Steel-Ceramic-Composites: Some basic considerations on particle selection criteria

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Content

- **Motivation & Approach**
- **Theoretical considerations**
  - General selection criteria for particles
  - Chosen criteria & particles
  - Calculation results
- **Results from tests on laboratory scale**
- **Summary & Conclusion**

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Motivation

- **Aim of project:**

  Reduction of density $\rho_{MMC} < \rho_{Steel}$
  Stiffness equal or higher than steel

- **Chosen approach to achieve the aim:**

  Combination of Steel & ceramic particles (d<10µm)
  Content of ceramic particles: < 20 Vol.-%

- **Final aim:**

  Production of Lightweight steels on large scale (CCC e.g.)

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criteria

- **General selection criteria for reinforcing phase of MMC‘s**
  - Density
  - Young‘s Modulus
  - Hardness
  - Thermal expansion coefficient
  - Thermal conductivity
  - Electrical conductivity
  - Price
  - Geometry
    - fibres, particles, …
    - mean diameter, …
  - Wettability
  - Thermodynamical stability
  - …

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$$M_{MMC} = \frac{\sqrt[3]{E_{MMC}}}{\rho_{MMC}}$$

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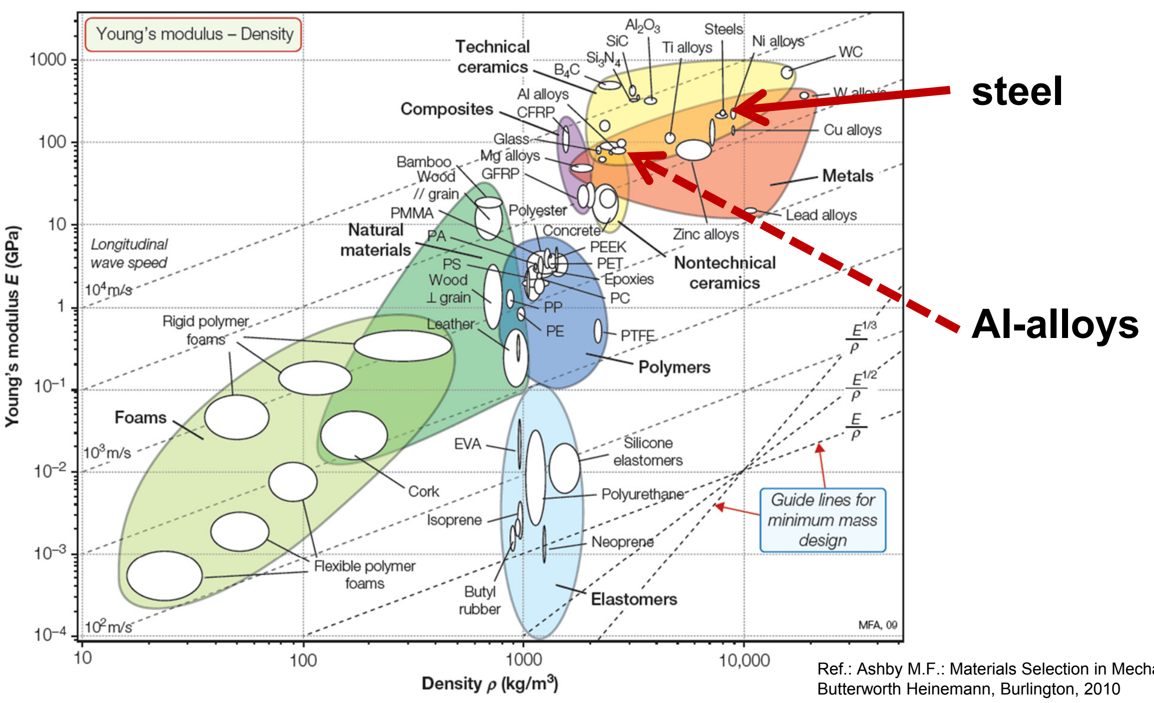
Idea:
Injection or stirring into liquid steel

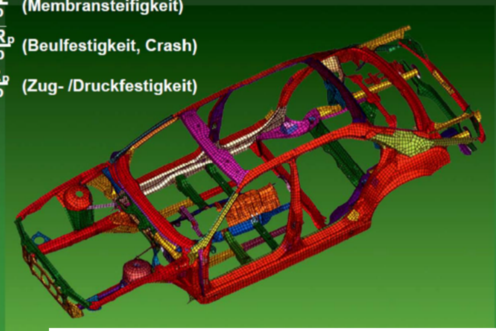
Criterion of Excellence



Ref.: Ashby M.F.: Materials Selection in Mechanical Design, Butterworth Heinemann, Burlington, 2010

Criteria for lightweight structures

1. $\frac{E}{\rho}$ (Membransteifigkeit)
2. $\frac{\sqrt{R_p}}{\rho}$ (Beulfestigkeit, Crash)
3. $\frac{R_p}{\rho}$ (Zug- /Druckfestigkeit)



Steel content in car structure ~65%

Ref.: Walch C.: „Vom Stahlblech zur Karosserie“, Presentation at CoM „Herstellungswege für Sonderstähle“, SS13.

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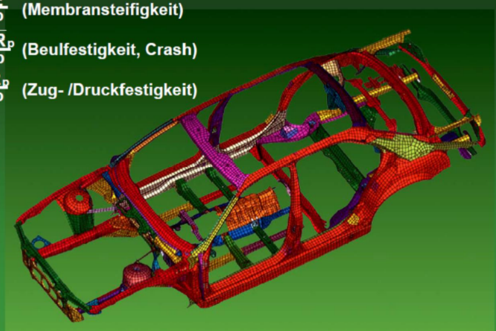

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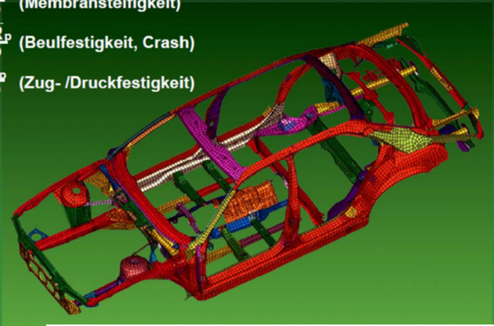

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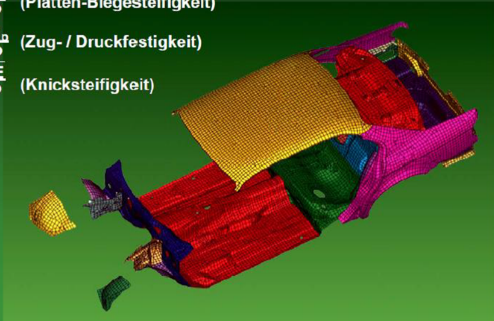

Steel content in car body shell ~35%

Ref.: Walch C.: „Vom Stahlblech zur Karosserie“, Presentation at CoM „Herstellungswege für Sonderstähle“, SS13.

Increase the amount of steel products (automotive body shell) → flat products

$$M_{MMC} = \frac{\sqrt[3]{E_{MMC}}}{\rho_{MMC}}$$

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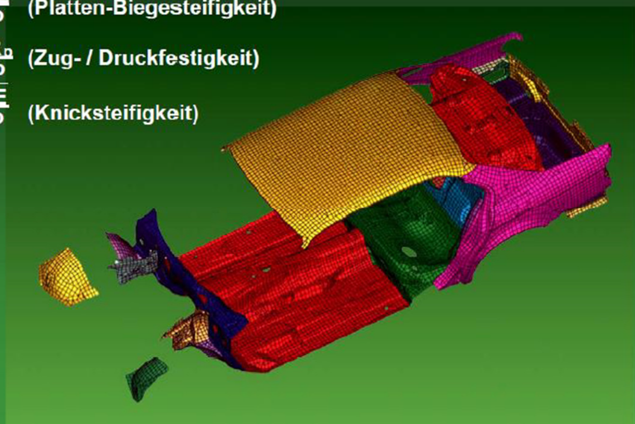

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Selected ceramics - data

	ρ [g/cm³]		T_m [°C]		E [GPa]		HV		θ [°]	
AlN	3.3	[3]	2760	[4]	310	[3]	1230	[4]	130 (NH_3)	[5]
BN (hex)	2.2	[6]	2966	[4]	90	[7]	1000	[3]	112 (1550°C)	[6]
TiB_2	4.5	[4]	2980	[4]	530	[4]	3300	[4]	42-92 (1550°C)	[8]
TiC	4.9	[4]	3150	[4]	450	[4]	3000	[4]	60 (1550°C)	[5]
ZrO_2	5.9	[9]	2680	[9]	210	[7]	1300	[9]	119-122	[10]

$$\rho_{MMC} = f_p \cdot \rho_p + (1 - f_p) \cdot \rho_M$$

$$E_{MMC} = \frac{E_m \cdot E_p}{f_p \cdot E_m + (1 - f_p) \cdot E_p}$$

$$M_{MMC} = \frac{\sqrt[3]{E_{MMC}}}{\rho_{MMC}}$$

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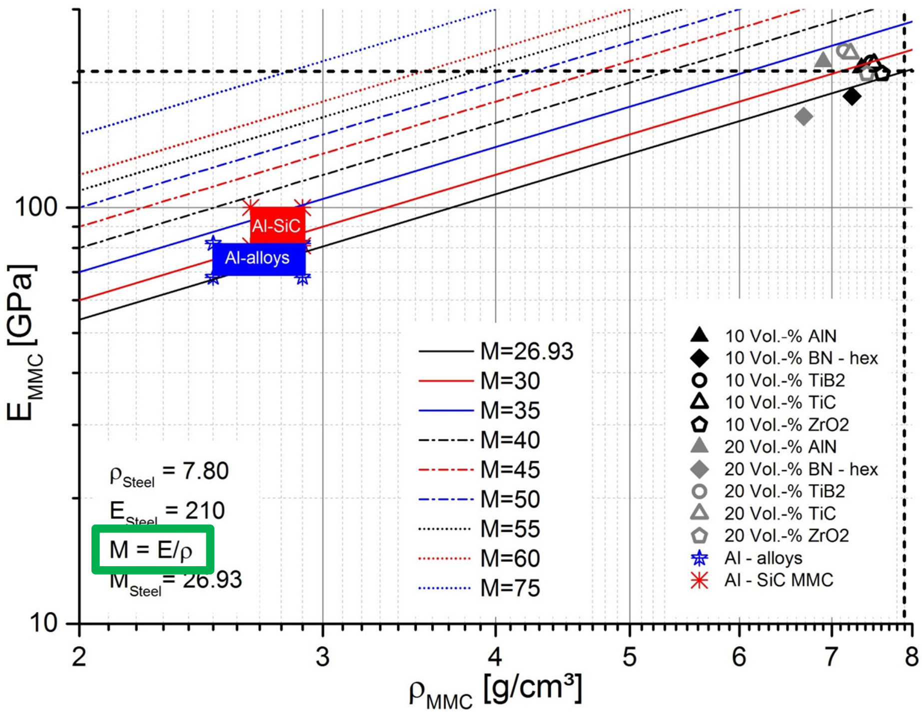
Results for e.g. car-pillars



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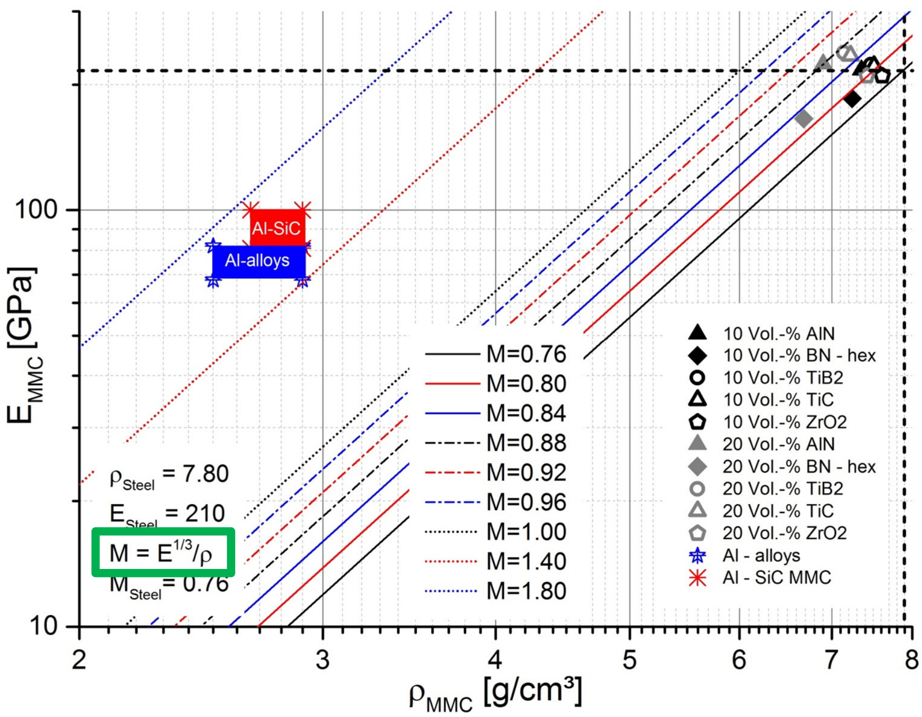
Results for e.g. body shells



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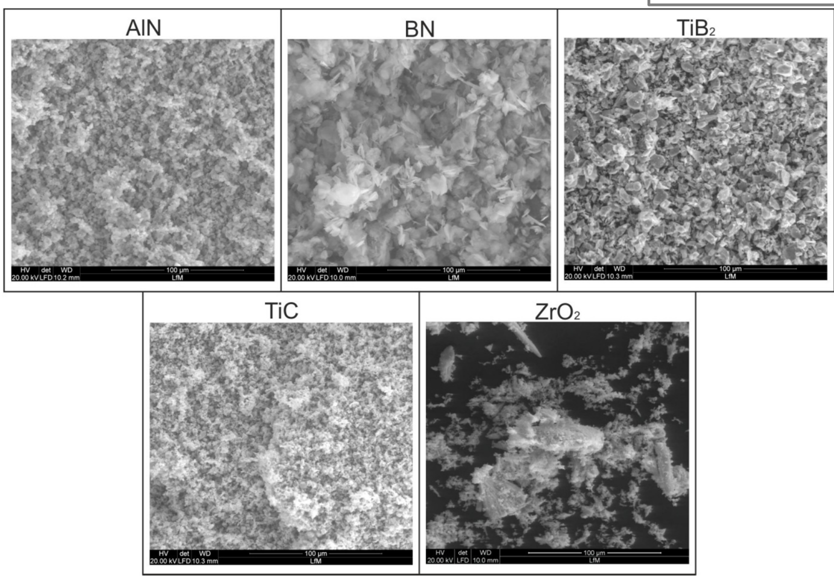
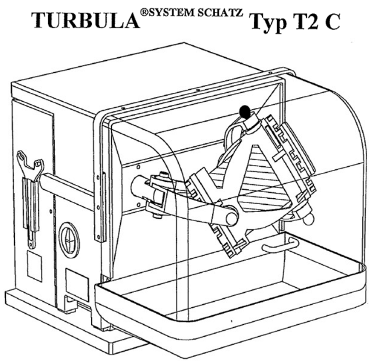
Selected particles

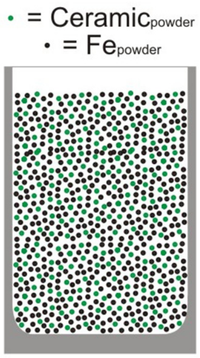


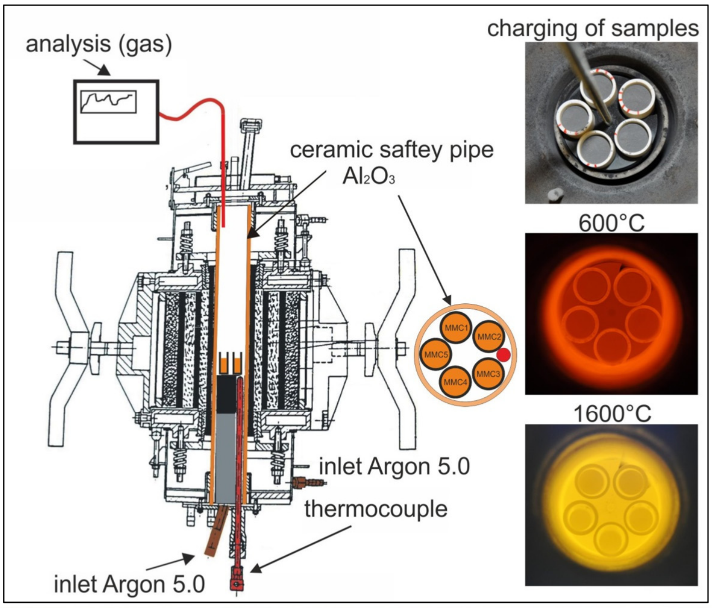
Ceramic	d_{50} [µm]	alternative size information	cleanness	geometry (after SEM/EDS images)
AlN	7.0 - 11.0	-	99%	square, fine powder
BN	4.0 - 7.5	-	99%	platelike
TiB_2	3.5 - 6.0	-	98.9%	square
TiC	1.0 - 3.0	-	99%	square, fine powder
ZrO_2	-	-325 mesh	99%	square, gross powder

Experimental Setup

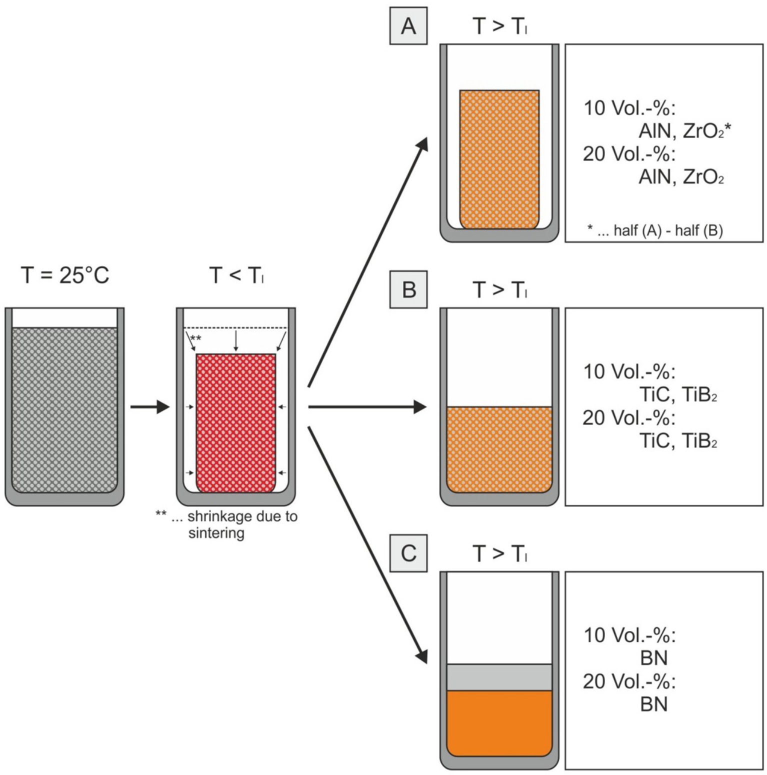


Iron powder &
10 or 20 Vol.-% ceramic particles





MMC – sample behavior

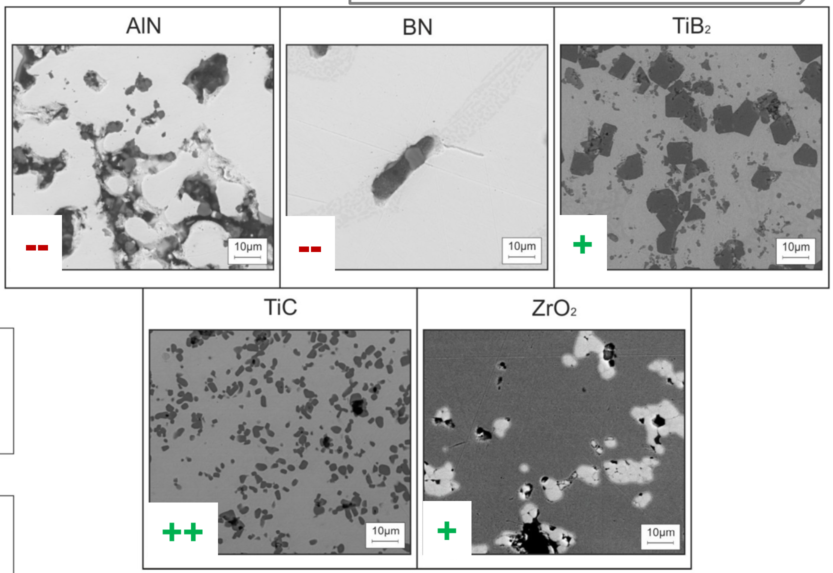


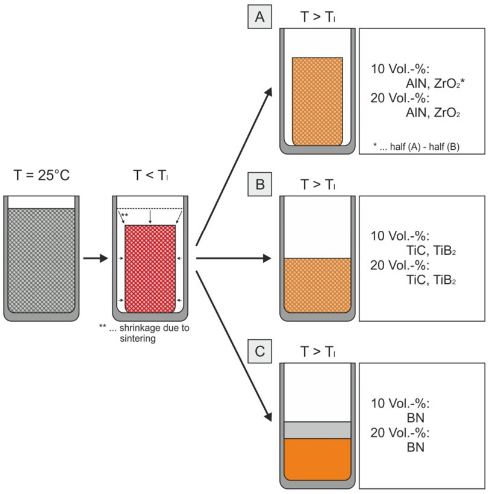
MMC keeps sintered geometry

MMC flows towards the inner alumina crucible geometry

Complete separation of both phases

MMC – sample behavior





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Summary & Conclusion

- **Density reduction & stiffness increasement possible**
  - Nitrides → thermodynamic instability is the main problem, no MMC.
  - Borides → dissolution leads to unfavorable phases (e.g. Fe_2B)
  - Carbides → dissolution leads to good wettability → good distribution
  - Oxides → poor wettability is the main problem → agglomerations

- **Thermodynamic stability & wettability are a key factor for MMC and have to be taken into account during particle selection.**

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Thank you for your Attention

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