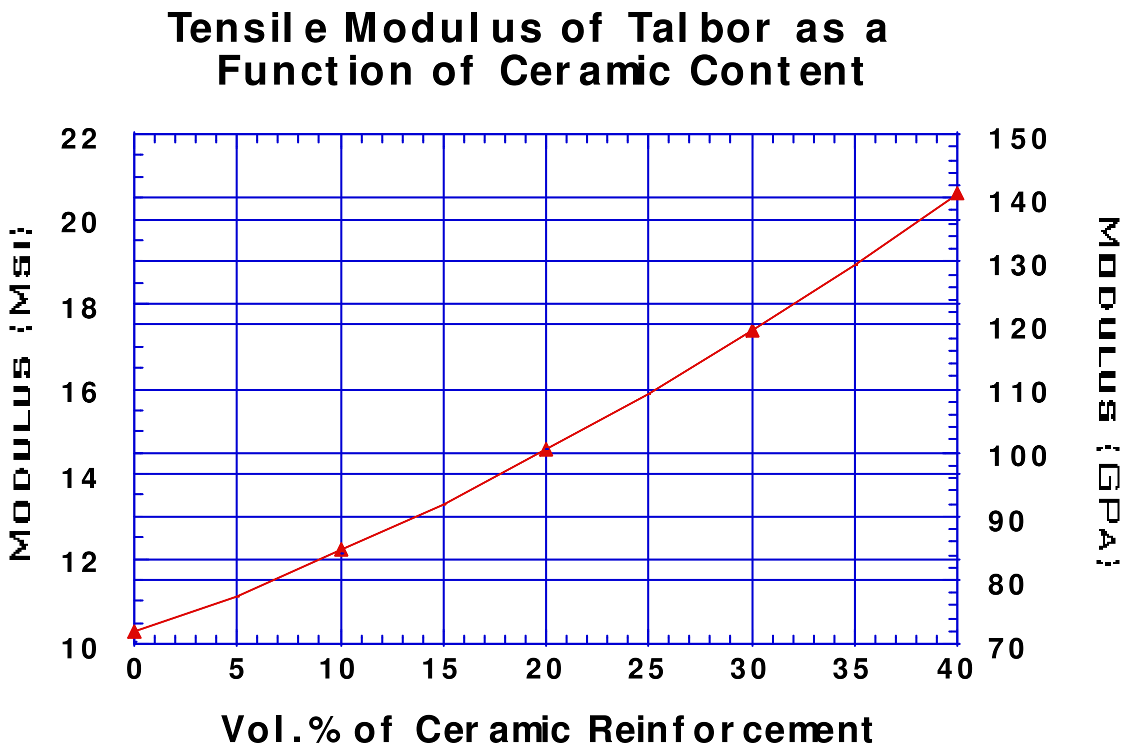
(SI Units)

Material	Reinforcement and v%	Density (g/cc)	Tensile Modulus (GPa)	Yield Strength (MPa)	Ultimate Strength (MPa)	Strain at Failure (%)	Thermal Expansion (ppm/°C)	Thermal Conduct. W/M°K)
6092 T-6	——	2.70	68.3	344.8	413.7	8	23.6	173
6092	B4C / 5%	2.681	77.9	358.5	413.7	8.00	22.5	173
T-6P	B4C / 10%	2.675	84.1	372.3	427.5	5.00	21.1	166
	B4C / 15%	2.667	92.4	386.1	441.3	4.00	19.1	156
B4C Series	B4C / 20%	2.661	101.4	399.9	455.1	3.00	17.5	151
Nuclear	B4C / 25%	2.653	111.0	413.7	468.9	2.00	16.2	145
	B4C / 30%	2.648	120.7	427.5	482.7	1.00	14.9	135
	B4C / 35%	2.639	131.7	448.2	496.4	0.75	14.2	125

6092	SiC / 5%	2.717	76.5	372.3	427.5	8.00	22.5	180
T-6P	SiC / 10%	2.741	84.1	386.1	441.3	6.00	21.1	183
	SiC / 15%	2.769	91.7	399.9	455.1	5.00	19.1	185
	SiC / 20%	2.796	100.7	413.7	468.9	4.50	17.5	187
SiC Series	SiC / 25%	2.824	109.6	434.4	489.5	3.00	16.2	187
	SiC / 30%	2.849	120.0	448.2	503.3	1.50	14.9	189
	SiC / 35%	2.876	130.3	462.0	524.0	1.00	14.2	189
	SiC / 40%	2.904	142.0	468.9	537.8	0.80	13.7	190

Modulus

The modulus of Talbor composites is an indication of the stiffness of the material or its resistance to strain. The stiffness is an intrinsic material property that does not change with temper. The modulus of the Talbor composite material is directly proportional to the vol.% of ceramic. At ~40 vol.% ceramic reinforcement, the modulus of Talbor can exceed 20 Msi. In perspective, this can translate into a significant advantage over titanium or steel, especially in light of the significantly lower density. The high modulus of Talbor composites is probably one of its most attractive attributes. No other class of engineering materials can yield the combination of high strength, high stiffness and low density.

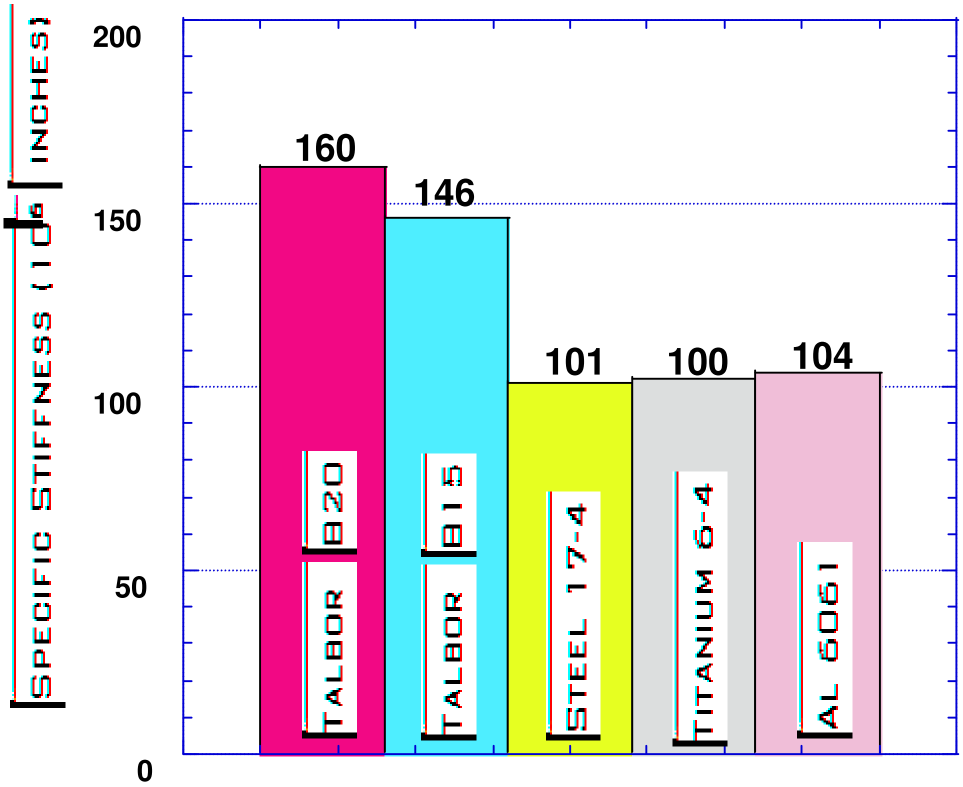


Note: To convert GPa to Pa multiply by 10^9.

Specific Stiffness

Specific stiffness represents stiffness per unit weight or material stiffness normalized by dividing the modulus by the density. The impressive value of the specific stiffness of the Talbor composites is one of the biggest advantages of the Talbor products. The value for a 15 vol.% Talbor can be ~40% higher than steel, titanium or conventional aluminum. In applications where stiffness is critical and weight is a major consideration, Talbor composites are the only choice. Pound for pound, Talbor composites are the stiffest commercially available isotropic engineering composite materials. Robotic arms are an example of a typical successful application of Talbor composites, which require high stiffness and lightweight. A comparison of several materials to Talbor is shown below with regard to specific stiffness.

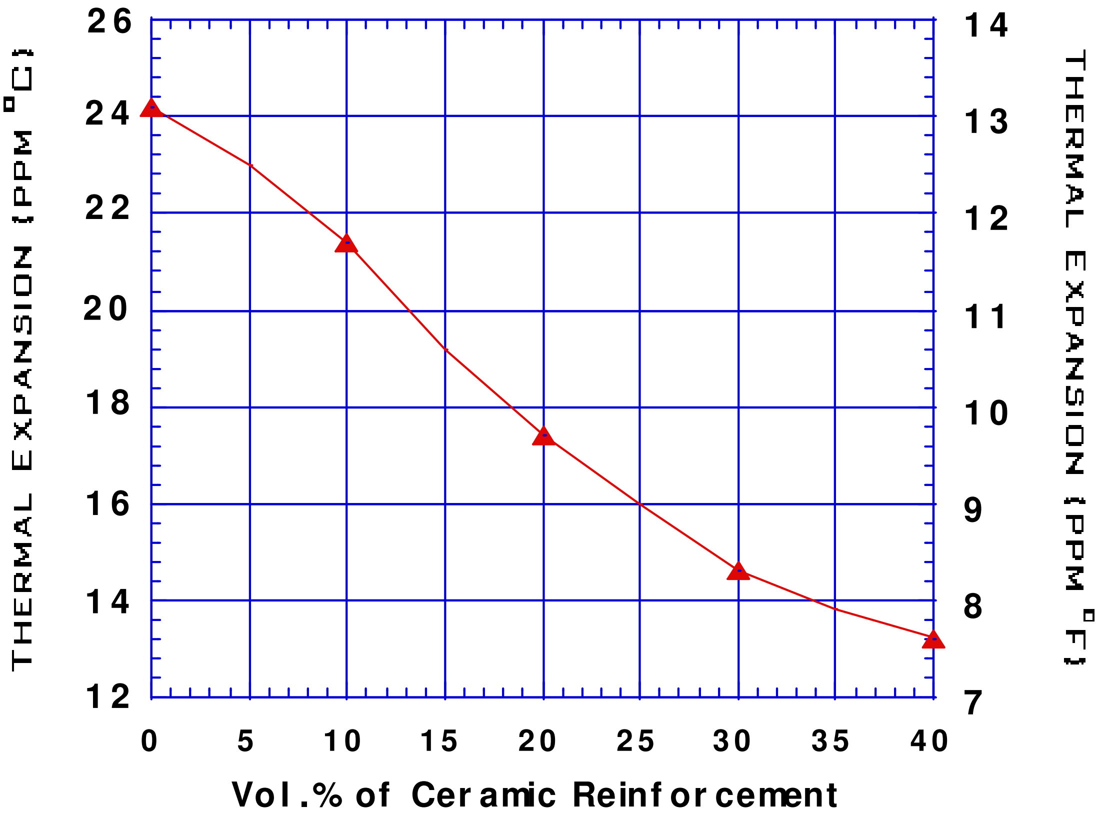
Specific Stiffness of Talbor Composites
Compared to Competing Materials



Thermal Expansion

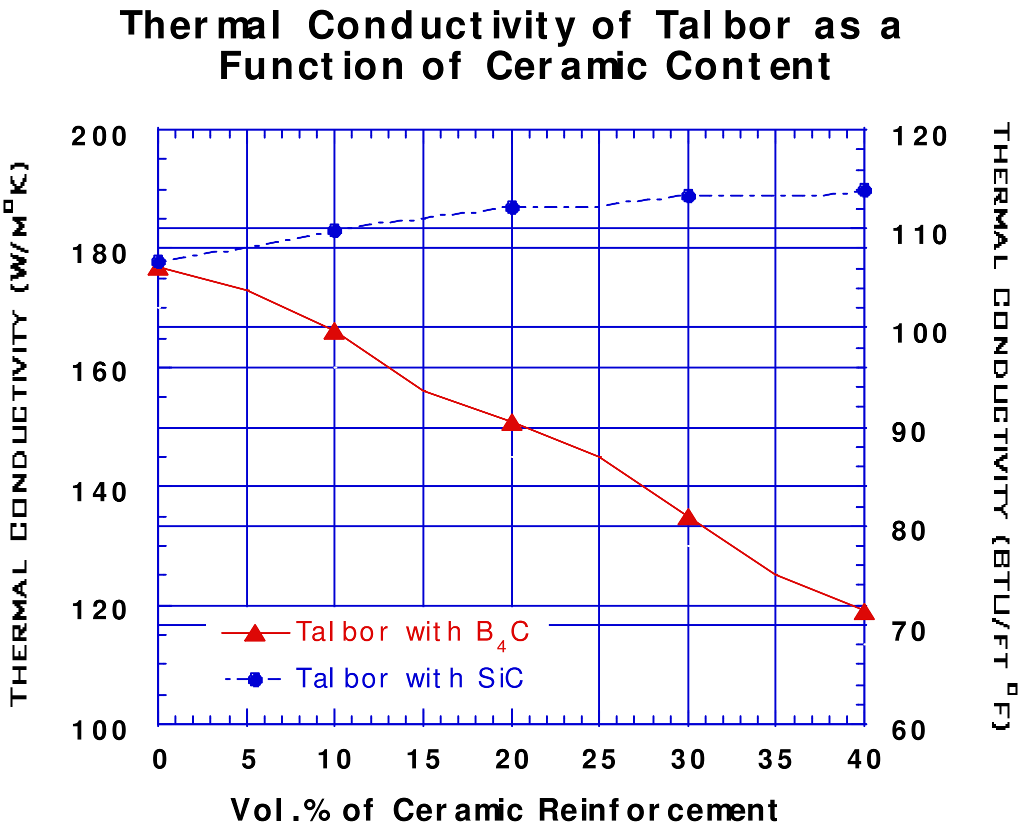
Talbor composites can be tailored to meet any desired thermal expansion coefficient between 7.5-12.5 ppm/˚F. The amount or type of reinforcement can be varied between 0-40 vol.%, respectively, to achieve the desired thermal expansion. The thermal expansion behavior of Talbor composites can be predicted by applying the rule of mixtures. This attribute makes Talbor composites ideally suited for Nuclear Shielding applications.

Thermal Expansion of Talbor as a Function of Ceramic Content



Thermal Conductivity

The thermal conductivity of Talbor composites is proportional to the amount of ceramic used. The rule of mixtures can be used to predict the thermal conductivity of resultant composites.



Hardness

The hardness of Talbor composites increases with various heat treatments similar to typical heat-treated aluminum alloys. In addition, the ceramic content also moderately increases the hardness in proportion to the vol.% of reinforcement. The higher the vol.% of reinforcement, the higher the hardness compared to the base alloy.

Notes on conversion tables:

There are many conversion tables available in various reference books however one should keep in mind that Each type of hardness test measures material resistance to deformation in slightly different ways, so any conversions between different hardness scales are therefore only approximate. Such conversions are useful, though, and should be used for reference purposes. To convert to an equivalent tensile strength is more difficult especially when dealing with aluminum alloys. The units of tensile strength are in terms of pull against a cross-sectional area, whereas BHN and other hardness scales measure pressure against a cross-sectional area, and these are actually two different attributes of the material. Atypical variance of ± 1-2% can be expected for harness measurements of the same material using different scales

Wear

The wear behavior of Talbor is superior to conventional aluminum alloys or titanium and equivalent or better than steel alloys. The wear characteristics are directly proportional to the ceramic vol.% in the composite. The higher the vol.% of ceramic the better the wear resistance of the composite The higher the ceramic content the lower the coefficient of friction. The ceramic particulates act in a way to lubricate the wear surface and minimize wear and reduce friction. Furthermore, it should be noted that wear of the Talbor or mating surface in the lubricated condition is very low. Wear test data is presented below for Talbor as well as some reference materials.

Wear Test Data (lubricated pin on ring test, ASTM G-77)

	Coefficient of Friction		Vol. Loss from Block (10^{-6} in^3)
Material	**Start**	**Finish**	
Talbor □B25*	0.101	0.123	3.80
Talbor □B20*	0.101	N/A	3.85
Steel with SPF-251*	0.141	0.129	8.00
A357 Squeeze Cast[§]	--	--	28.16

* Contact load of 120 pounds

§ Contact load of 30 pounds

Heat Treatment

Talbor composites, which utilize heat treatable base alloys, can be heat-treated to a variety of tempers including T3, T4, T5, T6, T7, T8 and a host of others. Specific heat treat parameters have been developed for the Talbor composites which differ from the typical heat-treat parameters for the base alloy. The ceramic content accelerates the aging kinetics thereby reducing the aging time required to reach temper. In addition, the solution soak times are often modified to accommodate the heat absorption behavior of the composite with is entirely dependent of the ceramic type and the vol.%. Also, it should be noted that water rather than a glycol solution should be used for the quench media for certain Talbor composite products and the quench delay time should be less than ~15 seconds for most situations. Specially developed T5 and T4 heat treatments have been developed for cast Talbor composites, which result in mechanical properties close to T6 without the added steps. Talbor composites can also be press quenched following extrusion to provide excellent mechanical strength at a greatly reduced cost compared to subsequent solution and aging treatments. TALON has several strategic partners with aerospace quality heat treatment facilities that are experienced with composite processing. Any specific heat treatment issues can be addressed directly with TALON

Chemistry Verification

The composite material chemistry cannot be quantified using equipment or methods designed for standard aluminum. Optical emission spectroscopy (OES) methods are not suitable for quantifying the chemistry of the Talbor composites. The ceramic content of the composite interferes with the algorithm used by the equipment to calculate the relative percentage of the various alloying constituents. Corrections can and must be made to the spark results to obtain reasonable semi-quantitative data. The P/M products do not lend themselves to OES methods at all due to the oxide films, which surround each of the individual powder aluminum particulate. OES results of P/M Talbor have shown to have very large errors and are entirely not reproducible. Inductively coupled plasma (ICP) of mass spectroscopy or atomic absorption (AA) wet chemistry methods must be used to obtain reliable and quantitative chemistry data.

Secondary Surface Treatment

Talbor can be plated or coated with materials normally used for aluminum coatings. Ni plating and anodizing has been successfully applied to Talbor composites. Typically, the surface of Talbor is prepped by chemical passivation or mechanical bead blasting to expose slightly the ceramic particles which provide an increase surface area to the coating to adhere to. Talbor composites can be polished to a mirror finish using mechanical and/or chemical means. Thermal spray coatings have also been successfully applied to Talbor composites. Nitride and carbide coating can also be applied to Talbor composites for specific applications.

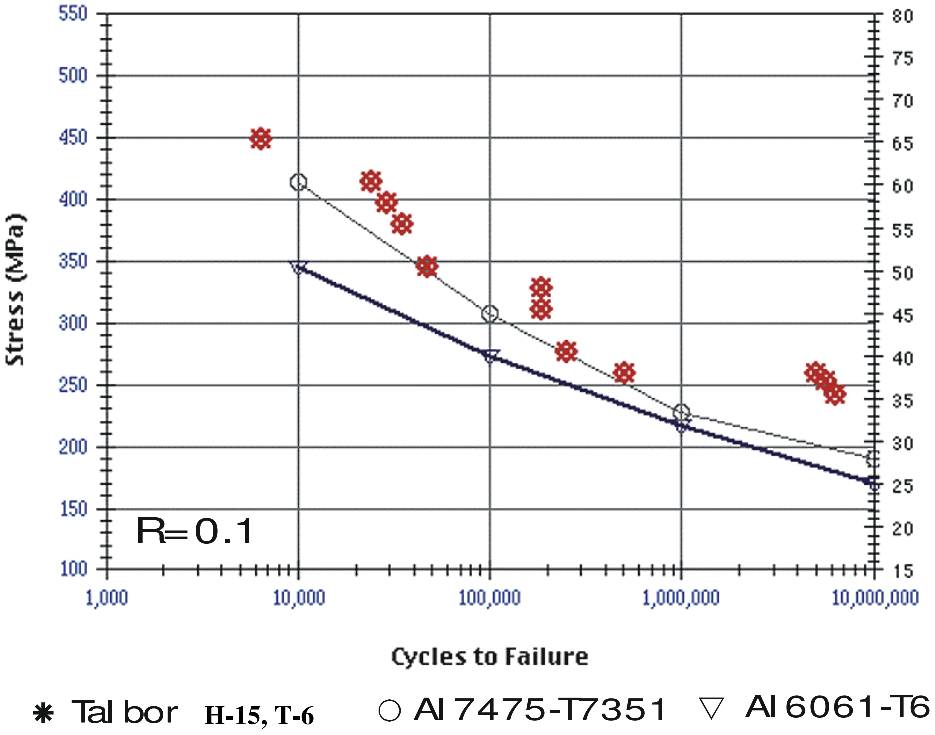
Elevated Temperature Properties

Talbor composites have improved elevated temperature performance compared to conventional aluminum alloys because the high strength of the ceramic content contributes to the overall improvement in strength at elevated temperature. This attribute can be further accentuated by combining the ceramic with a base aluminum alloy that has good elevated temperature properties. The Talbor materials are best suited for maximum performance in elevated temperature applications. Talbor composite materials are unique in their ability to offer lightweight, excellent wear resistance and improved stiffness at elevated temperatures.

Fatigue

It is well documented in the technical literature that aluminum based MMCs have improved fatigue behavior compared to conventional aluminum alloys. The fatigue performance improves with added vol.% of reinforcement up to ~20 vol.% above which the fatigue performance begins to decrease. Fatigue performance appears to be the most improved over conventional aluminum alloys in the cast Talbor products. This is a direct result of the excellent bonding between the ceramic and molten alloys. The fatigue crack growth rate of Talbor composites is lower at low stresses than that of aluminum alloy. At high stresses the fatigue crack growth rate of Talbor and un-reinforced aluminum alloys is similar. The fatigue performance of Talbor can be tailored to meet specific design requirement by a combination of ceramic content and heat treatment.

Comparison of Fatigue Behavior of Talbor
to conventional Aluminum Alloys



Impact Toughness/Fracture toughness

When ceramic particulates are mixed with a material such as Aluminum, which has moderate fracture toughness, the resultant composite has a fracture toughness resistance that is less than the base Aluminum alloy. The higher the vol. of ceramic, the lower the impact toughness/fracture toughness of the material.

Welding Study

The main characteristics of Aluminum composites that influence welding are hydrogen solubility, Aluminum oxides, thermal conductivity, thermal expansion, and solidification shrinkage. Weld porosity in Aluminum based metal matrix composites is caused principally by bubbles of hydrogen that form in the solidifying weld pool or outgasing caused by the ceramic reinforcement. The hydrogen solubility of Aluminum composites increases almost twenty times as the material makes the transition from solid to liquid state and continues to increase as the temperature increases. Hydrogen absorbed during its molten state is forced out of solution as the Aluminum composite cools and changes to its solid state. The hydrogen is trapped in bubbles and cannot effectively be removed from the weld. As the hydrogen comes out of solution, it can be a source of porosity or voids that can connect to form leak paths in a vacuum environment. The molten-solid hydrogen solubility ratio for Aluminum composites is 36 times higher than for iron. This makes Aluminum welds much more sensitive to this source of porosity than those of stainless steel do. Hydrogen contamination usually comes from moisture or oil (hydrocarbons) on the surface being welded or moisture or oil trapped on the surface of the ceramic reinforcement particles. The parts to be welded must be cleaned well in a detergent bath and dried before welding. H-series B_4C reinforced Talbor composites can be welded using any of the welding techniques associated with Aluminum Friction stir welding has been shown to be a viable way to join reinforced composites but it does have some limitations with regard to the configurations that can currently be welded using this methodology. Conventional methods of welding such as TIG, MIG, laser, electron beam can all be successfully used on B_4C reinforced composites. The ceramic particle (boron carbide) in Talbor Composites improves the materials' mechanical properties, but they can also lead to changes in the arc welding process. Fortunately, the problems can be minimized with some simple precautions and modifications to the standard arc welding practices for aluminum.

Equipment Required

Standard aluminum welding equipment can be used without modification. Filler wire of ER4043 or ER5356 have been successfully used. GTAW, gas tungsten arc welding, is preferred for thin sections, less than 1/8 inch (3 mm) and GMAW, gas metal arc welding, is preferred for thicker sections.

Joint Preparation

Due to the presence of the ceramic particles in the composite, conventional tungsten carbide tools can be used for joint preparation but will wear down at an increased rate. As with aluminum welding, joints must be clean prior to welding. Solvent degreasing and vigorous scrubbing with a clean stainless steel brush are important for obtaining clean welds.

The following procedure is typical of the GTA welding practice for welding bicycle frames.

Power Supply	Miller Sycronous 250
Machine Setting	150 A
Metered Current	Varies with joint geometry
Arc Cleaning	70/30 for maximum penetration
High Frequency	Continuous
Electrode	3/32-in. W-2% Thoria
Filler wire	3/32-in or 1/8-in. ER5356
Gas cup	Weldcraft #5
Shielding gas	100% Ar, 20 cfh

The above parameters are typical for one machine in a specific shop. The welding of Boralyn composites is similar to welding Aluminum with the precautions outlined above.

Forming

Talbor can be processed by a variety of forming methods suitable for Aluminum. However, often-specialized tooling or modified process parameters must be used to achieve good results. Talbor can be rolled, forged, extruded, swaged, drawn, stamped or cast. Special tooling such as ferro-TiC dies or diamond cut off saws are required in order to facilitate some of these forming operations. TALON has invested considerable effort, time and resources, to understand the subtleties associated with many secondary process operations and together with its strategic partners is very proactive in helping its customers optimize the process parameters for forming Talbor composites. This allows a potential customer to be able to procure composite materials and successfully fabricate end products without having to go through a learning curve related to the process parameters.

Extrusion study - verified shapes and sizes

Talbor can be extruded into a variety of shapes and sizes, however the extrusion of metal matrix composites requires the use of specific process parameters, which differ dramatically from conventional Aluminum alloys. Shear or conical dies can be used to extrude Talbor materials. Billets of Talbor can be fabricated in 3.5", 8", 11" and 14" diameters (other sizes available as special orders). The maximum size of the extruded product cross section is ~10". A minimum extrusion ratio for achieving typical mechanical properties is 15:1. The extrusion ratio is defined as the initial surface area of the billet divided by the cross sectional area of the extruded shape. A smaller extrusion ratio can be used for fabricating forging or rolling stock. Hollow shapes such as tubes can be extruded using all Talbor products. Ceramic die inserts are typically used to extrude Talbor composites. Temperature control of the initial billet and container are critical for obtaining consistent quality results. Parameters used for induction heaters typically used to preheat the billets must be modified to compensate for the heat capacity of the ceramic content.

Corrosion Resistance

The corrosion resistance of Talbor is dependent on the base alloy chemistry of the composite. The same rules that apply to Aluminum alloys, with regard to corrosion resistance, apply to Talbor. Controlled experiments have shown that the ceramic particles do not significantly affect the corrosion behavior of the composite. No galvanic couples were observed between the ceramic particles and the Aluminum base alloy. Aluminum base alloys with low copper (Cu) content are best suited for application requiring corrosion resistance. Anodization is used to stabilize and reduce corrosion.

Machining/Cutting

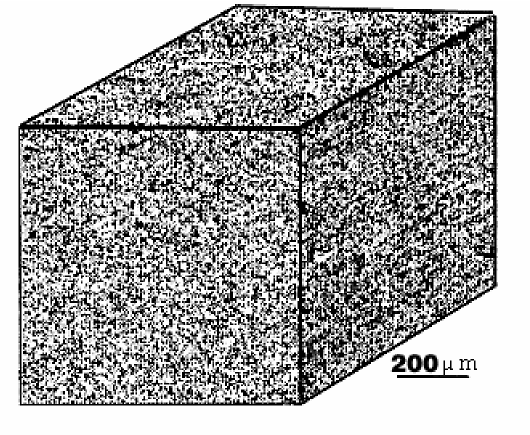
Talbor can be machined using the same equipment as conventional Aluminum alloys with the exception that only PCD diamond tooling should be used when machining Talbor composites. Electrode or wire Electro-discharge machines (EDM) have been shown to be very effective means of machining Talbor composites. A diamond band saw is required for sectioning or cutting Talbor. Talbor can be cut with a conventional saw but it will dull the blade quickly, especially when cutting high vol. (>10 vol.) ceramic composites. Tapping small diameter threads in high vol.% Talbor is difficult. Broaching or crush grinding can also be used to obtain desired shapes or finish from Talbor products. It is recommended that threads be rolled whenever possible. A complete machining guide is available from TALON, which gives specific feed/speed parameters for the various types of Talbor composites. In addition, Talon has developed a specific grade of diamond specifically suited for machining metal matrix composites. This special grade of diamond tooling is commercially available directly from TALON. Talbor can be formed by most traditional methods including machining, however, the presence of boron carbide within the proprietary Talbor matrix does not allow for machining like traditional Aluminum based materials.

For nearly all-machining applications, Talon Composites Corporation recommends the use of poly-crystalline diamond (PCD) tooling. PCD tooling is recommended because boron carbide is the third hardest man-mad material known. PCD tooling is available in most tool types (i.e. drills, end mills, reamers, etc.) but is considerably more expensive, and often times must be custom ordered. While it is possible to use carbide or cobalt tooling, tool life is rapidly degraded (possibly in a matter of minutes depending upon the percent ceramic reinforcement) due the boron carbide particulate. On average, PCD tooling will outlast carbide by 80 times. In addition, PCD tooling can be dressed and re-used. With PCD tooling, Talbor can be machined at rates up to 2,200 surface feet per minute (SFM), at a 0.005” to 0.01” chip load. Mill and lathe work should not exceed a cut depth of 0.07” per pass, with optimum performance at 0.050” depth (width does not affect performance).

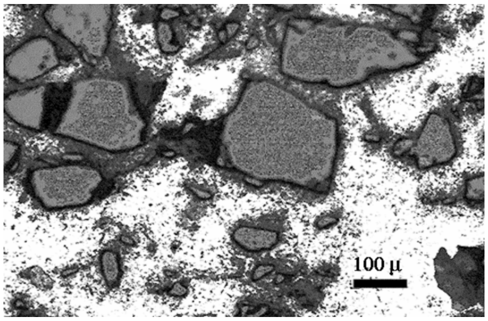
If carbide or cobalt tooling must be used, machining should be done at very slow speeds, and it may be difficult to hold tolerances better than +/- 0.002” per 4” span

Wrought Talbor composites / Microstructure

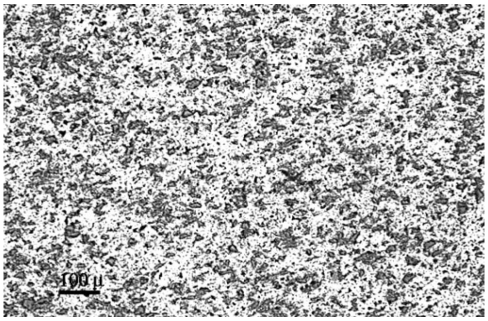
The Talbor wrought materials are produced using P/M methods. Consequently, the distribution of the ceramic particles is extremely homogeneous. The size of the ceramic particles is ~800 grit (~13 μm avg.). This fine ceramic particle size, combined with tailored metallic particle size distribution allows extremely efficient mixing and packing of the powders. The uniform particle distribution (see micrograph below) yields a composite product with isotropic mechanical properties. The ceramic particles in the composite act to pin grain boundaries, preventing grain growth during sintering operations or subsequent solution treatment. The fine, equiaxed grain structure facilitates reasonable ductility for a metal matrix composite product. The interface between any of the ceramic particle (B_4C) and the aluminum matrix does not show any deleterious reactions occurring during the processing of Talbor P/M composites. Talbor products exhibit little or no porosity due to a proprietary sintering process, which ensures that the final composite is 100% dense. This also allows the composites to be heat-treated to T6 temper without blistering. Since the microstructure of Talbor is composed of extremely hard reinforcement particles embedded in a relatively soft matrix, preparing polished cross sections requires the use of specific parameters. Talbor samples prepared using convention metallographic methods suitable for aluminum alloys will not yield satisfactory results. If the sample is not polished correctly, the microstructure may appear filled with porosity, which in actuality is a result of ceramic particle pull out due to incorrect polishing methods. Specific sample preparation instructions are available directly from TALON.



Microstructure of NN15 Talbor composite illustrating homogeneous distribution of the B_4C particles which lead to isotropic mechanical properties in the x, y and z plane. The Boron Carbide particle size averages about 10-12 microns in size.



Boral @ 200 X



Talbor® H-15 @ 200X

The photo's above show the fine grain structure of the Talbor material versus the structure of the Boral material. This fine grain structure is fully dense with allow for thermal stability. In the Boral structure there are gaps and porosity which cause swelling and warping of the plates. The fine grain structure of the Talbor is less likely to have channeling problems associated with Neutron Attenuation. The fine grain structure also promotes better mechanical properties.

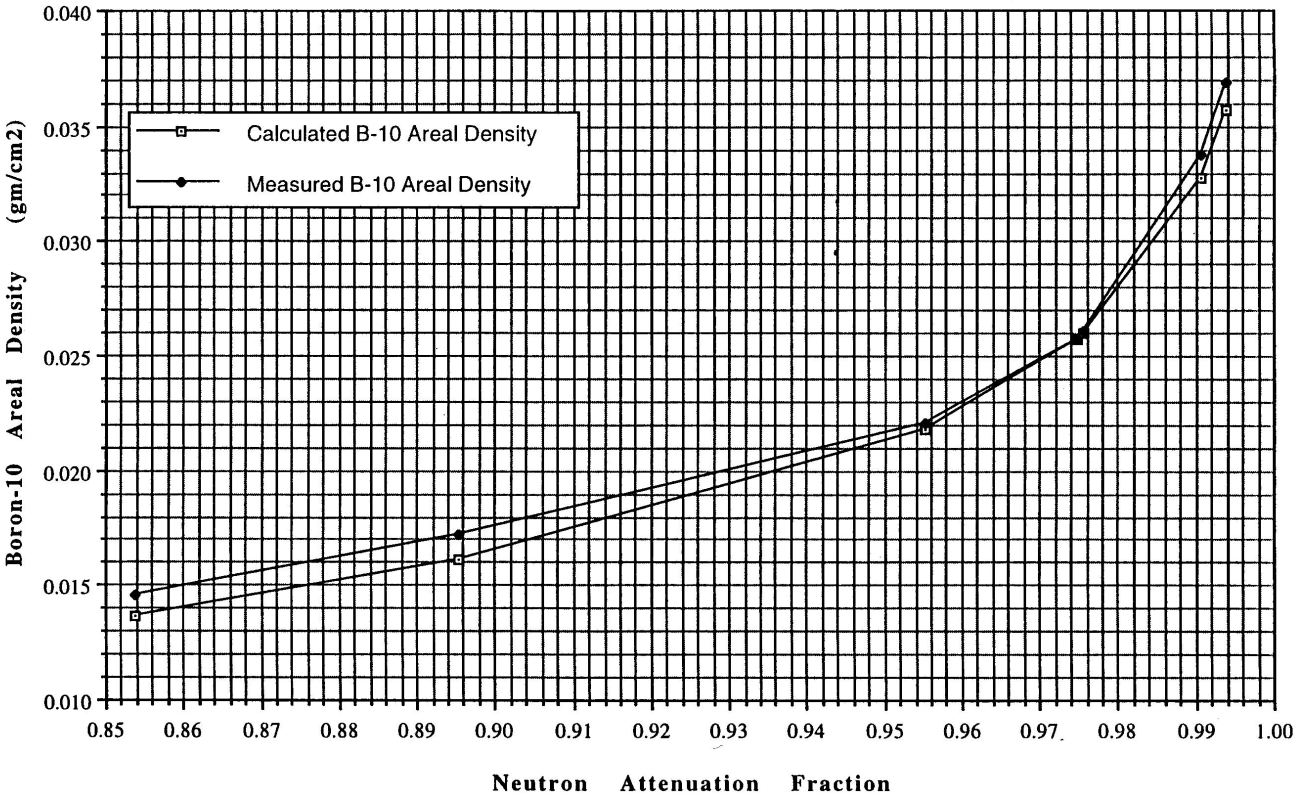
Neutron Attenuation

Neutron attenuation was measured in accordance with Nuclear Reactor Laboratory NRL – 007, revision 4, Neutron attenuation. The neutron spectrometer utilized for the measurements was calibrated using Boral standard, TS362-2-18, with a Boron – 10 loading of 0.0257 gm B10/cm2/

The measured and Calculated Boron –10 Areal Densities were measured and graphed. The plotted results showed very similar measurements.

The Graph Below shows the results from this test.

Measured and Calculated Boron-10 Areal Density Versus Neutron Attenuation



Talbor VHP Ingots – H-15 Material
Document 3980-44
Talon Composites, LLC

Microstructural Observation of Thermally Aged and Irradiated Talbor by Transmission and Scanning Electron Microscope

Thermally aged and irradiated tensile specimens were examined based in order to understand mechanisms of possible failure and to evaluate the current materials for long-term application. TEM observation of irradiation samples per has been completed and reported separately in a Radiation Damage report.

Thermally aged samples: Effect of thermal aging on microstructures was not significant at 700° F since B4C phase did not reveal any reaction with aluminum matrix. The phase transformation to produce new phases in this system appeared to occur between 1,000 – 1,100° F based on both color changes on surface and TEM observation of samples. Only grain growth or re-crystallization of the aluminum matrix was found up to 1,000° F. Thus both yield strength and ultimate strength of thermally aged samples is predicted to be lower than those of the as-received samples. Also total elongation of thermally aged sample would be predicted to increase due to softening of the microstructures. These predictions, based on microstructural analysis, are consistent with the tensile test results reported by Brown and Dunn in TTR-1.

Irradiated Samples: No evidence of neutron irradiation such as voids in Al grains was observed through electron diffraction patterns. The B4C phase was stable and interfaces were not affected by irradiation. No significant changes of grain sizes were noticed.

Fracture Surface: Typical intergranular fracture modes were observed in all samples indicating no significant failure sources present in this Al-B-C system. The interface between Al matrix and B4C grains were very tight and did not provide any cause for failure.

Prediction of lifetime: We can conclude that no microstructural changes are expected for a long time below 1,000° F, since there are no sources for failure present in this material as well as no phase decomposition except grain growth or recrystallization of the Aluminum Metal Matrix. Results of a 27 day aging study at 700° F saw only grain growth or recrystallization in microstructure, indication no effect of long term aging on phase transformation at low temperature.

Thermal and Tensile Samples: Samples were heat treated in a Helium environment at 500° F, 600°F, 700°F, 800°F, 900°F, 1,000°F and 1,200°F for 4 hours followed by water quench. The 700 and 1,200°F samples were prepared for the Transmission Electron Microscope (TEM). Tensile specimens were examined by SEM after tensile testing.

Observation of fracture surface: The fracture surface from one of the tensile specimens was cut by a diamond saw without contamination and observed by scanning electron microscope. The plan-view specimens for the TEM study were prepared by cutting the composites into sections from the area of interest. No apparent surface damages or surface oxidation after aging were observed since these samples were in He gas environment during thermal aging. Various magnifications were used to locate the source of fracture and examine detailed fracture patterns. In summary, there were no significant differences among the samples with respect to ductility, fracture behavior and presence of B4C or Fe-Al particles even though fine features were distinguished. The elongation properties among the samples were similar based on SEM fractography observation. Microstructural of samples aged at 700°F seemed to be similar of those as received samples in terms of the following aspects; Grain structures and chemistry, no reaction with B4C phase and no changes in Fe-Al phase distribution. Samples at 1,200°F showed invariably different Characteristics in many ways.

Testing and Observations were performed at the following Companies.

- Talon Composites LLC, San Juan Capistrano, CA
- Transnucleaire, Paris, France
- National Technical Systems, Acton, MA
- Alyn Corporation, Irvine, CA
- ATEA, France
- University of Mass, Lowell, MA
- University of Irvine, Irvine, California
- Nuclear Reactor Laboratory, University of Michigan
- Framatome, Paris, France
- Polese Company, San Diego, CA