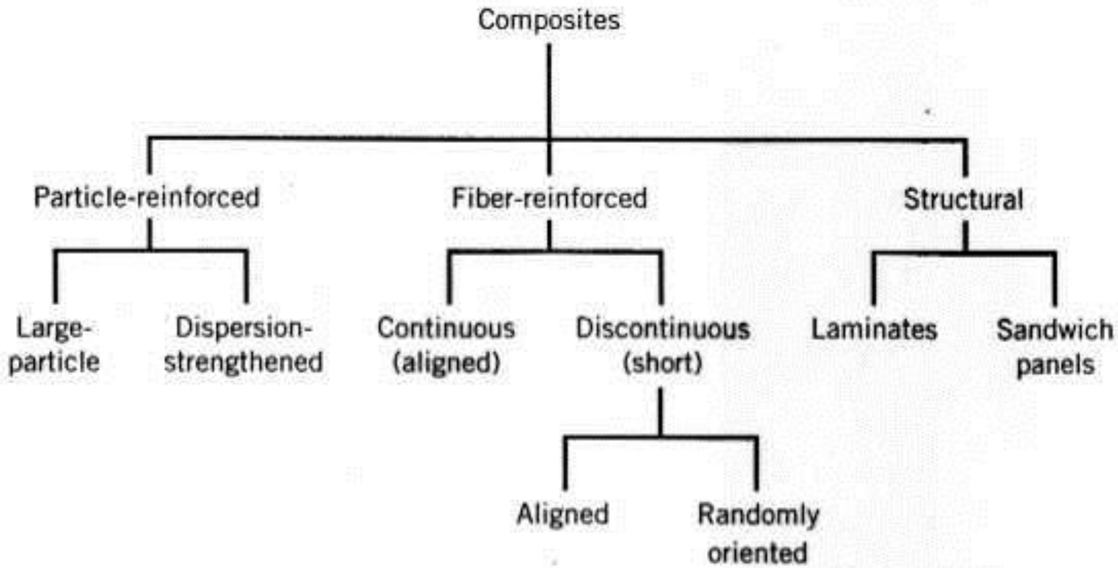
Composite definition

Composite is a man made material, consisting of two or more non soluble mutualy phases, which are made from one of 3 basic engineering materials; phases contribute to unique composite properties characteristic to constituent materials

Classification



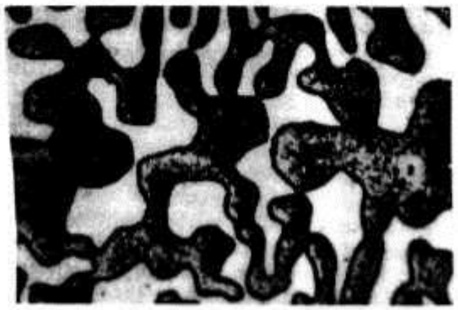
Parameters for Reinforcements

- Concentration (volume/weight fractions)
- Size/Shape (long or short)
- Distribution
- Orientation

Concentration and orientation are to major parameters.

I. Weight Fraction (wt%) and Volume Fraction (vol%)

Multi-Phase (2 to k phases) Materials



If the density of each phase is given

wt% ⇄ vol%

with

$$V_1 = \frac{W_1/\rho_1}{W_1/\rho_1 + W_2/\rho_2 + \ldots\ldots + W_k/\rho_k}$$

$$W_1 = \frac{V_1\,\rho_1}{V_1\,\rho_1 + V_2\,\rho_2 + \ldots\ldots + V_k\,\rho_k}$$

Example 2. The carbon/epoxy composite with 75 wt% of carbon.

$W_c = 75\%$, $W_e = 1 - 0.75 = 25\%$
$\rho_c = 1.76\ g/cm^3$, $\rho_e = 1.3\ g/cm^3$

$$V_c = (W_c/\rho_c)/(W_c/\rho_c + W_e/\rho_e)$$
$$= (0.75/1.76)/(0.75/1.76 + 0.25/1.3)$$
$$= 69\%$$

II. Theoretical Density of Two-Phase Materials

$$\rho = \frac{\rho_1\rho_2}{W_1\rho_2 + W_2\rho_1}$$

e.g. in Example 2,

$$\rho = (\rho_c\rho_e)/(W_c\rho_e + W_e\rho_c)$$

$$= (1.76\times1.3)/(0.75\times1.3 + 0.25\times1.76)$$

$$= 1.62\ g/cm^3$$

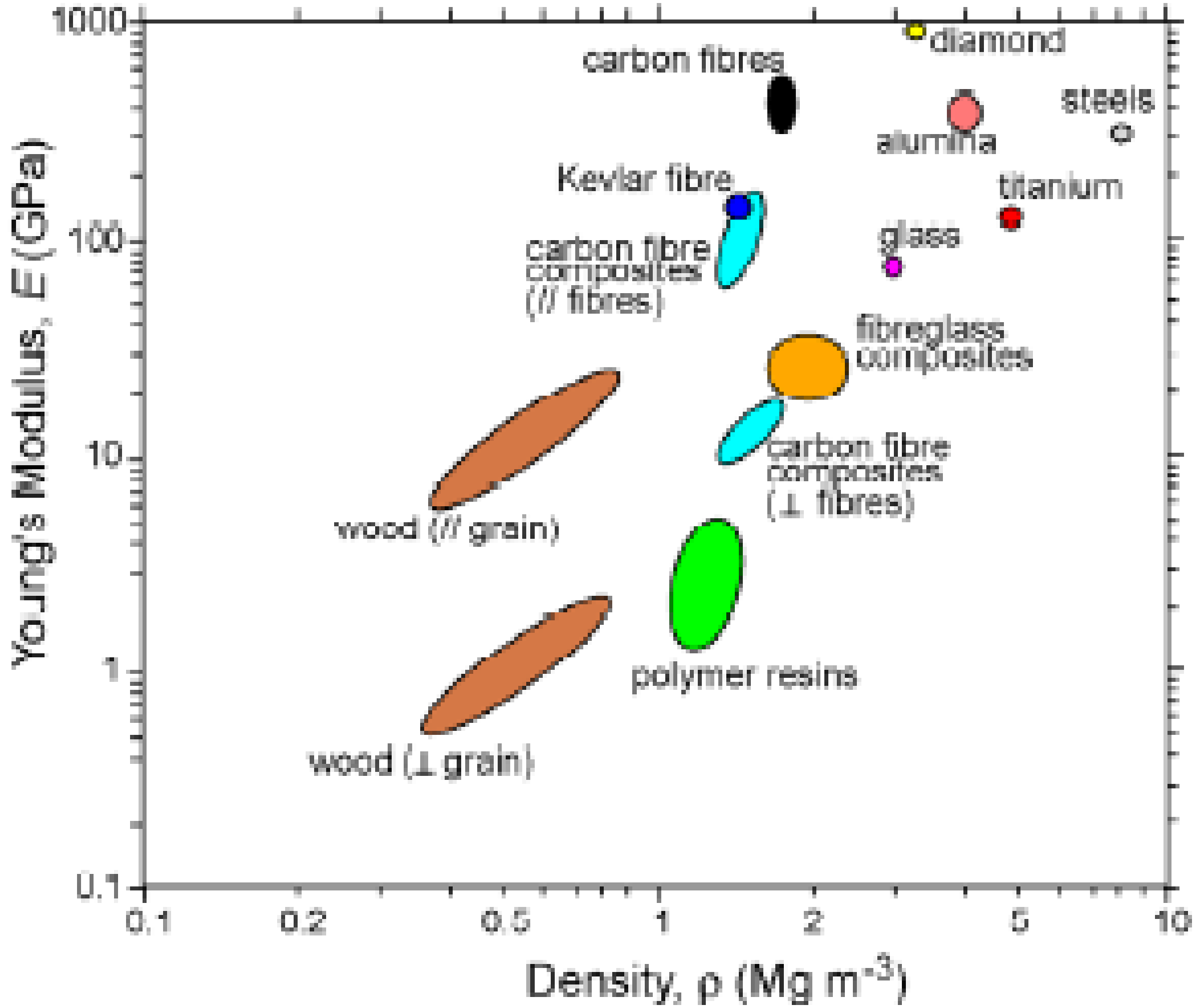
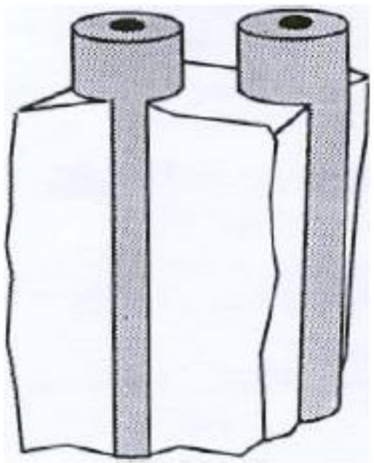


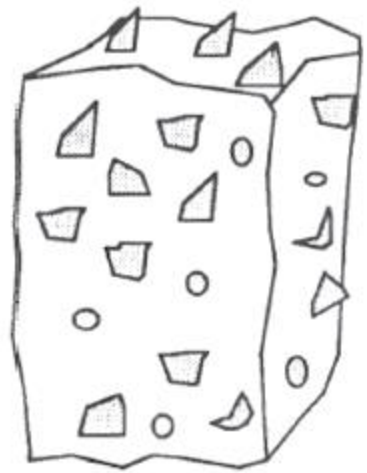
Fig.1.1 Data for some engineering materials, in the form of a map of Young's modulus against density.

Reinforcement shape



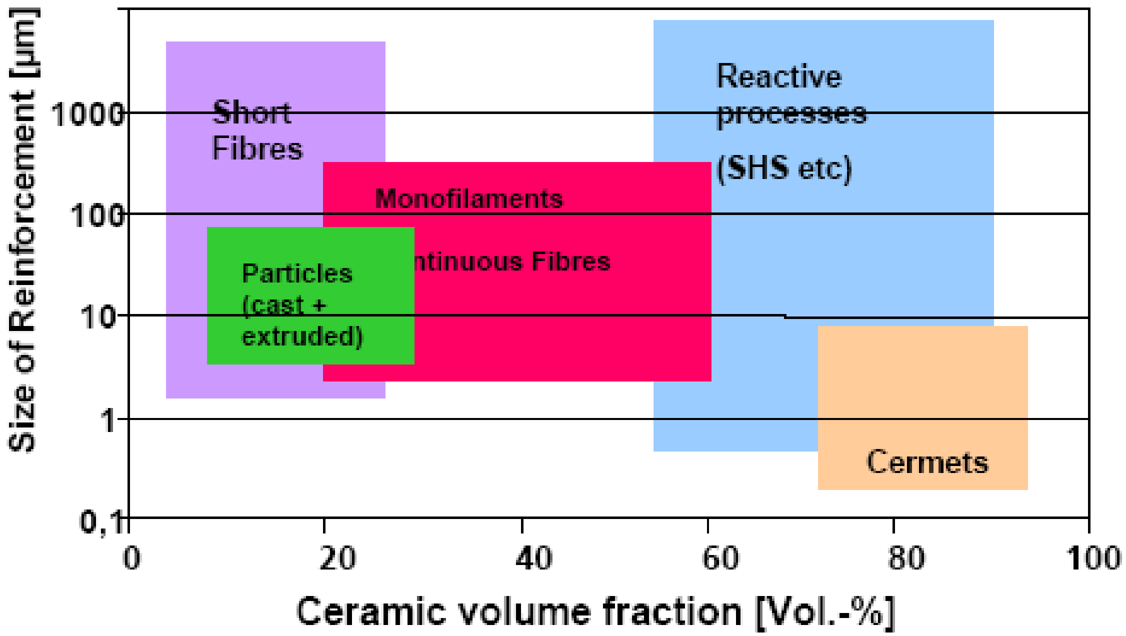
Fibers

Whiskers

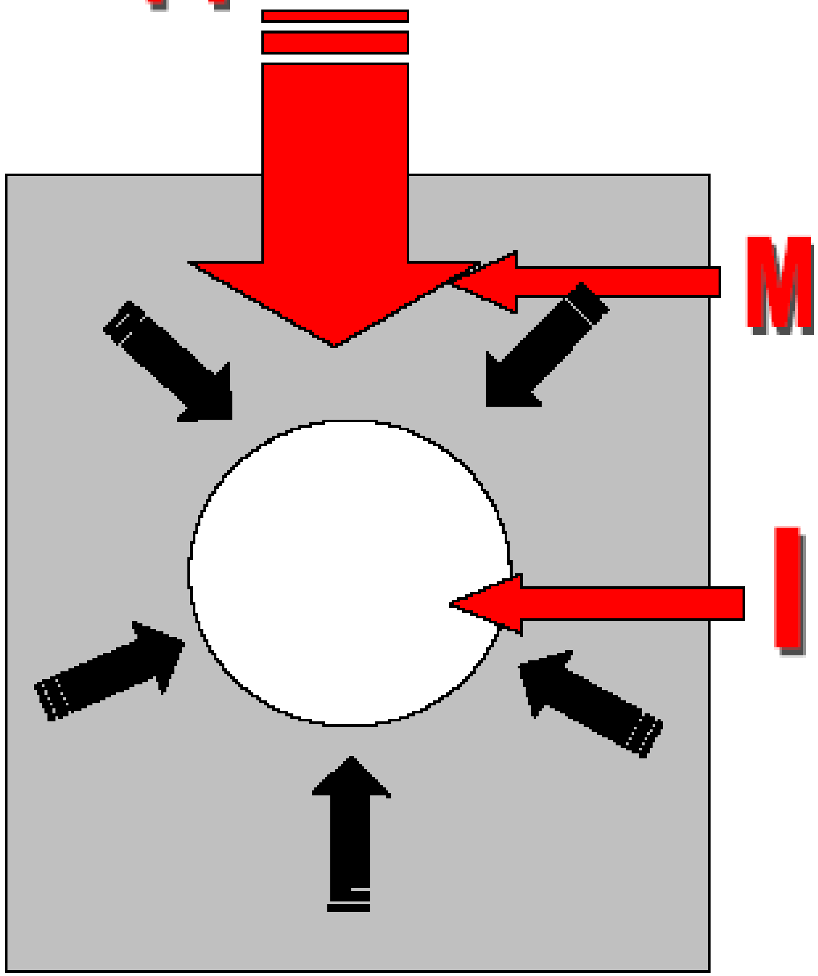


Particles

Metal-Ceramic-Composites



Applied load



Load transfer

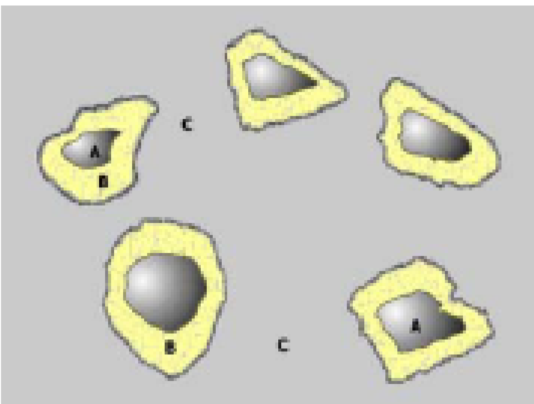
$$(1-f)\,\langle\sigma_M\rangle + f\,\langle\sigma_I\rangle = \sigma_A$$

- **Volume fraction (f);**
  Reinforcement shape;
- **Reinforcement orientation;**
- **Elastic properties of both phases.**

Introduction: Strengthening

What are the strengthening mechanisms in MMC ?

Strengthening mechanism 1: Strain hardening



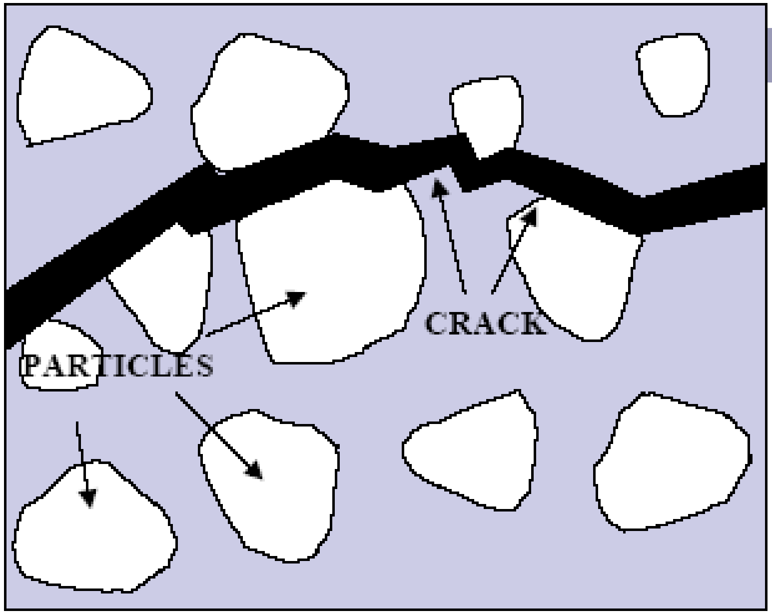
Source: MMC-Assess

- Reinforcement has lower thermal expansion coefficient than matrix

⇒ Upon cooling from manufacturing temperature misfit strains build up around particles

⇒ Strengthening relies on strain hardened zone (B) with high dislocation density around particles

- Strengthening is affected strongly by matrix properties
- Strength decreases with increasing temperature



MMC problem

15 % reinforcement volume fraction

> 30 MPa m$^{1/2}$

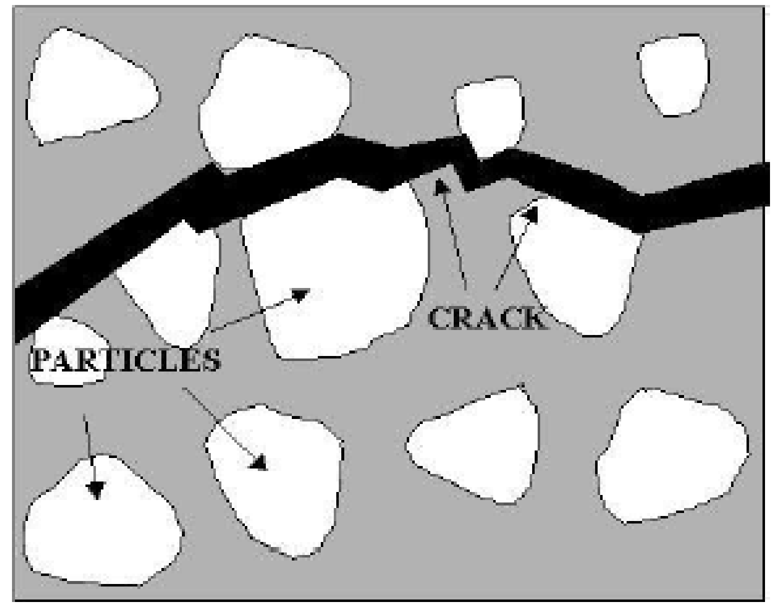
25 % reinforcement volume fraction

~ 10 MPa m$^{1/2}$

Low fracture toughness for "high" reinforcement volume fractions

The introduction of reinforcement in a Metal Matrix causes micro-stresses which may prove to be very **detrimental for the life of the component.**

For example **annealing thermal treatments introduce thermal mismatch stresses**, generated during cooling and due to the difference in the thermal expansion coefficient of the two phases.



Introduction: Strengthening

What are the strengthening mechanisms in MMC ?

Strengthening mechanism 2: Load transfer

- Reinforcement is stiffer than matrix

⇒ If the composite is strained load is transfered from the matrix to the stiffer fibre
⇒ Stress in matrix is smaller than the composite stress
⇒ Stress in fibres is increased
⇒ Composite fails when reinforcement strength is exceeded (e.g. alumina fibres 2 GPa)

- particularly effective for strong reinforcement with high aspect ratio
- predominant in continuous fibre composites
- Strength is controlled by reinforcement properties
- Strength is maintained at moderate temperatures (<400°C)

Samples (I Type): Brake Drum

Matrix:

AA359 Aluminium Alloy

Si	Fe	Cu	Mn	Mg	Zn
8,5 ÷ 9,5	max 0,20	max 0,20	max 0,10	0,5 ÷ 0,7	max 0,10

(%wt.)

Reinforcement:

Silicon Carbide (SiC):

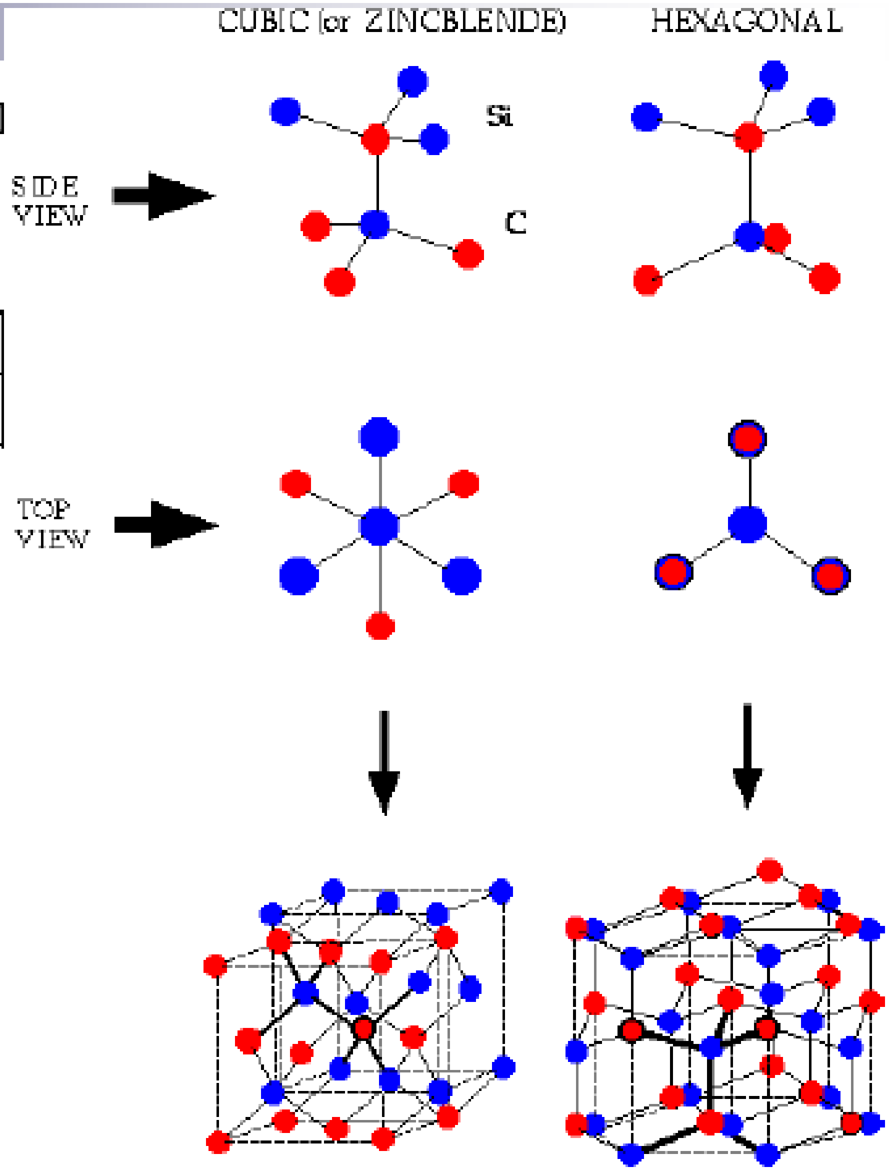
hexagonal and cubic structure

Reinforcement volume fraction:

20 %

Reinforcement shape:

particles



Brake Drum (AA359 + 20 vol. % SiCp)

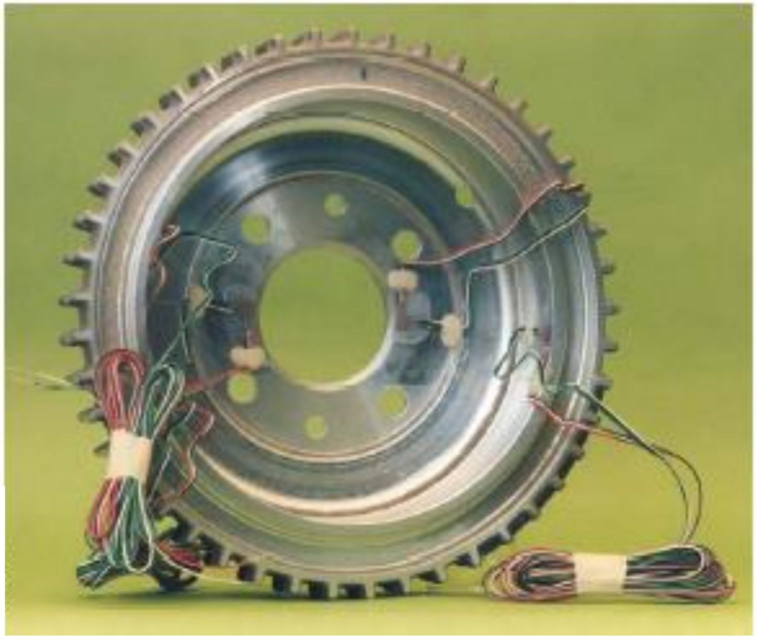
3 identical brake drums → Die-casting → T6 heat treatment

Solubilization: 560°C x 2 hours;
Quenching: H_2O at 20°C;
Aging: 177°C x 10 hours.

1) as-cast brake drum

2) 15000 N for 2065000 cycles
   25000 N for 2600000 cycles
   30000 N for 2500000 cycles
   35000 N for 2500000 cycles

3) broken after 782000
   cycles at 25000 N

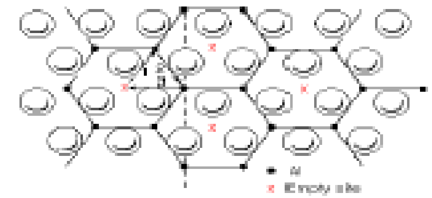


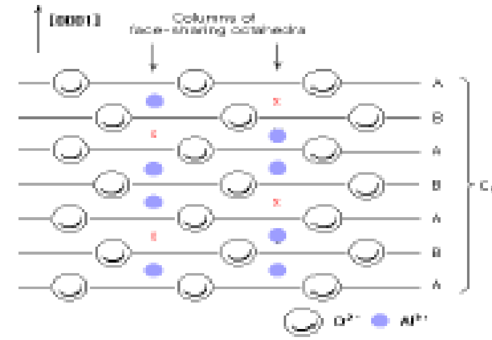
Samples (II Type): Wheel hub

Matrix:
AA6061 Aluminium Alloy

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0,40 ÷ 0,80	max 0,70	0,15 ÷ 0,40	max 0,15	0,8 ÷ 1,2	0.04 ÷ 0,35	max 0,25	max 0,15	base

(% wt.)



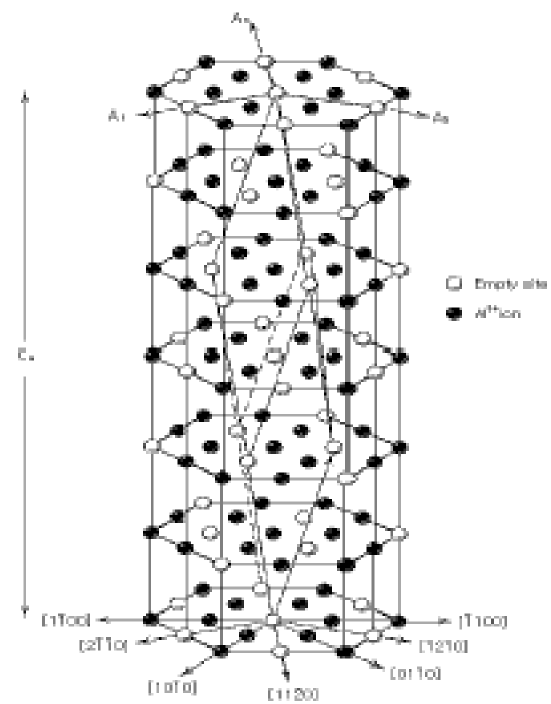


Reinforcement:
Aluminium Oxide (Al_2O_3)

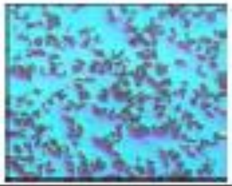
Rhombohedral structure

Reinforcement volume fraction:
22 %

Reinforcement shape:
particles



Introduction: Classical MMC



Particle reinforced MMC

Classical Example: Duralcan

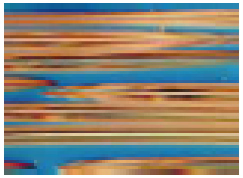
- 10-20% Al_2O_3 particles in AA6061 Al alloy
- Produced by stir casting and extrusion

Properties (15% Al_2O_3)

- Ultimate strength 360 MPa
- Ultimate strength (371°C) 69 MPa
- Elongation at fracture 6%
- Young's modulus 89 GPa
- Fracture Toughness 22MPa√m
- Improved Wear Resistance

Applications:

- Brake Discs (Lotus, VW Lupo 3L)
- Driveshafts etc.



Introduction: Classical MMC

Continuous Fibre Reinforced MMC

Source: 3M

Example: Al alloy reinforced with continuous fibres

- 45-60% Al_2O_3 (Nextel 610) fibres in Al
- Produced by metal infiltration

Properties (in fibre direction, 45% Al_2O_3)

- Ultimate strength 1200 MPa
- Ultimate strength (285°C) 1140 MPa
- Elongation at fracture 0,7%
- Young's modulus 165 GPa
- Low off-axis strength

Applications:

- Composite conductor cables
- Automotive pushrods etc.

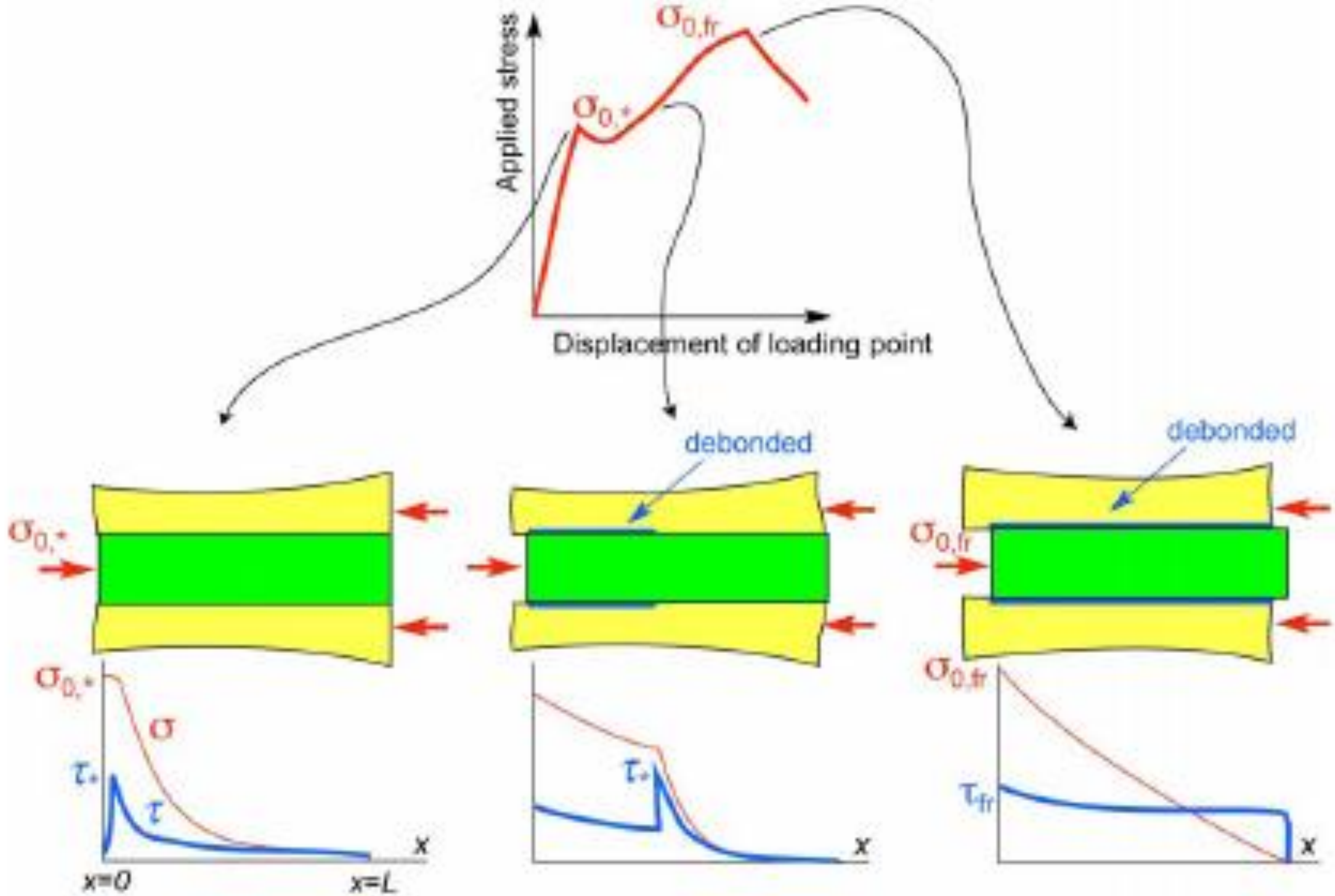


Fig.7.3 *Schematic stress distributions and load-displacement plot during the single fibre push-out test. One difference from the pull-out test is that the Poisson effect causes the fibre to expand (rather than contract), which augments (rather than offsets) the radial compressive stress across the interface due to differential thermal contraction.*

Energy of Interfacial Debonding in Fibre Composites

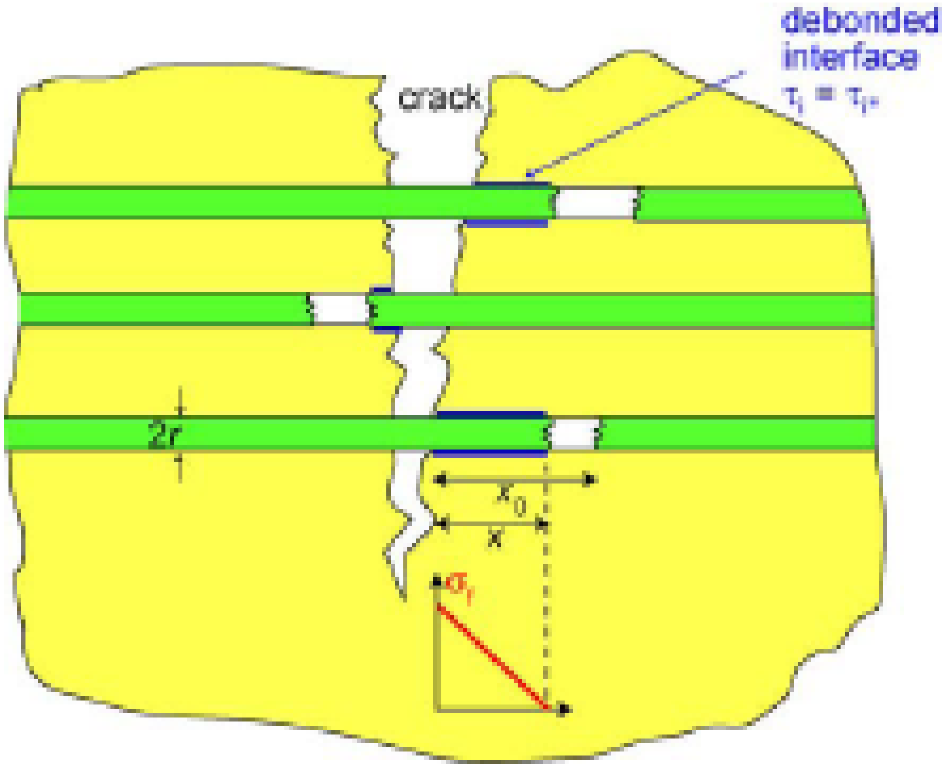


Fig.9.1 Schematic representation of the advance of a crack in a direction normal to the fibre axis, showing interfacial debonding and fibre pull-out processes.

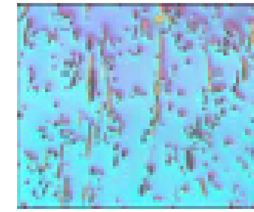
Reinforcement Properties (Table 17.4)

Table 17.4 Characteristics of Several Fiber-Reinforcement Materials

Material	*Specific Gravity*	*Tensile Strength [GPa (10^6 psi)]*	*Specific Strength (GPa)*	*Modulus of Elasticity [GPa (10^6 psi)]*	*Specific Modulus (GPa)*
		Whiskers			
Graphite	2.2	20 (3)	9.1	700 (100)	318
Silicon nitride	3.2	5–7 (0.75–1.0)	1.56–2.2	350–380 (50–55)	109–118
Aluminum oxide	4.0	10–20 (1–3)	2.5–5.0	700–1500 (100–220)	175–375
Silicon carbide	3.2	20 (3)	6.25	480 (70)	150
		Fibers			
Aluminum oxide	3.95	1.38 (0.2)	0.35	379 (55)	96
Aramid (Kevlar 49)	1.44	3.6–4.1 (0.525–0.600)	2.5–2.85	131 (19)	91
Carbon[a]	1.78–2.15	1.5–4.8 (0.22–0.70)	0.70–2.70	228–724 (32–100)	106–407
E-Glass	2.58	3.45 (0.5)	1.34	72.5 (10.5)	28.1
Boron	2.57	3.6 (0.52)	1.40	400 (60)	156
Silicon carbide	3.0	3.9 (0.57)	1.30	400 (60)	133
UHMWPE (Spectra 900)	0.97	2.6 (0.38)	2.68	117 (17)	121
		Metallic Wires			
High-strength steel	7.9	2.39 (0.35)	0.30	210 (30)	26.6
Molybdenum	10.2	2.2 (0.32)	0.22	324 (47)	31.8
Tungsten	19.3	2.89 (0.42)	0.15	407 (59)	21.1

[a] The term "carbon" instead of "graphite" is used to denote these fibers, since they are composed of crystalline graphite regions, and also of noncrystalline material and areas of crystal misalignment.

Introduction: Classical MMC



Short Fibre Reinforced MMC

Source:Kolbenschmidt

Example: piston alloy reinforced with short fibres
- 11-27% Al_2O_3 short fibres (Saffil) in AlSi12CuMgNi
- Produced by squeeze casting

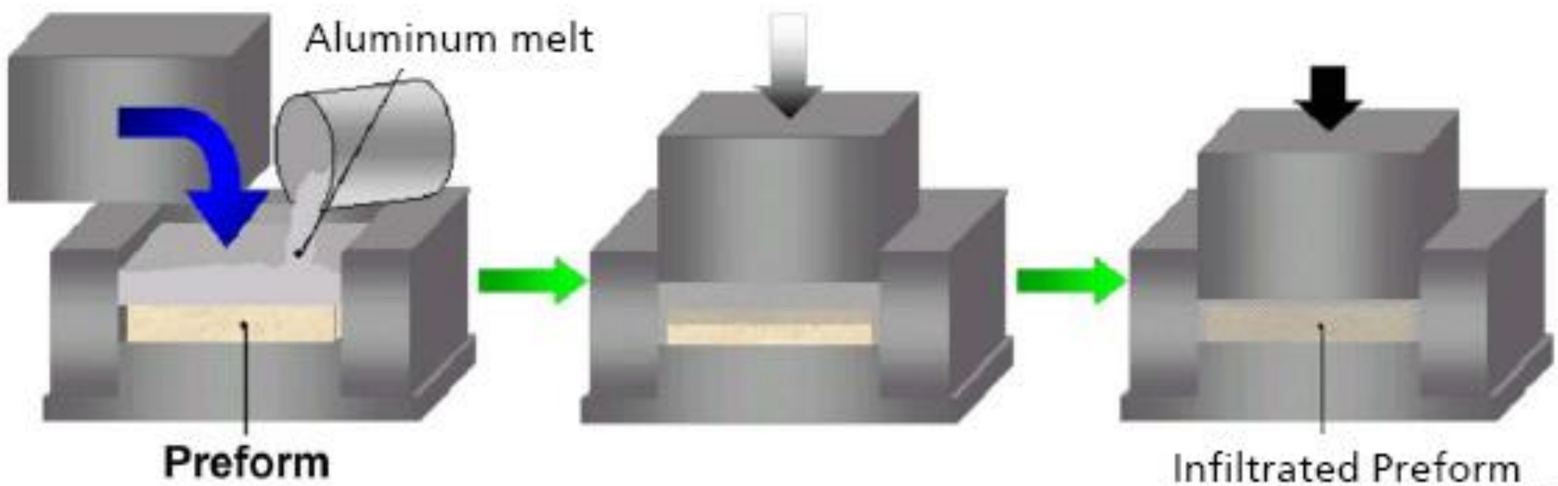
Properties (20% Al_2O_3)
- Ultimate strength 330 MPa (vs 220 MPa pure matrix alloy
- Elongation at fracture 0,35% (vs 1% pure matrix alloy)
- Young's modulus 98 GPa (vs 78 GPa pure matrix alloy)
- 3 times life time increase during thermal cycling at 350°C

Applications:
- Local reinforcement of pistons

Preform-MMC -Definition

Potential Solution: Preform MMC

produced by infiltration of a metal melt (typically Al alloys) into a low cost porous ceramic preform (e.g. Al_2O_3, SiC, Si, TiO_2)



Preform-MMC: Infiltration

How does the infiltration process work ?

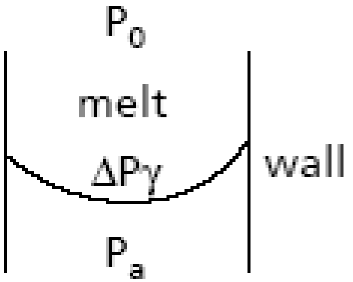
=>
Pressure p at the liquid-gas interface is required to move infiltration front

Pressure acting on the liquid-gas boundary P is governed by the difference between the external and pressure inside the preform (P_0-P_a) and the capillary pressure $\Delta P\gamma$:

$$P = P_0 - P_a - \Delta P_\gamma$$

where

$$\Delta P_\gamma = -\frac{A_v \gamma_m \cos\theta}{(1-V_f)}$$



θ is the wetting angle,
γ_m is the surface energy of the melt,
A_v is the interfacial density (in m^2/m^3) and
V_f relative density of the preform

3.2 Typical Values and Trends

K_{Ic} values of typical ceramics (MPa√m): 2-6 (up to 20 for WC);
metals and alloys: 20-200.

↓

Ceramic with metal reinforcement: increase toughness.
Metal with ceramic reinforcement: increase stiffness, (strength), abrasion resistance, lower CTE.

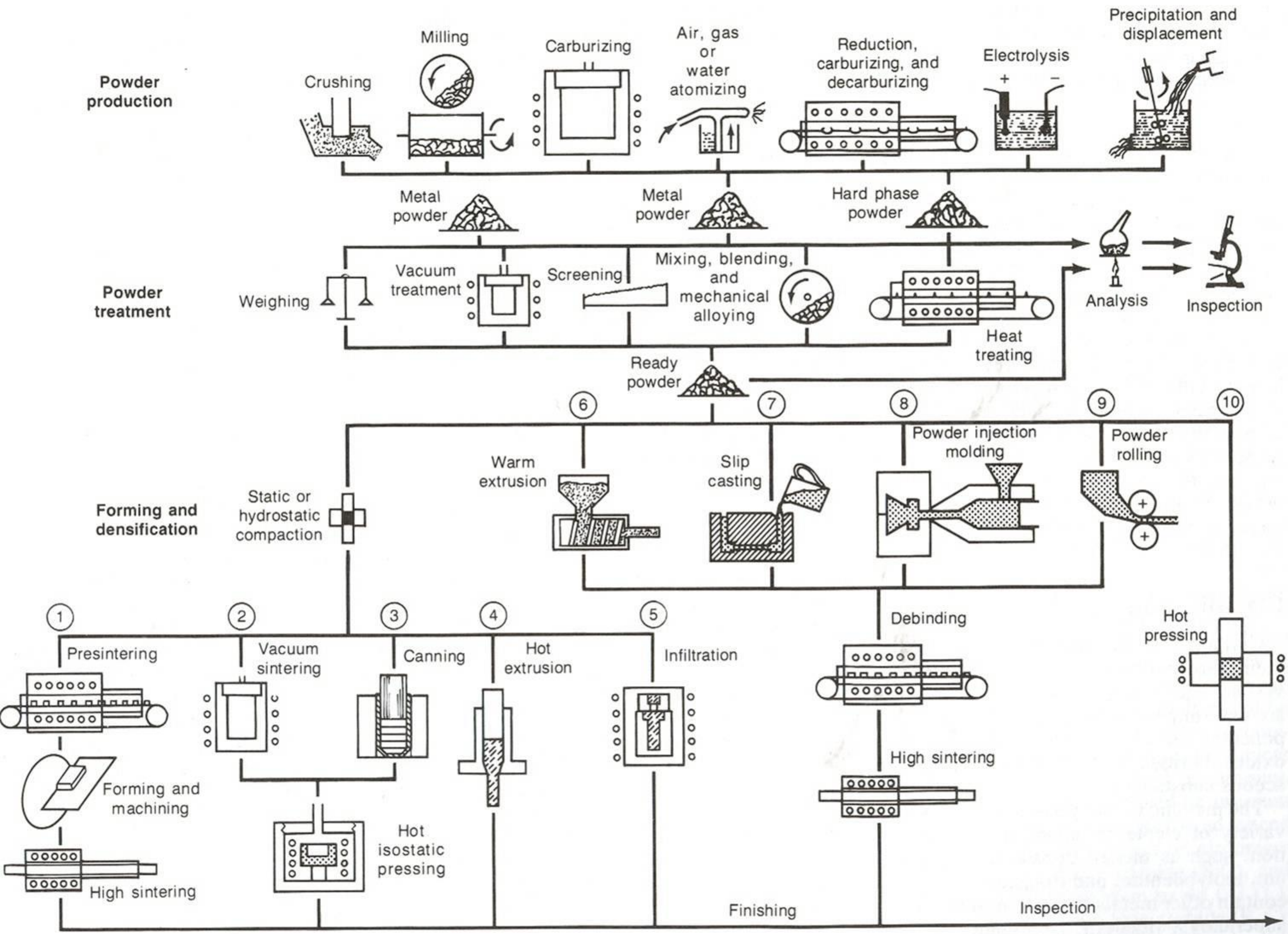
↓

"Metallic character": metal reinforced with particles or short fibres; metal reinforced with long fibres, stressed normal to the fibre axis.
"Ceramic character": ceramic reinforced with particles or fibres; interpenetrating composite.
Specific cases: metal reinforced with long fibres, stressed parallel to the fibre axis, layered composite.

Table 1 History of cermet product development and marketing

Year	Composition	Trademark	Manufacturer
1930–1931	WC-Co	G1	Krupp-Widia
1930	$TiC-Mo_2C$-(Ni, Mo, Cr)	Titanit S	Metallwerk Plansee
1930	TaC-Ni	Ramet	Fansteel Corporation
1933	TiC-TaC-Ni	...	Siemens AG
1938–1945	TiC-VC-(Fe, Ni, Co)	...	Metallwerk Plansee
1949–1955	TiC-(NbC)-(Ni, Co, Cr, Mo, Al)	WZ	Metallwerk Plansee
	TiC-(Nb, Ta, Ti)C-(Ni, Mo, Co)	Kentanium	Kennametal
1952–1954	TiC-(steel, Mo)	Ferro-TiC	Sintercast (Chromalloy)
1960	TiC-(Ni, Mo)	...	Ford Motor Company
1970	Ti(C, N)-(Ni, Mo)	Experimental alloys	Technical University Vienna
1974	(Ti, Mo) (C, N)-(Ni, Mo)	Spinodal Alloy	Teledyne Firth Sterling
1975	$TiC-TiN-WC-Mo_2C$-VC-(Ni, Co)	KC-3	Kyocera
1977–1980	$TiC-Mo_2C$-(Ni, Mo, Al)	...	Ford Motor Company, Mitsubishi
1980–1983	(Ti, Mo, W) (C, N)–(Ni, Mo, Al)	...	Mitsubishi
1988	(Ti, Ta, Nb, V, Mo, W) (C, N)-(Ni, Co)-Ti_2AlN	TTI, TTI 15	Krupp-Widia

Source: Ref 4 and Kennametal, Inc.



Powder production
Crushing
Milling
Carburizing
Air, gas or water atomizing
Reduction, carburizing, and decarburizing
Electrolysis
Precipitation and displacement
Metal powder
Metal powder
Hard phase powder
Powder treatment
Weighing
Vacuum treatment
Screening
Mixing, blending, and mechanical alloying
Heat treating
Analysis
Inspection
Ready powder
Forming and densification
Static or hydrostatic compaction
6
Warm extrusion
7
Slip casting
8
Powder injection molding
9
Powder rolling
10
Hot pressing
1
Presintering
Forming and machining
High sintering
2
Vacuum sintering
3
Canning
Hot isostatic pressing
4
Hot extrusion
5
Infiltration
Debinding
High sintering
Finishing
Inspection

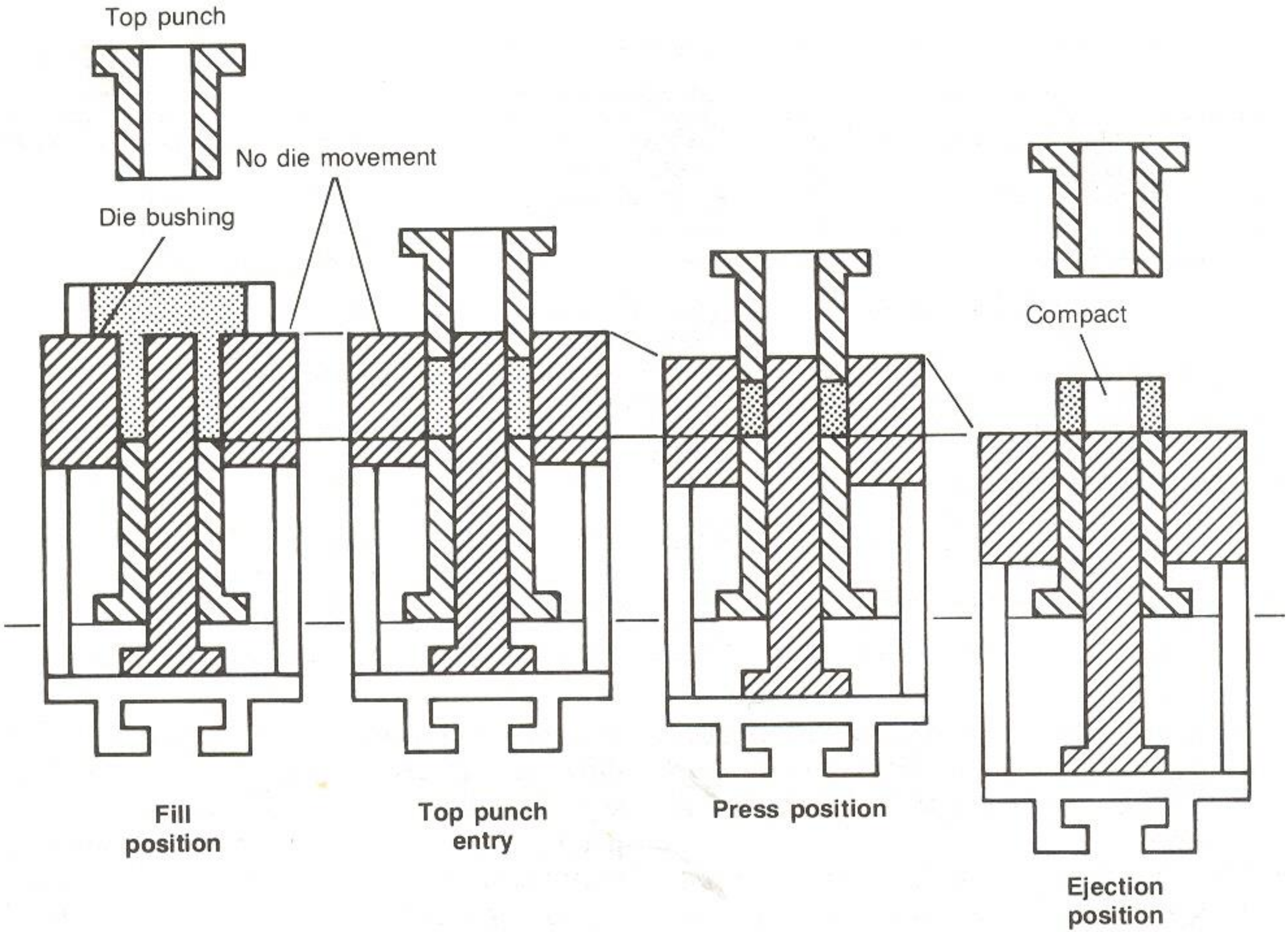


Fig. 3 Withdrawal press cycle with controlled die motion (top and bottom pressure). Courtesy of Dors America

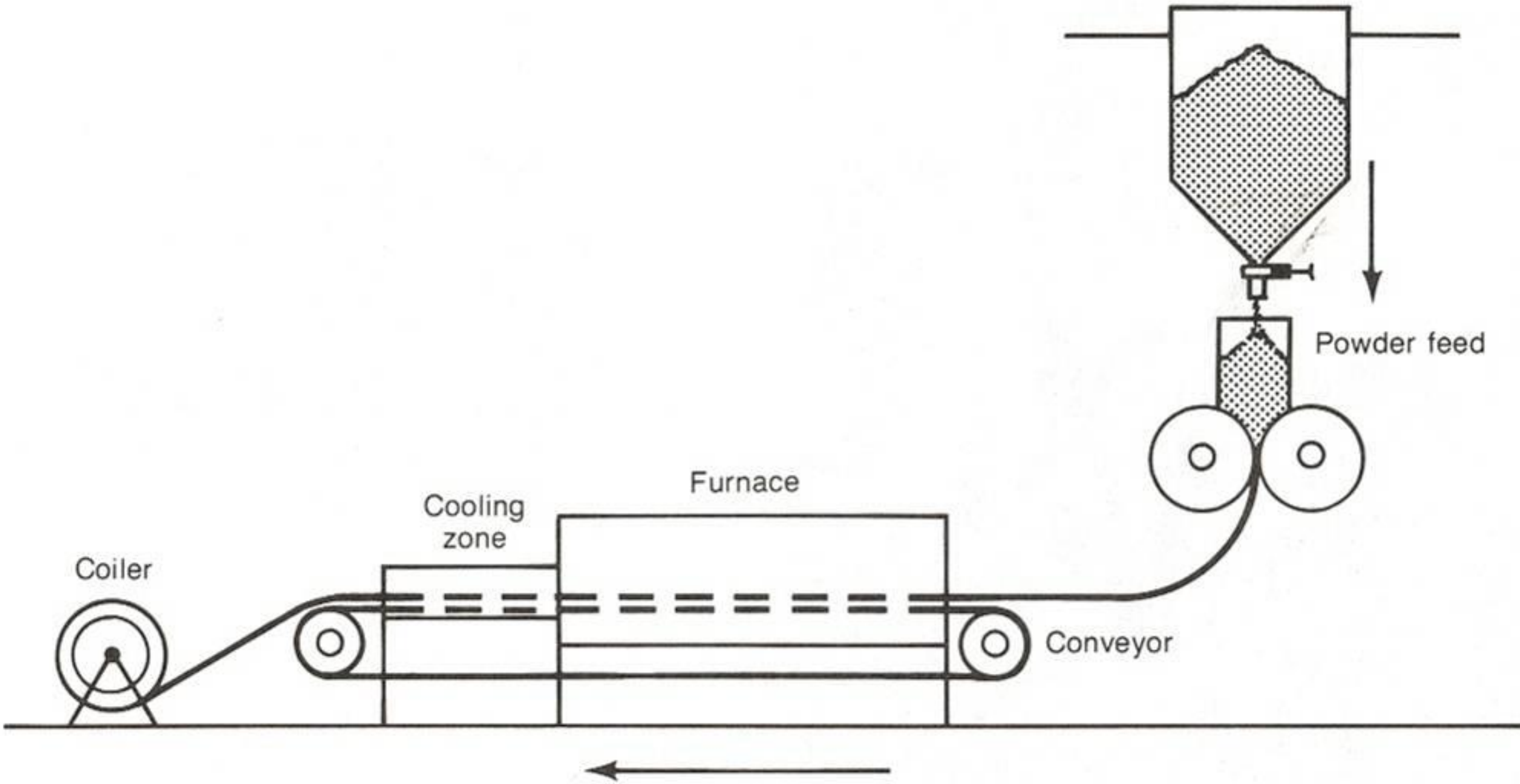


Fig. 8 Powder rolling process with strip reeled into individual rolls after first sintering treatment. Source: Ref 7

How to produce "In situ" reinforced Titanium Matrix Composites (2)

Process developed at INASMET (N° PCT/ES03/00596)

1. **Production of Ti/TiB master compound (SHS).**
2. **Dilution of this master compound in a casting process to obtain TMCs (Investment casting).**

SHS

Production of highly reinforced Ti/TiB master compound

INVESTMENT CASTING

Welding of the master compound on the titanium alloy ingots/or direct addition

Induction/arc melting

Casting

Final TMC component: Isotropic properties or anisotropic when further extruded or forged

Composite Processing

- **We assist advanced composite manufacturing through every life-stage:**
  - …through tooling…

Composite Processing

Gurit

- **We assist advanced composite manufacturing through every life-stage:**
  - …through build…

SWAN 601 CASE STUDY - DECK

Composite Processing

- **We assist advanced composite manufacturing through every life-stage:**
  - From initial sketches…