Talbor Navigator

This Navigator is designed to introduce Talbor composites and simplify the Talbor material selection for a given application. Each pertinent Talbor engineering design attribute is listed herein. An explanation of how its magnitude can be varied is given below each heading. In addition, engineering equations, graphs or trends define the relationship between a given attribute and ceramic content. In addition, some best-suited applications are listed for each material type.

In using this Navigator, one should keep in mind that this is only a guide to help narrow the selection of Talbor composites best suited for a given application. The information presented herein is intended for reference and selection purposes only. This information is not intended to define design criteria. Continuous research and process development results in periodic changes in the values of various attributes consequently mandating updated data to be published. Specific design parameters as well as engineering guidance for material selection can be obtained directly from Talon Composites, Inc.

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The following is a list of topics of interest related to engineering attributes pertinent to Talbor composites discussed within this Navigator:

Introduction

Talbor is a patent pending metal matrix composite (MMC) composed of an aluminum base alloy and a particulate ceramic reinforcement. Talbor composites are fabricated using powder metallurgy (P/M) and melt-stirring techniques and are available in wrought and cast compositions as extrusion billets/forging stock and casting ingots. The amount of ceramic reinforcement in Talbor composites can very between 5-40 vol.% for P/M products and 5-15 vol.% for melt-stirred products. The volume % of reinforcement is custom tailored to the given application. Talbor composites have been fabricated using 6XXX, 7XXX, 2XXX, 5XXX and 3XX series aluminum base alloys. The advantages of Talbor composites compared to standard aluminum, steel or titanium include: higher specific stiffness, 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. Current applications for Talbor composites range from neutron shielding, automotive to aerospace.

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™ Composites

Material description	Talbor Designation	
7093 base alloy	Talbor Ω- series	Ω = omega series
7005 base alloy	Talbor Κ- series	Κ = kappa series
6092 base alloy	Talbor Δ- series	Δ = delta series
6061 base alloy	Talbor Ψ- series	Ψ = psi series
1100 base alloy	Talbor Γ- series	Γ = gamma series

Material description	Talbor Designation	
336 base alloy	Talbor σ- series	σ = sigma series
356 base alloy	Talbor λ- series	λ = lambda series
365 base alloy	Talbor θ- series	θ = theta series
380 base alloy	Talbor η- series	η = eta series
390 base alloy	Talbor α- series	α = alpha series

Ceramic reinforcement	Talbor Designation
Boron Carbide (B_4C)	B
Silicon Carbide (SiC)	S
Alumina (Al_2O_3)	A
Silicon Hexaboride (SiB_6)	X

Example:

Trade name	Base alloy	Ceramic reinforcement type	Vol.% ceramic
Talbor	6092	Boron Carbide	25 vol.%

Written as: Talbor™ ∆B25

Ceramic Type (SiC, B_4C, Al_2O_3)

SiC, B_4C and Al_2O_3 are the three reinforcements that are currently used in fabricating Talbor products. Each of the (3) reinforcements has its intrinsic advantages as well as its shortcomings. The following addresses the pertinent differences among the ceramic reinforcement materials. SiC is denser than B_4C and consequently results in a higher density composite compared to B_4C. SiC has better bonding to aluminum compared to B_4C and results in higher strength composites. However, SiC reacts with molten aluminum to form brittle carbides and, because of the higher density, as compared to aluminum, tends to settle out quickly. This attribute significantly complicates various casting operations; therefore SiC is not used in melt-stirred Talbor composites. SiC reinforced composites cannot be readily welded due to “out-gassing” of the particles, which form porosity bubbles in the heat-affected zone (HAZ). B_4C-reinforced aluminum alloys can be welded if the base alloy chemistry can be welded. It should be noted that SiC is more commercially established compared to B_4C and, as a result, it is more difficult to purchase B_4C that consistently meets procurement criteria. B_4C has an intrinsic ability to absorb neutron radiation making it the only ceramic type to be use for neutron shielding applications. Al_2O_3 has the highest density of the three reinforcements. Al_2O_3 can yield high strength composites stronger than SiC and can be adapted to molten metal processing due to its minimal reactivity with molten aluminum. However, Al_2O_3 tends to segregate during casting and the best grade of product comes from an unreliable source. In the future other reinforcement materials such a silicon Hexaboride may be used in Talbor composites for specific application.

Description of P/M made wrought Talbor products

ΩB-series Talbor (Omega-B series)

The ΩB series Talbor products are designed for high strength/high stiffness applications. The ΩB-series Talbor products are available with tensile strength near 90 ksi. This product is based on a 7093 type aluminum alloy and is available with B_4C reinforcement. The major advantage of the ΩB-series Talbor is high strength, excellent fatigue resistance and high modulus. This material can be extruded, forged, rolled, stamped or drawn into a variety of shapes and sizes. The ΩB-series Talbor materials are also fully heat treatable. This composite material is also **weldable** using conventional techniques so it lends itself to high strength application involving a welded assembly. In addition, since ΩB-series Talbor utilizes B_4C reinforcement, it has the ability to attenuate neutrons while providing structural integrity and strength while in a radiation environment. The Talbor ΩB 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.

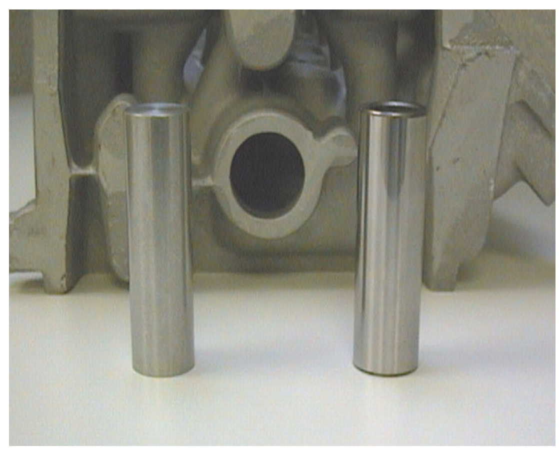
Applications of ΩB series Talbor composites include: automotive suspension and Chassis components, drive-shaft applications, spent nuclear fuel transportation casks.



ΔB-series Talbor (Delta-B Series)

The ΔB series materials are designed for medium strength application consistent with 6XXX series aluminum applications. B_4C is used as the reinforcement for this series of Talbor. This composite is best suited for formed shapes such as tubing or applications where good welding capabilities are required. This material also has exceptional high temperature strength, making it ideal, as a replacement of 2618 or 4032 conventional aluminum applications such as forged pistons or connecting rods. The Talbor ΔB-series products offer exceptional strength; lightweight and stiffness at elevated temperature and at the same time provide superior wear and abrasion resistance comparable to that of steel alloys. Recently, the ΔB series Talbor material has been submitted for qualification for structural neutron shielding applications. Upon completion of the qualification testing, ΔB-series Talbor will become the first structural aluminum based neutron-absorbing product. The ΔB-series Talbor can be extruded, forged, rolled, stamped or drawn into a variety of shapes and sizes. This material is also fully heat treatable.

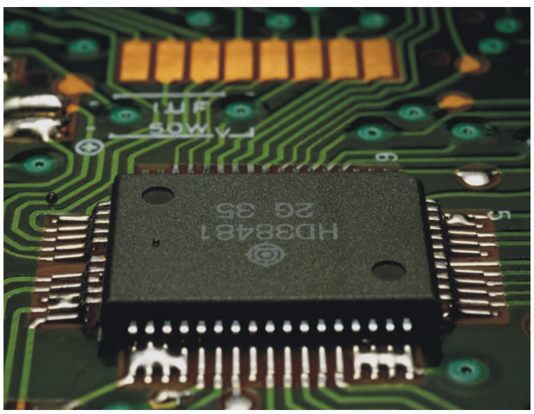
Some typical applications of ΔB-series Talbor include: gears in engine applications, sport equipment tubing, structural neutron absorption applications, exit guide vanes for military aircraft, pistons, wrist pins and skid plates.



ΩS –series Talbor (Omega-S Series)

The ΩS series Talbor is made using SiC as the reinforcement material. This product is designed for the most demanding high strength/high stiffness applications. As the ΩB –series before, the ΩS Talbor is based on a 7093 type aluminum alloy. This composite is **not weldable** using conventional methods but offers the maximum strength of the entire Talbor product line. Tensile strength of ~100 ksi can be realized using this product. The ΩS -series Talbor also offer an excellent fatigue resistance compared to conventional aluminum products. This material can be extruded, forged, rolled, stamped or drawn into a variety of shapes and sizes. The ΩS-series Talbor materials are also fully heat treatable. In addition, this material also has exceptional thermal conductivity and superior wear and abrasion-resistance characteristics. The Talbor ΩS 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.

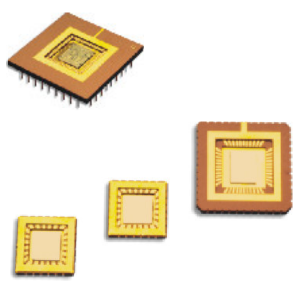
Applications for Talbor ΩS-series composites include: light weight/high strength structural components for the aerospace and Automotive markets, forged pistons for racing applications, sport equipment shafts (golf, hockey, lacrosse, baseball), electronic packaging applications demanding dimensional stability, skid plates, robotic arm assemblies requiring light weight and high strength and stiffness.

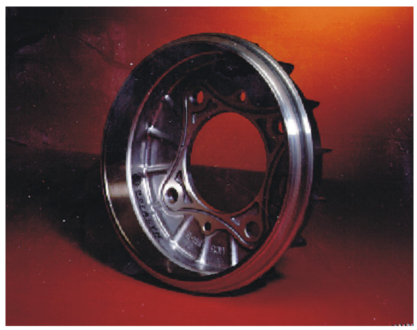


ΔS-series Talbor (delta-S series)

The ΔS series Talbor is made using SiC as the reinforcement material. This product is designed for the most demanding high strength/high stiffness applications at elevated temperatures. The ΔS-series Talbor is based on a 6092 type aluminum alloy. The ΔS-series materials have the highest thermal conductivity of any Talbor products. The combination of high elevated temperature strength, great wear resistance, low thermal expansion, and excellent thermal conductivity, make this product an ideal candidate for automotive engine applications such as piston, rods, cylinder liners etc. It offers excellent formability with the highest strength of any aluminum alloy at elevated temperatures. It should also be noted that the ΔS-series Talbor exhibits excellent ductility, comparable to that of 2618 Al alloy, at elevated temperature. These materials are also easier to form compared to ΩS-series Talbor materials and offer more ductility or elongation. This composite is **not weldable** using conventional methods but can be joined using friction stir or inertia welding techniques. This material can be extruded, forged, rolled, stamped or drawn into a variety of shapes and sizes. The ΔS-series Talbor materials are also fully heat treatable. The Talbor ΩS 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.

Applications for Talbor ΔS-series composites include: engine applications such as pistons, wrist pins, cylinder liners, valve guides, connecting rods, as well as, electronic packaging applications, exit guide vanes for military aircraft. Instrument housings, robotic arm assemblies, non-welded tubing applications (bicycle frames, automotive chassis, motorcycle frame components) gears and friction components





ΓB-series Talbor (gamma-B series)

The ΓB-series Talbor is based on 1100-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 ΓB -series 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 ΓB -series material does not exhibit significant gains from heat treatment. This composite material is also **weldable** using conventional techniques. The Talbor ΩS 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.

Applications for Talbor ΓB-series composites include: plates and extruded shapes used for neutron shielding applications, sleeves for replacing deteriorating materials in spent fuel pools and shielding applications for nuclear powered military ships and submarines, bus connection rails for amusement rides that require wear resistance but provide good conductivity for data transmission, light weight, high ductility/high abrasion resistance applications such as motorcycle racing suit body skid armor

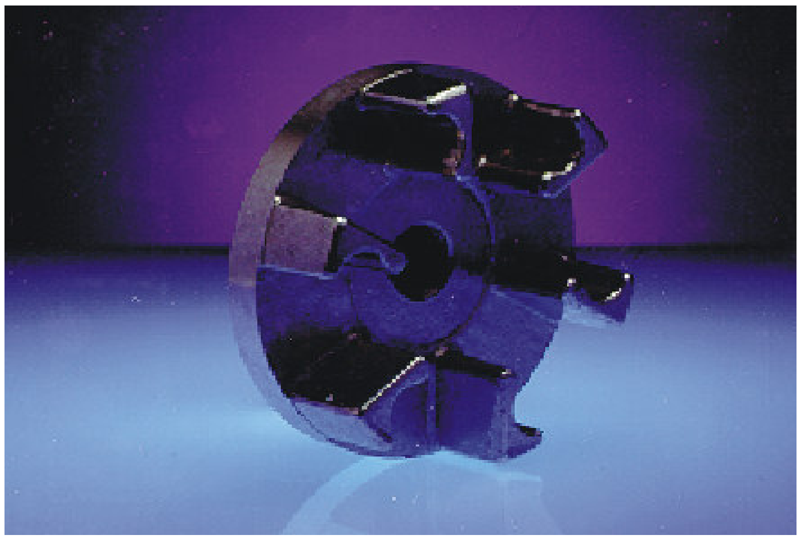


Description of Melt-Stirred Cast Talbor products

Talbor **λB**- series **(lambda-B Series)**

The λB-series Talbor is based on 356-series aluminum reinforced with various amounts of B_4C. This material is specifically designed to be the workhorse alloy for various casting applications such as automotive and aerospace. It can be substituted into applications normally using A356 or 357 Al alloys where improved stiffness, wear, or strength are required. This material also exhibits excellent pressure tightness and good resistance to corrosion while having the highest strength of all Talbor cast composites. This Talbor product has excellent casting characteristics. The λB-series Talbor material has excellent fluidity and mold fill characteristics. The material can be cast at temperatures ranging from 1250-1400°F. The magnesium (Mg) content as well as the heat treatment can be varied to achieve the desired strength and ductility combination. This material also has the unique attribute in that its strength dramatically increases (from 35 ksi up to 55ksi) upon exposure to neutron radiation. This characteristic allows the λB-series Talbor materials to be used for structural applications in storage and transport of spent nuclear fuel. The λB-series Talbor materials can be welded using traditional methods and respond well to various heat treatments. Since the B_4C does not react with the molten aluminum, the λB-series Talbor materials can be re-cycled and re-cast many times without any noticeable property loss. A variety of casting methods including, sand, permanent mold, investment and squeeze can be used to cast λB-series Talbor composite components. Specific casting guidelines for each method can be obtained directly from LMC. Product is available in ingot form (~30lbs) or as finished castings through our strategic partners

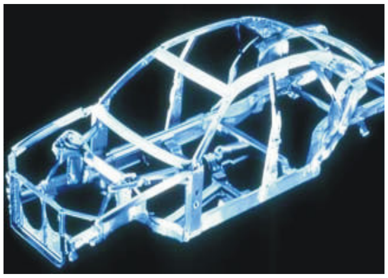
Applications for Talbor λB-series composites include: automotive components such as transmission cases, suspension components, Aerospace applications such as pump housings, instrument housings, door frames, structural applications for structures used to store and transport spent nuclear fuel.

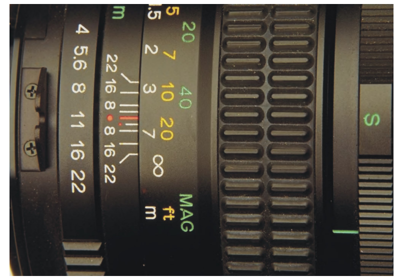


Talbor **θB**- series **(Theta-B Series)**

The Talbor θB- series material was specifically designed for die casting applications where good ductility and strength are required. This alloy does not contain iron (Fe) and consequently exhibits excellent combination of ductility and strength while minimizing die-soldering tendencies. When this alloy is used in conjunction with a vacuum system, die cast components can be fabricated with the strength and ductility of a sand-cast 356 alloy. This material is well suited for automotive applications, which require good structural strength, and better ductility than normally available from a die cast product. In addition, Talbor θB-series composite components exhibit excellent wear and abrasion resistance as well as excellent fatigue resistance properties. Use of the vacuum system allows relatively, porosity-free die-castings. This allows the parts to be heat-treated to a T6 temper. The θB-series Talbor materials can be welded using traditional methods and respond well to various heat treatments. Since the B_4C does not react with the molten aluminum, the θB-series Talbor materials can be re-cycled and re-cast many times without any noticeable property loss. A variety of casting methods including, Die casting and squeeze casting can be used to cast θB-series Talbor composite components. Specific casting guidelines for each method can be obtained directly from LMC. Product is available in ingot form (~30lbs) or as finished castings through our strategic partners.

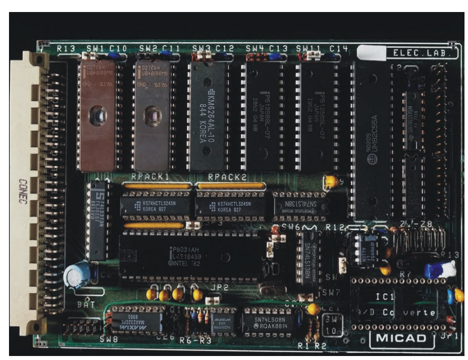
Applications for Talbor θB-series composites include: connecting nodes for automotive space frames, notebook computer cases, camera and cell phone housings, motorcycle frame and gas tank components, safety shoe inserts, gears, instrument housings and suspension components.



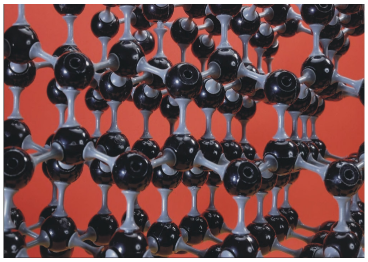


W36-series materials

The W36 alloy is based on a 336 base casting alloy. The chemistry of the Talbor composite is further modified to make the composite have excellent casting characteristics as well as excellent high temperature strength. This material has successfully been utilized for cast piston applications. It offers excellent wear behavior as well as high temperature strength that rivals a forged 4032 Al alloy material. In addition, since the silicon content is near the eutectic composition, the solidification in a permanent mold application is ~30% faster than a hypereutectic 390 alloy often used for pistons. The W36 material is being tested for applications in the nuclear shielding sector. The W36 Talbor composite may become the first and only castable composite suitable for neutron absorbing applications. This development has allowed the re-design of conventional sandwiched structure cask baskets into one-piece solid structural cast basket, which is lighter than its predecessor and exhibits a higher areal density of B_{10} with a significantly better thermal conductivity.



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

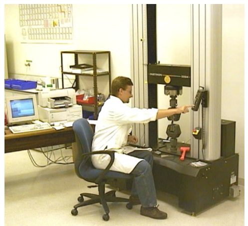
Summary tables on page 24 and 25 shows the density of various Talbor composites.

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)

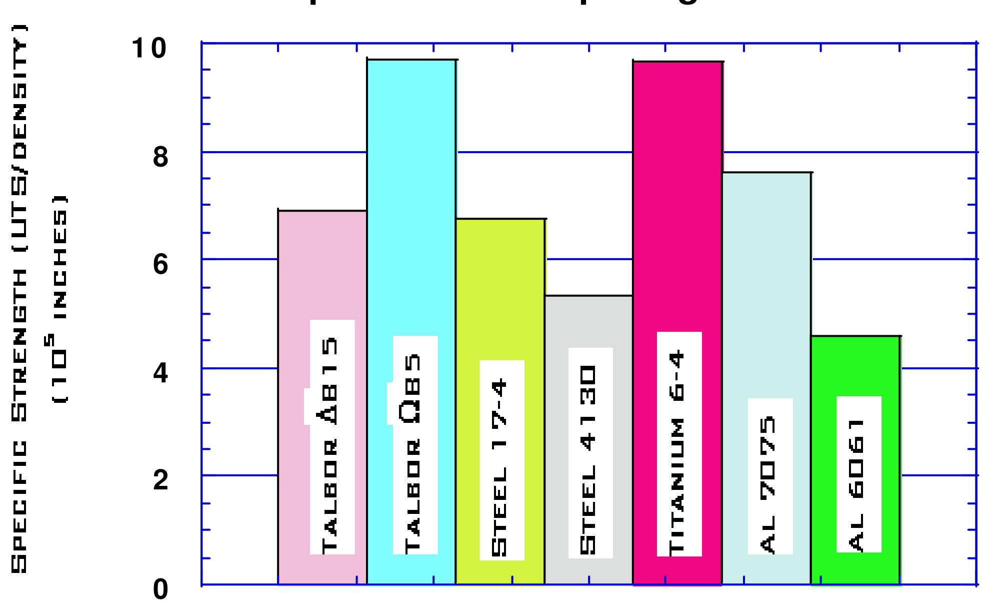
The strength of the composite material is a function of 3 things: (1) the strength of the base alloy, (2) the strength of the ceramic, and (3) bonding between the matrix and the ceramic. In general, the strength of the composite increases in proportion to the volume fraction of the ceramic up to a certain 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. SiC and Al_2O_3 powders bond better with the aluminum matrix materials and consequently result in higher strength composites than B_4C reinforced aluminum composites. 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

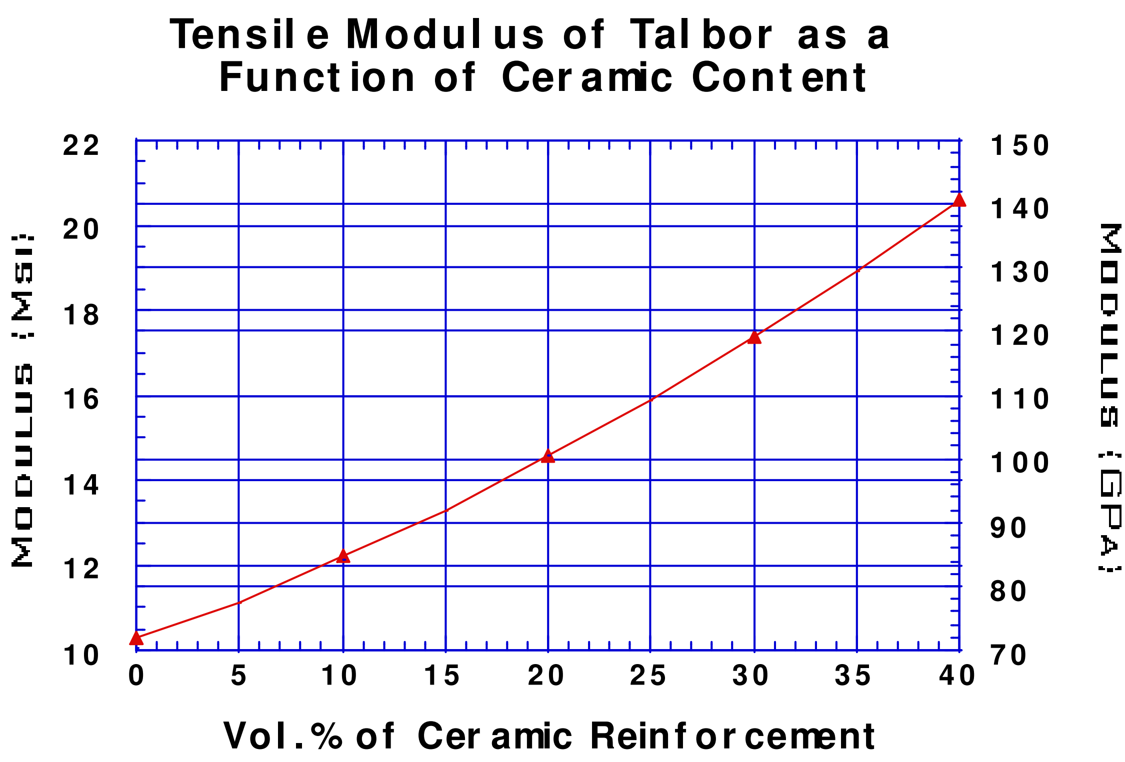
Specific strength represents the ultimate tensile strength divided (or normalized) by the density. The specific strength values for Talbor composites are superior to steel and conventional aluminum alloys and in some cases titanium. The high specific strength makes the Talbor composites ideally suited for high strength, weight critical application. The graph below gives a comparison of the specific strength of Talbor compared to conventional materials. The highest specific strength of Talbor composites is achieved by using SiC as the reinforcement material (for wrought products only). This a direct result of the superior bonding characteristics of SiC to the matrix material (in wrought products) as well as the higher overall strength intrinsic to SiC compared to other reinforcement materials. The Talbor ΩS-series composites will have the highest specific strength compared to any other Talbor composites.

Specific Strength of Talbor Composites Compared to Competing Materials



Modulus

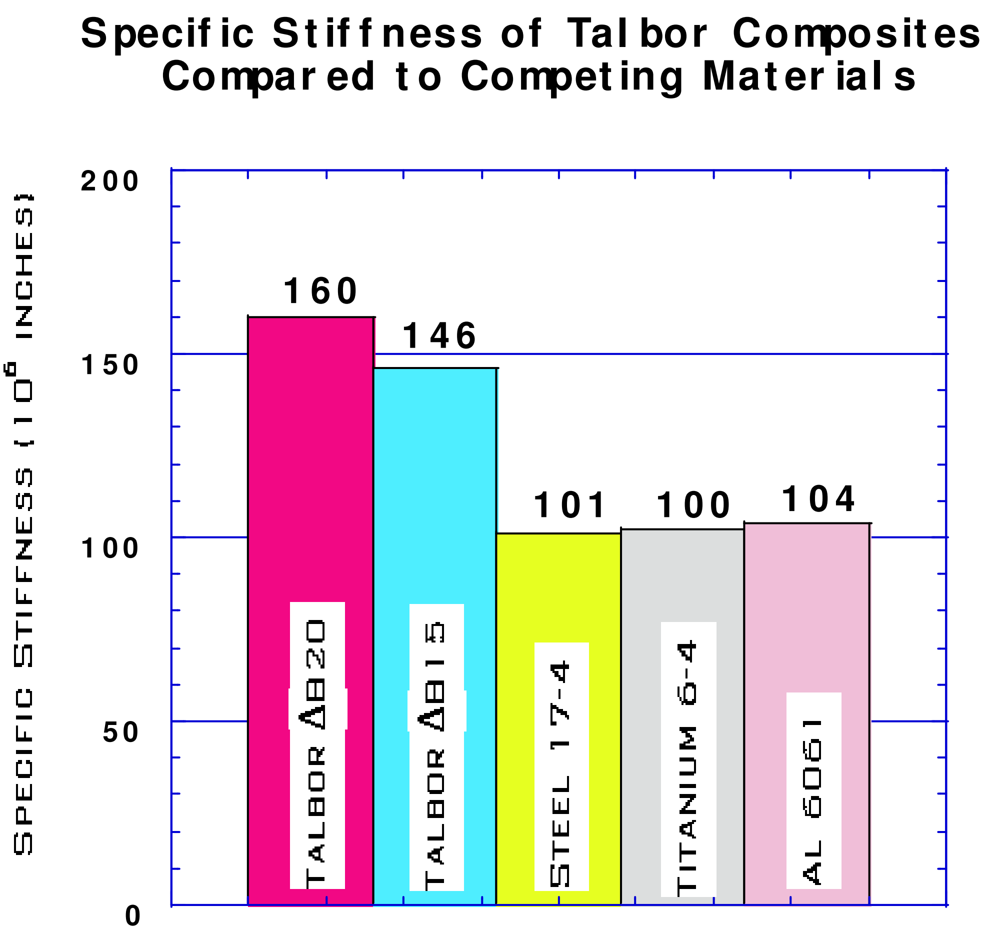
The modulus of Talbor composites is an indication of the stiffness of the material or its resistance to strain. The stiffness is an intrinsic material property that does not change with temper. The modulus of the Talbor composite material is directly proportional to the vol.% of ceramic. Each of the (3) types of ceramic reinforcements (B_4C, SiC and Al_2O_3) offers approximately equivalent improvements in the modulus (B_4C offers a slight advantage). 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.

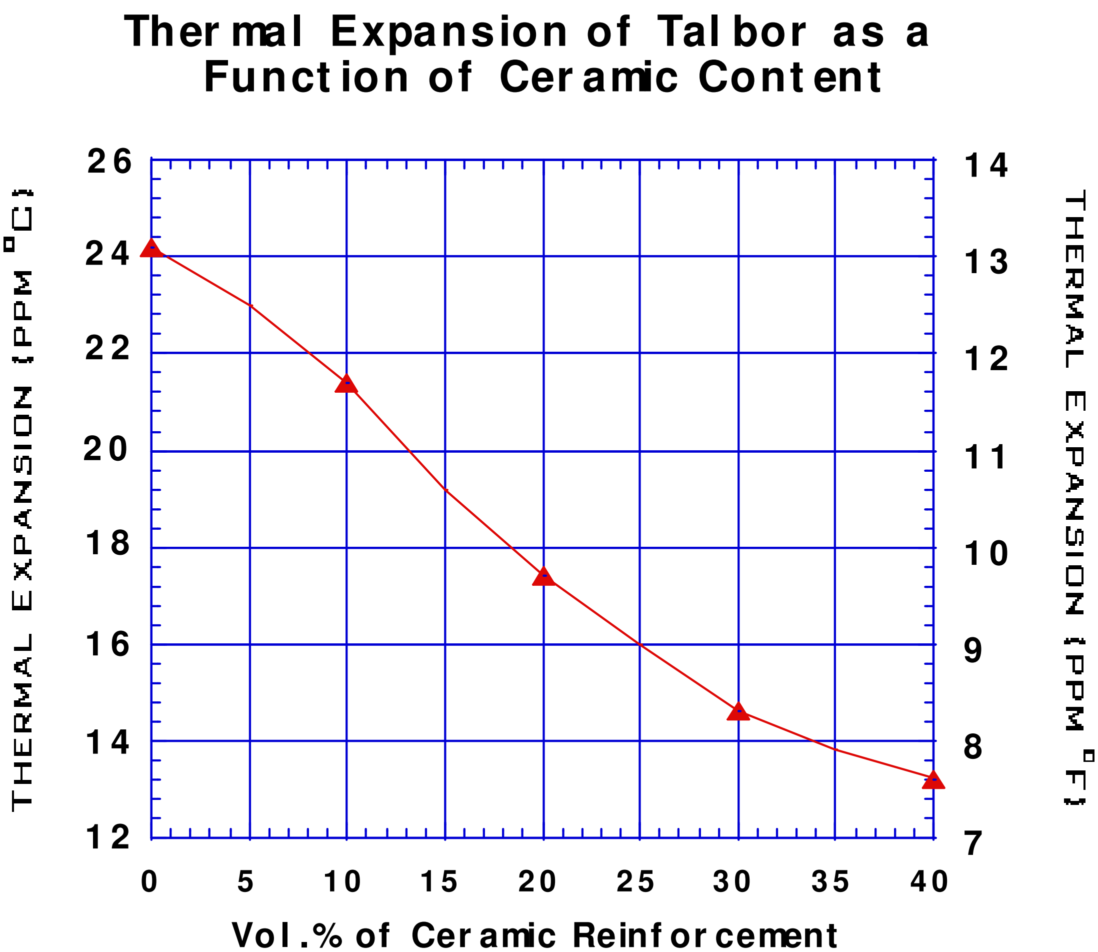
Specific Stiffness

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 light weight. A comparison of several materials to Talbor is shown below with regard to specific stiffness.



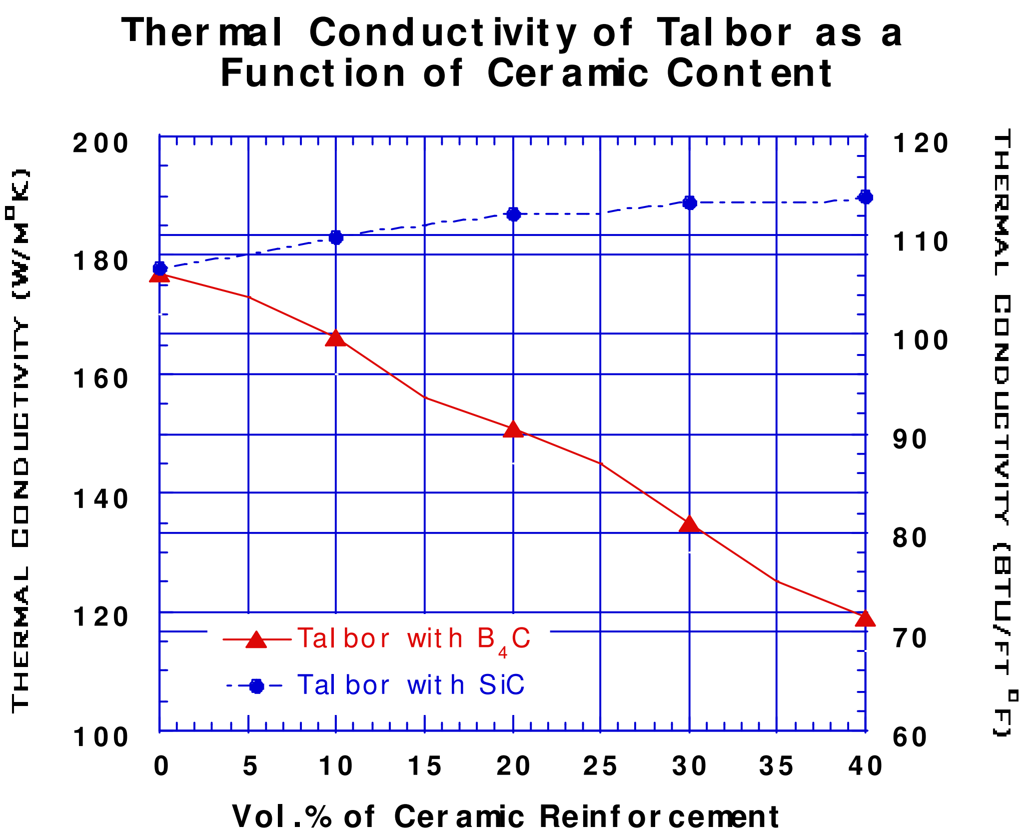
Thermal Expansion

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 electronic packaging applications.



Thermal Conductivity

The thermal conductivity of Talbor composites is proportional to the amount and type of ceramic used. Since, SiC has a higher thermal conductivity than B_4C and aluminum, composites made with SiC tend to exhibit a higher thermal conductivity than the base alloy while composites made with B_4C exhibit a lower thermal conductivity than the base alloy. 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 $\pm$ 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. There does not appear to be a big difference in the wear attributes of B_4C vs. SiC. 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. In addition, it has been determined that un-lubricated brass surfaces may be incompatible with Talbor materials. 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 ΔS20*	0.096	0.119	3.87
Talbor ΔS30*	0.098	0.119	2.53
Talbor ΔB25*	0.101	0.123	3.80
Talbor ΩB20*	0.101	N/A	3.85
Steel with SPF-251*	0.141	0.129	8.00
A357 Squeeze Cast§	--	--	28.16

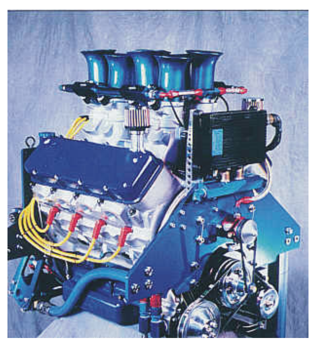
* Contact load of 120 pounds
§ Contact load of 30 pounds

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. LMC 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 LMC

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.

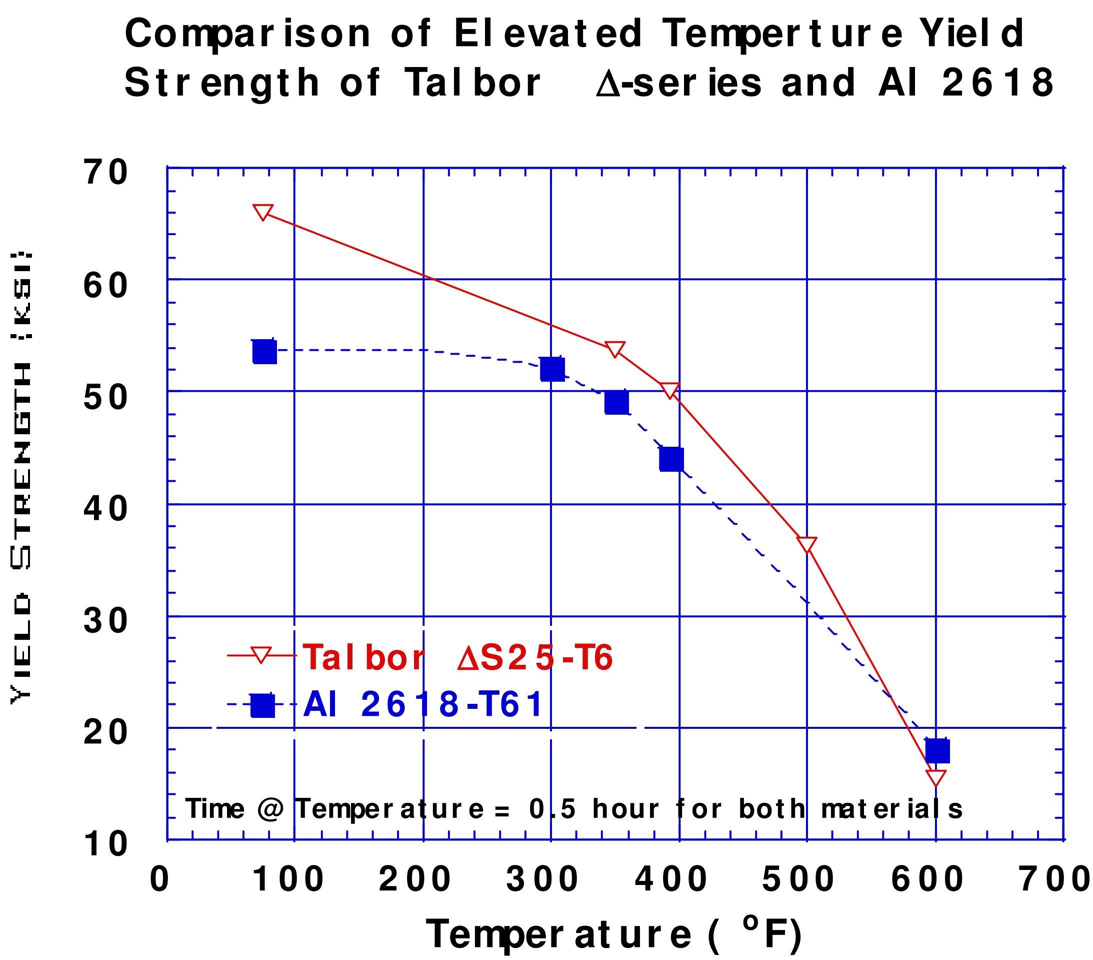


Secondary Surface Treatment

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

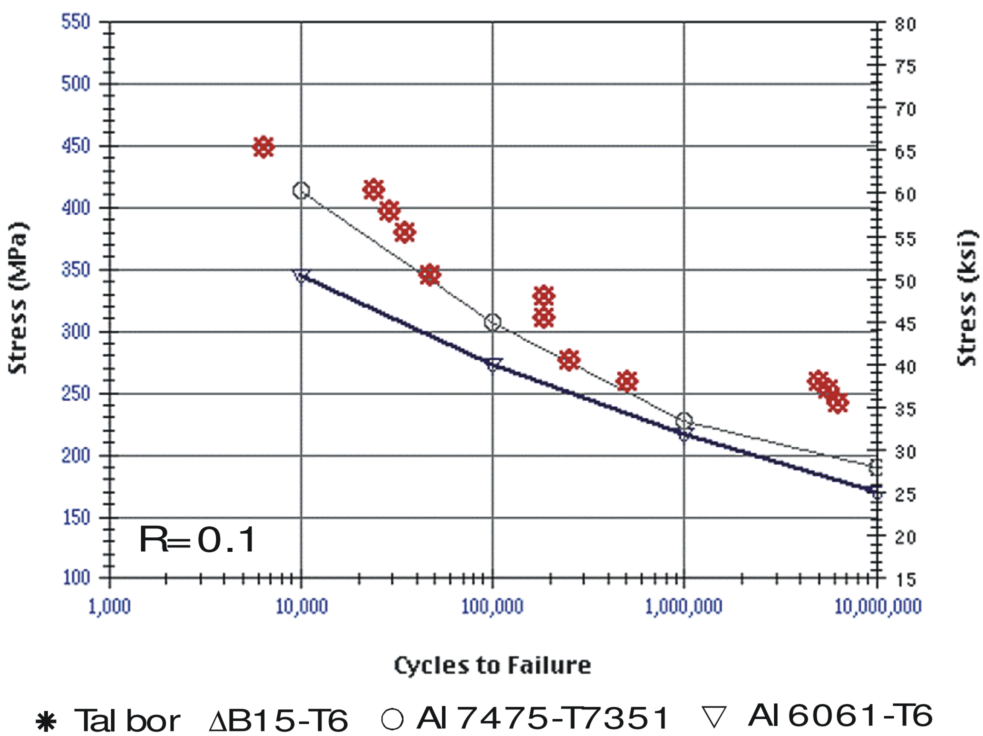
Talbor composites have improved elevated temperature performance compared to conventional aluminum alloys because the high strength of the ceramic content contributes to the overall improvement in strength at elevated temperature. This attribute can be further accentuated by combining the ceramic with a base aluminum alloy that has good elevated temperature properties. The Talbor Δ-series, and σ-series 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

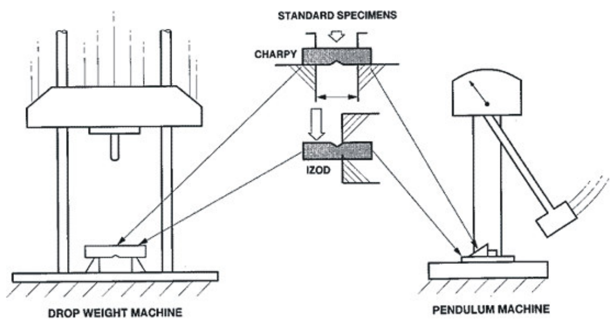
It is well documented in the technical literature that aluminum based MMCs have improved fatigue behavior compared to conventional aluminum alloys. The fatigue performance improves with added vol.% of reinforcement up to ~20 vol.% above which the fatigue performance begins to decrease. Fatigue performance 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

Impact toughness of Talbor composites is not exceptional because of the ceramic content. Ceramic materials have poor 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

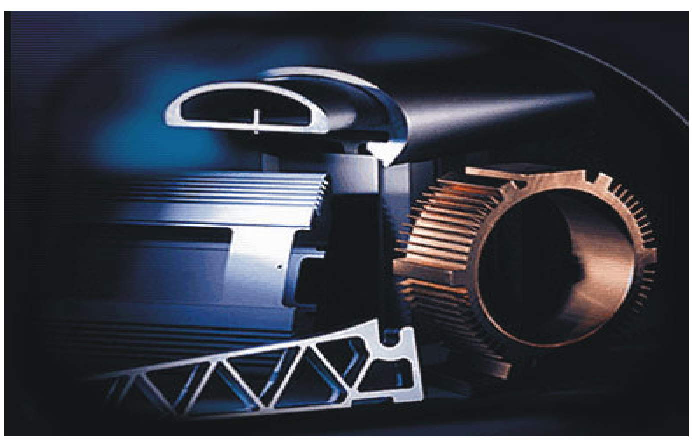
The main characteristics of aluminum composites that influence welding are hydrogen solubility, aluminum oxides, thermal conductivity, thermal expansion, and solidification shrinkage. Weld porosity in aluminum based metal matrix composites is caused principally by bubbles of hydrogen that form in the 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. 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. SiC reinforced composites are difficult to weld due to the formation of brittle aluminum carbides in the weld pool. In addition, SiC/Al composites are prone to gas evolution during welding, which causes porosity in the weld zone. Friction stir welding has been shown to be a viable way to join SiC 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.

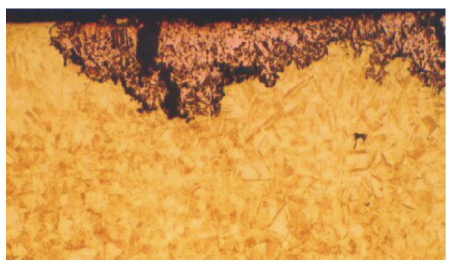
Forming

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 operation. LMC 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.



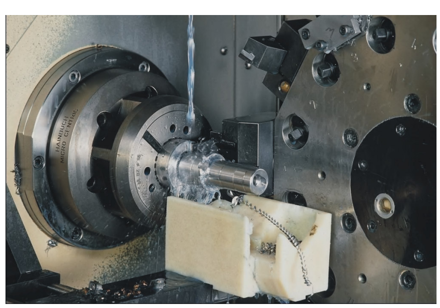
Extrusion

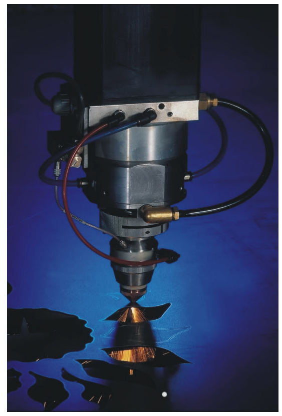
Talbor can be extruded into a variety of shapes and sizes, however the extrusion of metal matrix composites requires the use of specific process parameters, which differ dramatically from conventional aluminum alloys. Shear or conical dies can be used to extrude Talbor materials. Billets of Talbor can 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. LMC can provide any and all extruded profiles for their composite products through their strategic alliance partners.



Corrosion Resistance

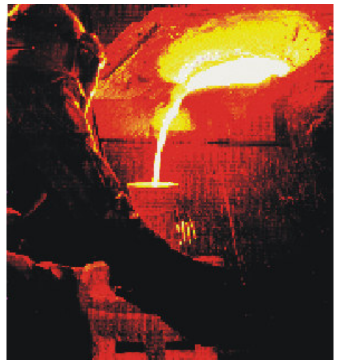
The corrosion resistance of Talbor is dependent on the base alloy chemistry of the composite. The same rules that apply to aluminum alloys, with regard to corrosion resistance, apply to Talbor. Controlled experiments have shown that the ceramic particles do not significantly affect the corrosion behavior 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.





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 LMC, which gives specific feed/speed parameters for the various types of Talbor composites. In addition, LMC 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 LMC.



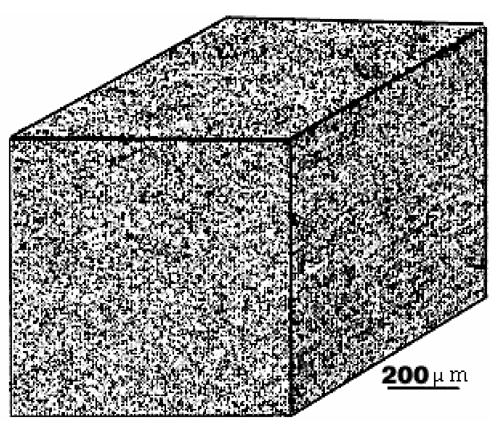
Casting (investment, sand, permanent mold, and die casting)

Talbor composites are currently available from 1-8 vol.% for gravity cast applications. Filters are required for most types of castings since they reduce turbulence during pouring and ultimately reduce entrained porosity as well as remove any oxide inclusions in the melt. Cloth or sock filters can be used for investment castings. Shaped ceramic filters can be used in sand or permanent mold castings. It has been determined that 10-25ppi type ceramic filters are best suited for Talbor Composites. Castings need to be poured 15-50°F degrees hotter than equivalent parts in conventional aluminum. Care must be taken during metal handling to minimize air entrapment in the melt. It is difficult to degas the melt using lance methods. Chlorine gas or tablets should never be used to degas a Talbor melt. It is necessary to use a rotary-degassing unit with Argon (Ar) or Nitrogen (Ni) bubbling through the shaft. The Talbor melt should not be let to sit more than 15 min after degassing and prior to casting. If a continuous casting of small parts is required over extended periods of time, then it is necessary to stir the melt every hour or continually stir it during casting. Talbor castings can be re-melted making it fully recyclable. LMC uses a propriety processing step to passivate the surface of the B_4C particles in order to make them stable in molten aluminum. The density of the B_4C is close to the density of molten aluminum. This attribute keeps the B_4C uniformly suspended in molten aluminum for an hour or more, giving a practical window for gravity casting parts from the melt. Large and or thick section parts can be cast using Talbor because the B_4C does not segregate or settle out during casting. Talbor can be fabricated with a B_4C content as high as 20 vol.%, but with increasing ceramic content the fluidity of the composite decreases significantly, making it impractical to cast using gravity methods. Squeeze casting or semi-solid forming can be used successfully with higher vol.% of ceramic composite. When casting complex or large parts, it may be necessary to feed the casting with a higher head pressure compared to conventional aluminum. Gating for castings should be designed in such a way as to minimize turbulent flow through the down sprue. Inline ceramic or sock filters accomplish this function well with the added benefit of removing any entrained oxide inclusions or large agglomerates. A detailed casting parameter guide is available to assist end users with melting and casting Talbor composites.

Microstructure

Wrought Talbor composites

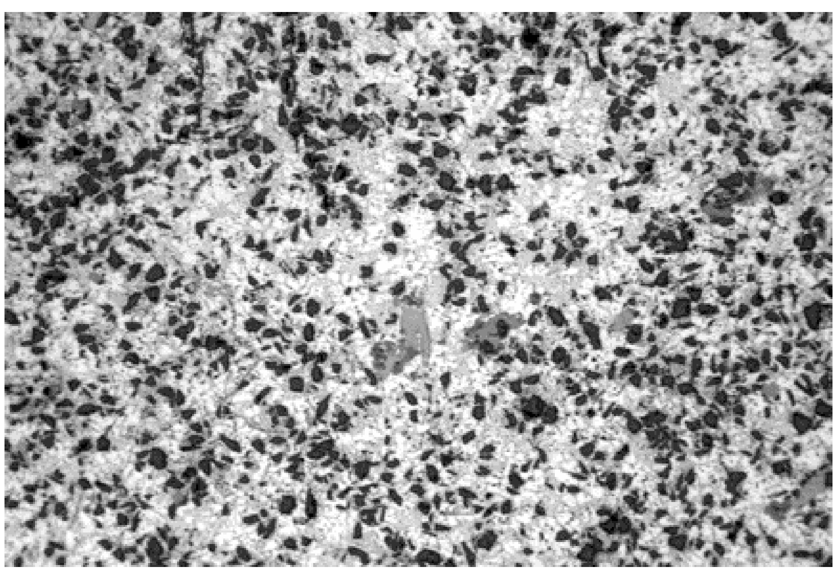
The Talbor wrought materials are produced using P/M methods. Consequently, the distribution of the ceramic particles is extremely homogeneous. The size of the ceramic particles is ~800 grit (~13 μm avg.). This fine ceramic particle size, combined with tailored metallic particle size distribution allows 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 particles (SiC, B_4C or Al_2O_3) 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 LMC.



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.

Microstructure of Cast Talbor composites

Talbor cast materials are produced using proprietary melt stirring methods to incorporate B_4C into various aluminum alloys. Fine B_4C particles ~25μm (600 grit) are used to fabricate Talbor composites. The resultant microstructure of the cast Talbor composites exhibits a fairly uniform distribution of B_4C particles accompanied by small clusters of particles. The clustered particles always appear fully wetted or infiltrated with molten aluminum. B_4C also acts to pin grain boundaries during solidification, resulting in a relatively small grain size. The grain size of Talbor castings can vary between 20-200 µm depending on the solidification and heat treatment parameters. High magnification analysis of the interface between the B_4C particles and the aluminum matrix reveals a distinct interfacial reaction zone surrounding each B_4C particle in the matrix. It is this deliberate boundary layer, initiated by a proprietary processing step, which passivates the B_4C particles and makes them stable in molten aluminum (at 1200°F) for up to 100 hours. The boundary layer consists of a functionally gradient coating which improves bonding and wetting of the B_4C to the matrix material, which consequently improving the load transfer from the matrix to the particles. This very efficient load transfer, resulting from superior bonding characteristics, ultimately allows Talbor castable composites to exhibit substantial strength improvements for relatively low vol.% reinforcement present in the composite. Because of the combination of substantial strength improvement and excellent castability, Talbor castable composites are currently available with ceramic loading limited to ~8 vol.% for gravity cast applications.



Microstructure of W56-10 illustrating the uniform distribution of B_4C.

Talbor Selection Chart

	Talbor Composite Materials							
	E	ES	H	HS	NN	W56	W36	W65
Property/attribute								
Thermal Conductivity	A	A	A	A	A	A	A	A
Thermal Expansion	A	A	A	A	A	A	A	A
Stiffness	A	A	A	A	A	A	A	A
Ductility	C	C	B	B	A	B	C	A
Strength	B	A	B	A	C	A	A	B
Weldability	D	D	A	D	A	B	B	B
Formability	B	B	A	A	A	A	A	A
Wear	A	A	A	A	B	A	A	A
Fatigue Resistance	A	A	B	B	B	A	A	A
Castability	F	F	F	F	D	A	A	A
Elevated Temperature strength	C	C	B	A	D	C	A	C
Neutron Absorption	A	F	A	F	A	A	A	A
Impact Toughness/Fracture toughness	D	D	C	C	B	C	D	C
Response to heat treatment	A	A	A	A	D	A	A	B
Available ceramic§	V,O	S	V,O	S	V	V	V	V
Hardness	A	A	A	A	C	B	B	B
Corrosion resistance	C	C	B	B	A	B	C	C

Legend:

A= excellent
B= good
C= fair
D= poor
F= unacceptable

§ Note: the following designations apply

S= SiC (Silicon Carbide)
V=B_4C (Boron Carbide)
O=Al_2O_3 Alumina (Aluminum oxide)

Useful Conversions

To convert B to A multiply by	A (English Units)	B (SI units)	To convert A to B multiply by
3.61273×10^{-5}	lb/in^3	kg/m^3	27679.9
10^{-3}	g/cm^3	kg/m^3	10^3
5.77791×10^{-1}	BTU/ft °F	W/mK	1.73073
1.450377×10^{-4}	pounds/in^2 (psi)	Pascal	6.89476×10^3
2.2046226	pounds	kg	4.5359237×10^{-1}
39.3701	inch	meter	2.54×10^{-2}