Metal Matrix Composites (MMCs)

from Space to Earth

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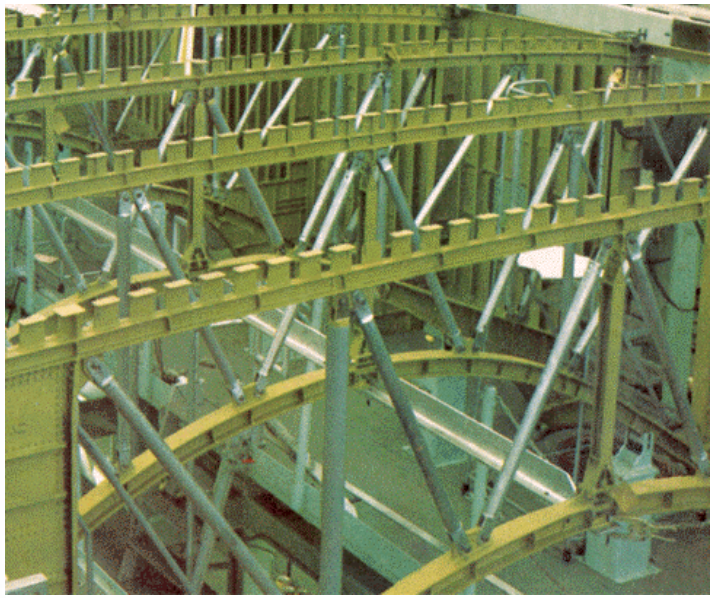
ca. 1975



sources: NASA & AFRL

Space Shuttle - main cargo bay struts

material: MMC - 6061/B/50f

total weight saving: 145 kg (-44% vs Al)

materials costs: > 1’000 US-$ / kg

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ca. 1999

source: VW

VW-Lupo (Tdi) - rear brake drums

material: MMC - A359/SiC/20p

weight of drum: 1.55 kg

materials costs: < 5 US-$ / kg

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structure of the talk

- introduction to MMCs
- typical properties of MMCs
- applications of MMCs in transportation
- outlook - trends in R&D, market forecasts

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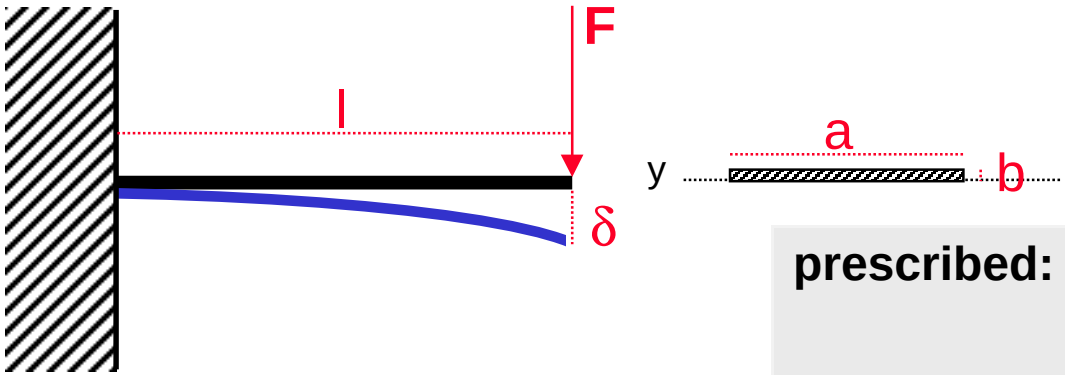
criteria for selection of materials (example)



prescribed:	$S = F/\delta$	(stiffness)
	l	(length of beam)
	a	(width of beam)
variable:	(b), E, ρ	(material)
target:	m_{min}	(min. weight of beam)

$$m = abl\,\rho \quad (1)$$

$$S = F/\delta \quad (2)$$

$$\delta = Fl^3/3EI_y \quad (3)$$

$$I_y = ab^3/12 \quad (4)$$

(source: M.F. Ashby)

(2), (3), (4): $b = (\alpha S l^3/Ea)^{1/3}$ (5)

(1), (5): $\mathbf{m = \underbrace{(\alpha S l^6 a^2)^{1/3}}_{prescribed}\ \underbrace{(\rho/E^{1/3})}_{variable}}$ $\Rightarrow$ maximize: $\mathbf{E^{1/3}/\rho}$

α = const.

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physical & mechanical properties of engineering metals

	ρ [g/cm³]	E [GPa]	R_m [MPa]		α [$10^{-6}K^{-1}$]	λ [$Wm^{-1}K^{-1}$]	E/ρ
Cu	8.96	130	200	(1500)*	16.5	398	14.5
Fe	7.87	208	70	(2500)*	11.8	80	26.4
Ti	4.5	120	235	(1500)*	8.4	26	26.7
Al	2.7	70	45	(750)*	23.6	247	25.9
Mg	1.74	45	90	(500)*	26.1	157	25.9
Be	1.85	295	200	(400)*	12.0	194	**159.5**

***** maximum strength obtained by alloying and (thermomech.) processing

problem with Beryllium: toxicity (and costs)

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MMCs - materials with tailored properties ...

... by combination of metals and ceramics

specific properties of metals and ceramics

metals.....	toughness
Al	electrical & thermal conductivity
Mg	heat resistance, "environmental stability"
(Ti)	processability

ceramics.....	hardness, Young's Modulus
SiC	strength
Al_2O_3	low coefficient of thermal expansion
C, B_4C	*(shape of ceramic:* ***fibres, particles****)*

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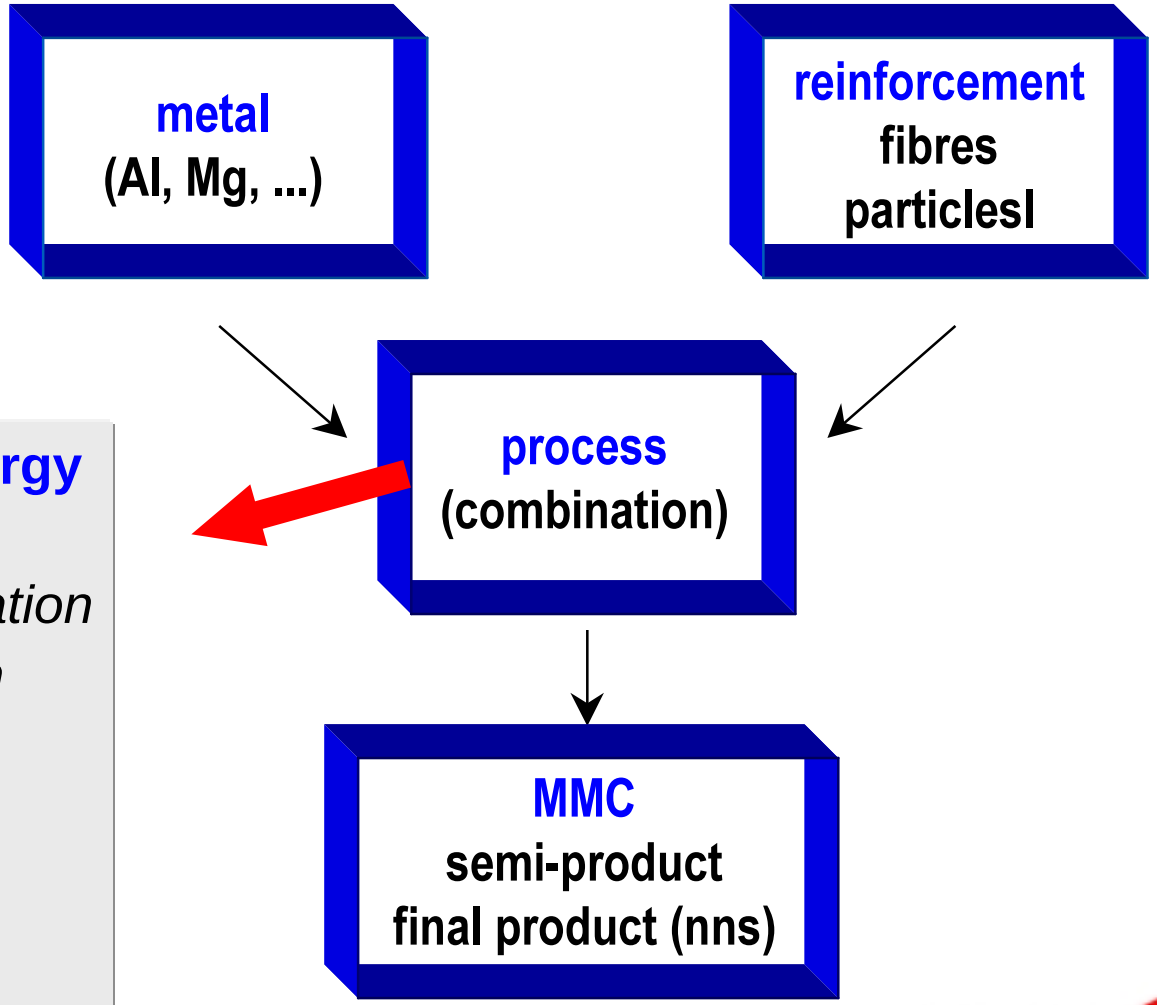
primary processing of MMCs - principle



liquid metal metallurgy

- *stir-casting*
- *pressurized infiltration*
- *reactive infiltration*
- *in-situ processes*

spray deposition

powder metallurgy

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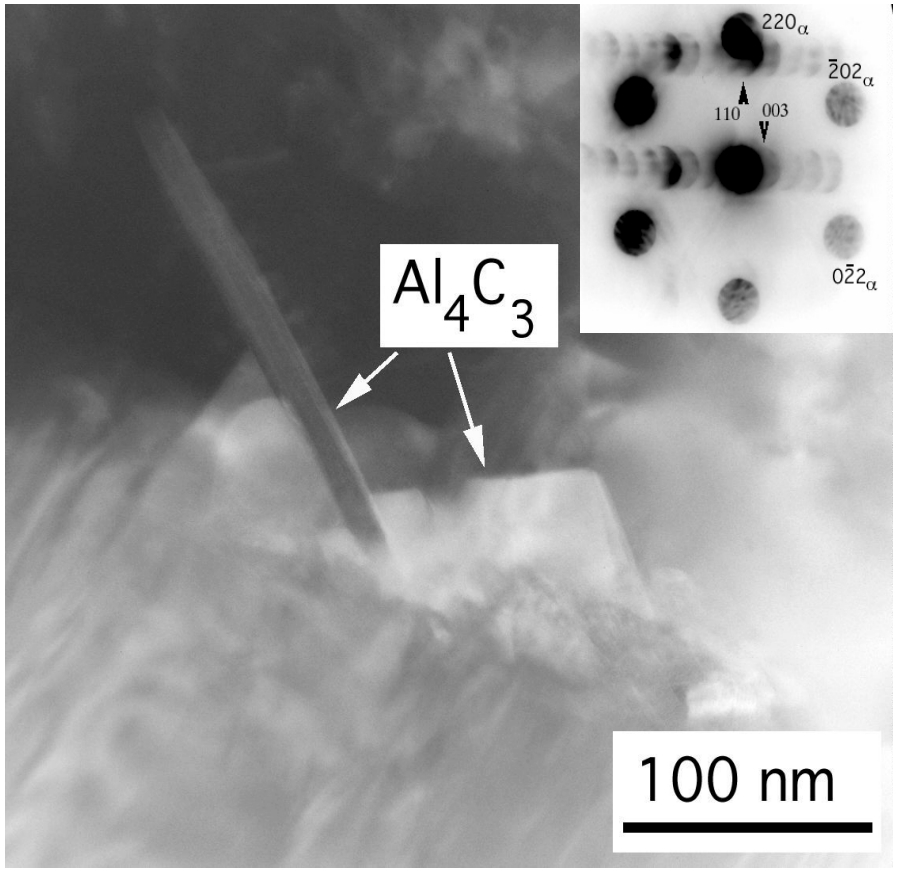
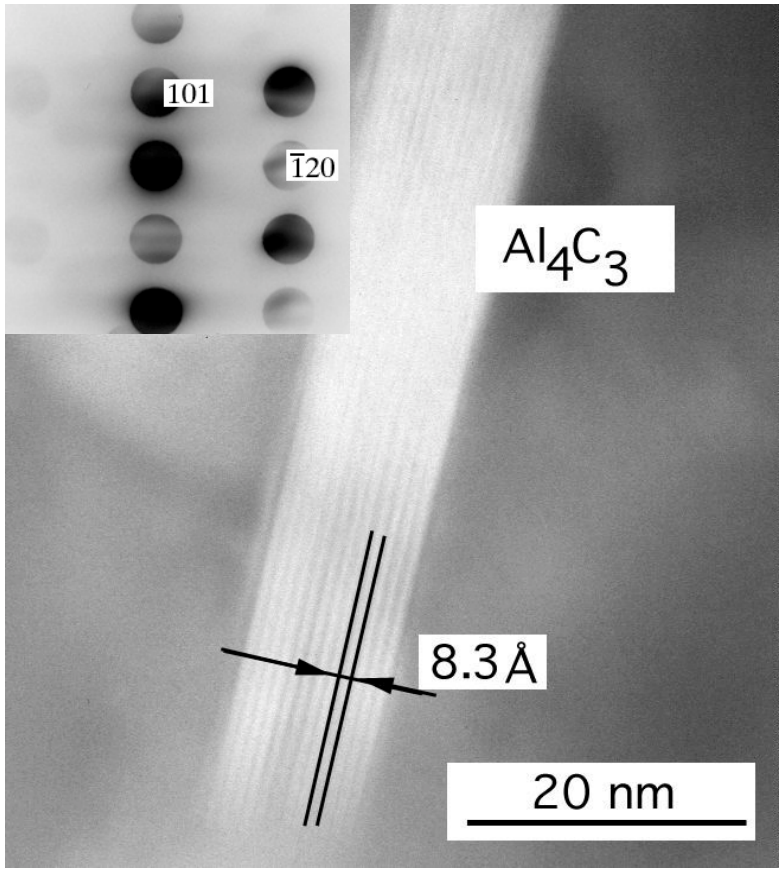
(in) compatibility of constituent materials

MMC: AlCu4Mg1Ag0.5 / SiC / 55_p (T6) **reaction:** $4Al + 3SiC \Rightarrow Al_4C_3 + 3Si$





source: CIME-EPFL / EMPA

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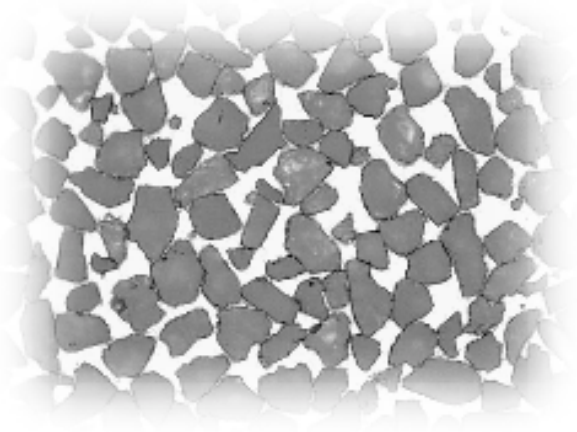
particle reinforced MMCs (PRM)



example (AlCuMgAg/SiC/60p)

matrix	reinforc.	temper	E (GPa)	σ_B (MPa)	σ_{UTS} (MPa)	K_{IC} (MPa$\sqrt{m}$)	CTE (ppm/K)	TC (W/mK)	ρ (g/cm^3)
-	SiC	-	>400	300-600	n.a.	3-6	3.5-4.5	80-200	3.2
AlCuMgAg	-	T6	74	-	450	24	23	180-200	2.8
AlCuMgAg	SiC, 60%	T6	200	700	> 500	9.5	11	190	3.04

density	2.6-3.1 g/cm^3
E-Modulus	90-300 GPa
strength	300-1000 MPa
CTE	7-20 ppm/K
TC	120-200 W/mK

spectrum of properties for PRM
(vp: 10-80 vol-%)

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variety of low volume fraction PRM (10-30 Vol-%)

Alcan cast engineered products
(formerly: Duralcan®)

other companies:

DWA
AMC
"Alyn Corp."
"Lanxide"
....

wrought alloys

2014/Al_2O_3/10-20p (Al-4.4Cu-0.5Mg-Si-Mn)
6061/Al_2O_3/10-20p (Al-1.0Mg-0.6Si-Cu-Cr)
7005/Al_2O_3/10p (Al-4.6Zn-1.4Mg-Mn-Cr-Zr-Ti)

applications: bicycle frames, drive shafts, cylinder liners, ... (examples)

cast alloys

gravity casting

A357/SiC/10-20p (Al-7.0Si-0.5Mg)
A359/SiC/10-20p (Al-9.0Si-0.5Mg)
A339/SiC/10-20p (Al-12Si-1.0Mg-1.0Ni-2.25Cu)

die casting

A360/SiC/10-20p (Al-9.5Si-0.5Mg)
A380/SiC/10-20p (Al-8.5Si-3.5Cu)

applications: brake drums, brake discs, ... (examples)

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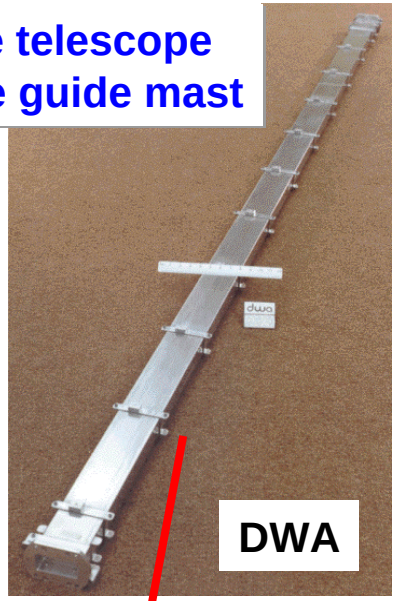
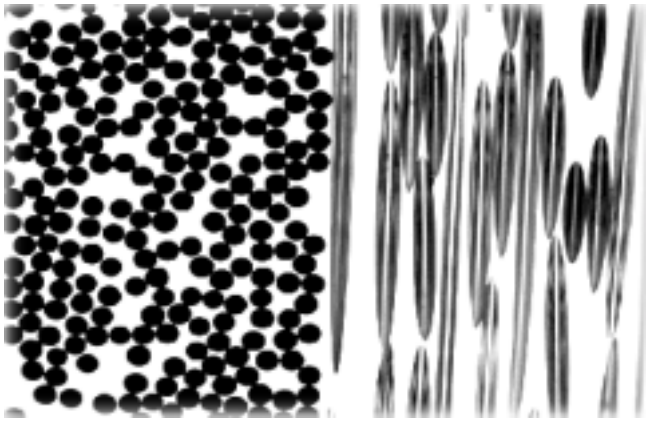
Hubble space telescope antenna wave guide mast





continuous fibre MMCs (CFRM)

matrix	6061	6061	hpAl	hpAl	AlCu2	MgAl1
fibre type	B (monofilament)	P100 (C-fibre)	Nextel 610	Nextel 610	Nextel 610	T300 (C-fibre)
MMC producer	(Dynamics/Convair and Amercom, Inc)	(DWA)	(Al_2O_3, 3M)	(Al_2O_3, 3M)	(Al_2O_3, 3M)	(EMPA)
v_f, (%)	50, UD	42, UD	45, UD	60, UD	60, UD	60, UD
$\sigma_{11.T}$, (MPa)	1100	905	1200	1600	1500	1470
E_{11}, (GPa)	235	342	165	240	240	155
$\sigma_{lim/25°C/R\ 0.1/N\ 10E7}$, (MPa)	n.a.	n.a.	n.a.	800	700	n.a.
ρ, (g/cm^3)	2.70	2.50	3.20	3.40	3.40	1.80
CTE, (ppm/K)	5.80	-0.49	6.60	7.00	n.a.	n.a.
	space shuttle		electrical conductors			inserts for select. reinf.

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automotive applications - brake discs & drums

Alcan cast engineered products
(formerly: Duralcan®)

brake discs & drums

material: MMC - type A359/SiC/20p
VW Lupo
Toyota RAV-4EV
Plymouth Prowler
GM EV-1, Precept, Impact
Ford Prodigy
race carts (various)
....

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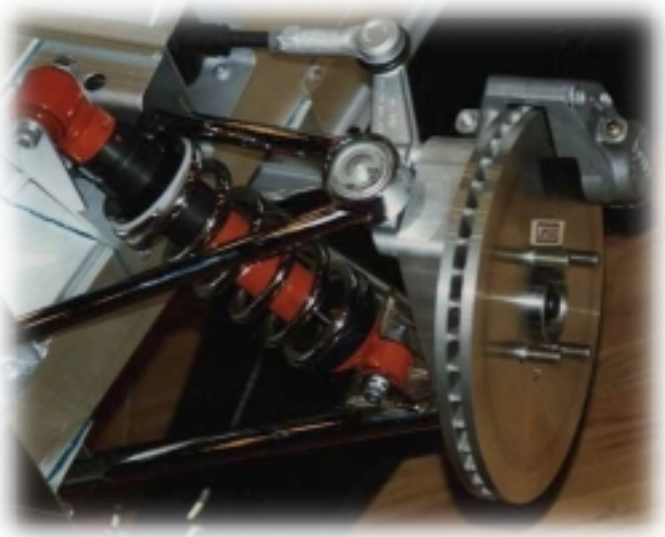
automotive applications - brake discs (Lotus Elise)

source: Lotus Cars Ltd.



brake discs (rear and front)

material: MMC - AlSiMg/SiC/30p (Lanxide)

MMC: TC 160 W/mK

disc temperature: Tmax 380°C (Stelvio Pass)

car weight: < 700 kg

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automotive applications - drive shafts

Alcan cast engineered products
(formerly: Duralcan®)

drive shafts

material: MMC - 6061/Al_2O_3/10p
GM Corvette
GM Trucks (various)
Ford Crown Victoria Police Interceptor
racing cars (various)
....

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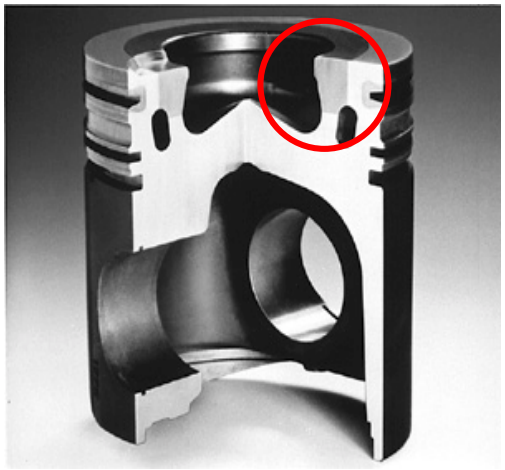
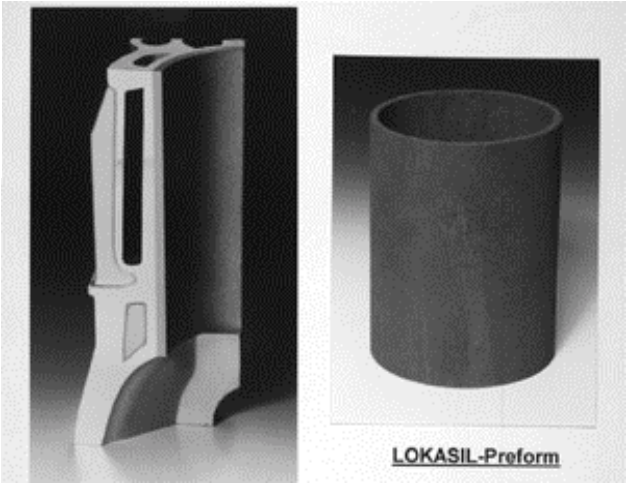
automotive applications - engine

Toyota Celica

source: Honda



source: Kolbenschmidt



cylinder blocks and pistons

(local reinforcement for wear and creep resist.)

material: AlSi + short fibres and/or particles

Porsche 911, Boxster

Toyota Celica

Honda Prelude, NSX, ...?

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MMCs - racing / competition applications

brake calipers

MMCC

cylinder liners

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3M

pushrods

valve spring retainers

AMC

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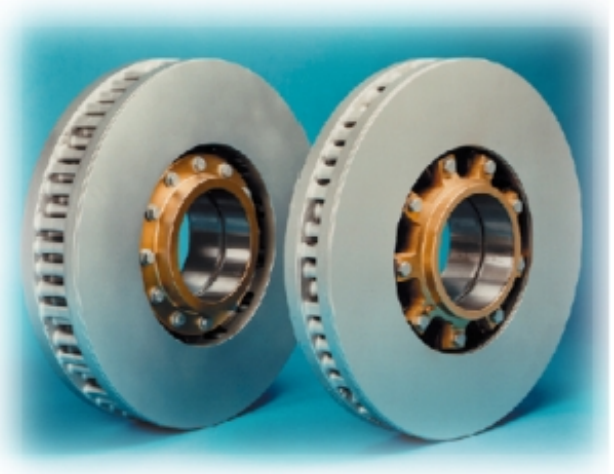
railway applications



ICE - brake discs

material: MMC - A359/SiC/20p

weight of disc: 74 kg (-38% vs cast iron)

total weight saving: 10 tons (192 discs)

sucessfully tested: over 1 Mio km

application introduced in the new Copenhagen metro

source: Knorr Bremse

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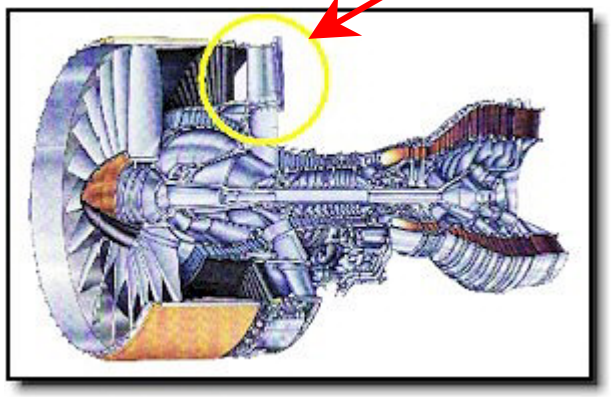
aerospace applications

source: DWA



FEGVs (Fan Exit Guide Vanes)

material: MMC - 6092/SiC/17.5p (DWA)

extrusions by Universal Alloy Corporation (USA)

engines: Pratt & Whitney 4XXX-series

aircraft: Boeing 777

military applications:

6092/SiC/17.5p

2009/SiC/15p-T4

F-16: *fuel access door covers*
ventral fins

Eurocopter: *blade sleeves*

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Power transportation (composite conductors)

source: 3M

electrical conductors (3M)

material: MMC - Al/Nextel610/45f

tensile strength: 1200 MPa

density: 3.2 g/cm^3

CTE: 6.6 ppm/K

electrical conductivity: 34 % IACS

common project between 3M and EDF

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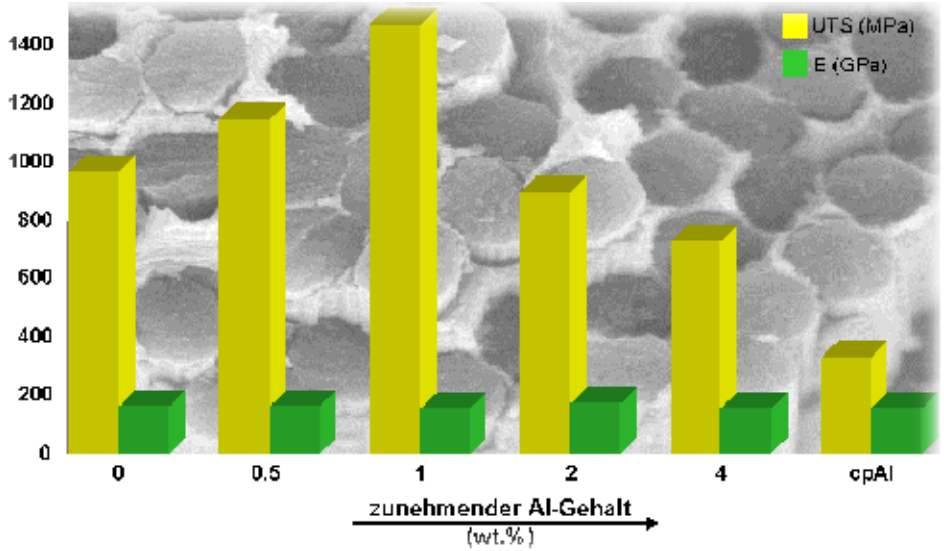
selectively reinforced Mg-castings by MMC inserts

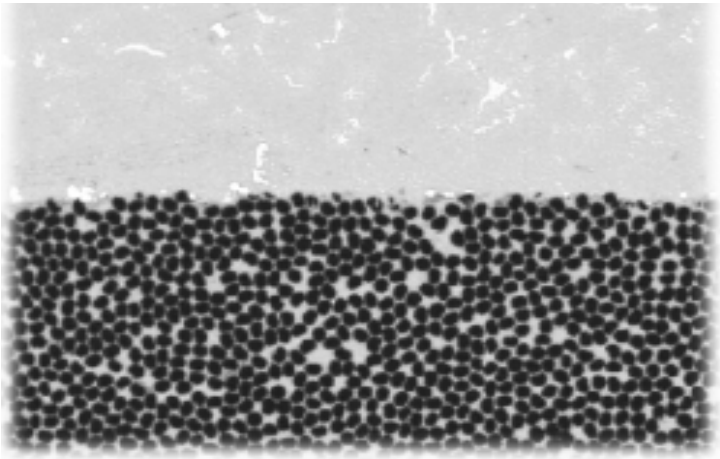
Hub

casting: AZ91

insert: MgAl1/T300

courtesy of Georg Fischer +GF+





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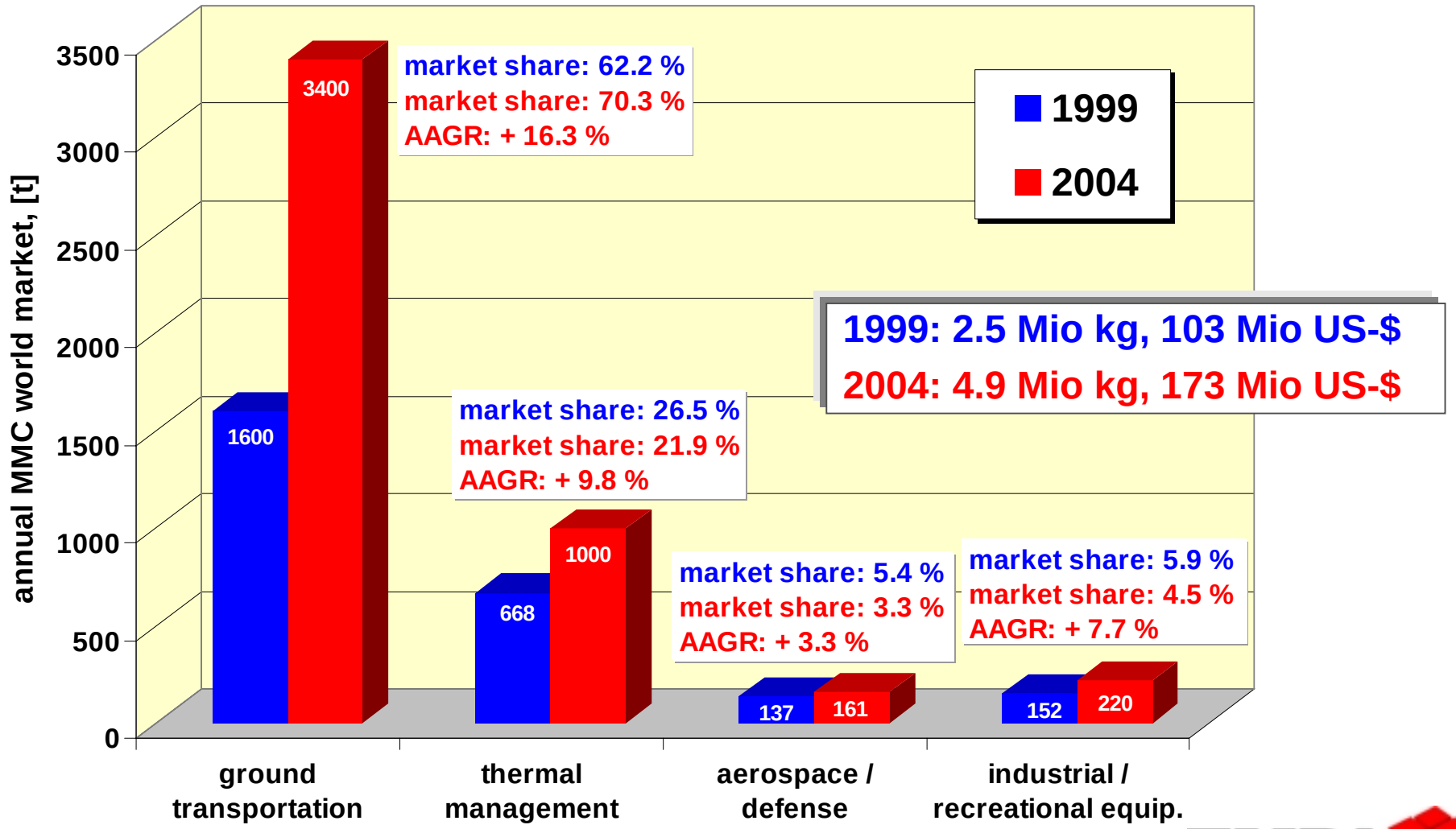
MMC market forecasts 1999-2004



source: BCC, USA

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http://www.swiss-mmc.ch

http://www.empa.ch/abt126

http://mmc-assess.tuwien.ac.at

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