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Reinforced Light Metals for Automotive Applications

Florian Bechmann, Peter Fallböhmer, Rudolf Stauber
BMW Group

Christian Rauber, Andreas Lohmüller, Mark Hartmann, Robert F. Singer
Neue Materialien Fürth GmbH

ABSTRACT

Efficiency and dynamic behavior of a vehicle are strongly affected by its weight. Taking into consideration comfort, safety and emissions in modern automobiles, lightweight design is more of a challenge than ever in automotive engineering. Materials development plays an important role against this background, since significant weight decrease is made possible through the substitution of high density materials and more precise adjustment of material parameters to the functional requirements of components. Reinforced light metals, therefore, offer a promising approach due to their high strength to weight ratio. The paper gives an overview on matrix and reinforcement structures suited for the high volume output of the automotive industry. Further analytical and numerical approaches to describe the strengthening effects and the good mechanical characteristics of these composite materials are presented. The potential of reinforced light metals is shown by means of compression samples cast in laboratory scale.

INTRODUCTION

Lightweight design is a central aim in the present-day automobile development process. As fuel economy and exhaust emissions are strongly connected with a vehicle's weight, tightened customer and legal requirements as well as the voluntary ACEA (European Automobile Manufacturers Association) commitment necessitate lightweight material and design concepts.

Beyond economical and ecological reasons lightweight construction is an important measure to ensure the driving pleasure that BMW automobiles stand for. In recent years, significant innovations in this sector were introduced, such as the reduced-weight aluminum front-end in the BMW 5-series or the composite Mg/Al crankcase in the new six cylinder engines.

Weight reduction has not only played an important role for the current vehicle generation. Figure 1, employing the 3-Series as an example, illustrates that measures to reduce mass have always been taken. Aluminum and polymers have been in particularly high demand in recent decades in order to reach target weights. From model year 1979 to model year 2005 the vehicle weight increases by 30 percent due to significantly augmented vehicle options and functionality. Through further employment of lightweight construction, the increasing weight spiral in the current 3-series sedan could be completely stopped in its tracks.

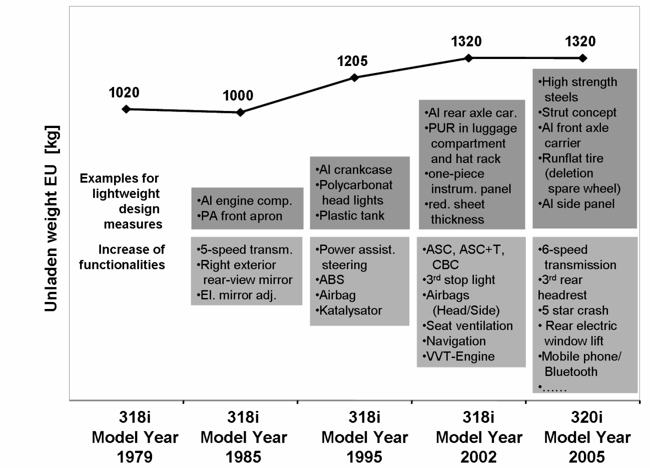

Figure 1: Unladen weight (EU) of BMW 3-series

In the following section, we will discuss the vehicle weight obstacles that future automobiles face.

LIGHTWEIGHT DESIGN

CHALLENGES

The progress in automobile development is accompanied by a large number of customer valued improvements. Compared to 70s version a present-day 3-series model shows:

- Larger dimensions:
  Length: +4%, Width: +25%, Height: +3%

- Higher efficiency:
  Fuel consumption: -25%, Engine output: +50%, Engine torque: +40%
- More comfort functions:
  Seat functions, electric mirror adjustment, air conditioning system, …

These improvements involve, on one hand, installation of additional components and periphery, and on the other, engine, chassis and body components that could withstand greater loads. Both aspects have high mass increase potential. New customer-worth functionalities are always being developed, for instance equipment to enable car-to-car communication and park-assistance poses further challenges for lightweight design.

Another function that has a direct correlation to lightweight design is vehicle safety. Here one has to distinguish between active and passive safety. Active safety systems help to avoid accidents. Some examples are electronic stability control systems, adaptive head lighting or two stage brake force display. The integration of such systems entails the installation of additional components, promoting weight increase.

Passive safety systems protect the occupants once an accident becomes unavoidable. Thereby the body-in-white is a decisive part of the vehicle. It has to fulfill two major tasks during an accident: minimization of occupant strain and maintenance of necessary survival space. The latter task requires a stiff body structure. Sophisticated solutions are demanded to realize high stiffness without mass increase by means of higher wall thickness or additional struts.

As new, stricter legal requirements concerning matters such as pedestrian safety are introduced in coming years, the consequential advances in active and passive safety technology are another major challenge in lightweight construction.

In addition to comfort and safety functions, a new cause for weight increase has arisen. CO_2/emission technologies and hybrid power train concepts require a multitude of new modules, for instance electric motor, storage units, electronics and cable infrastructure. The additional weight of these systems results in higher fuel consumption, and thus a part of the CO_2 saving potential is lost.

EFFICIENT DYNAMICS

The correlation between increase of functionalities and decrease of efficiency is illustrated in figure 2 on the vertical axis. The horizontal axis gives the second major dependency. As important as lightweight design is for achievement of efficiency targets, it is just as important for a vehicle's dynamic behavior. Due to additional translatory and rotatory inertia, heavy vehicles offer low acceleration and agility.

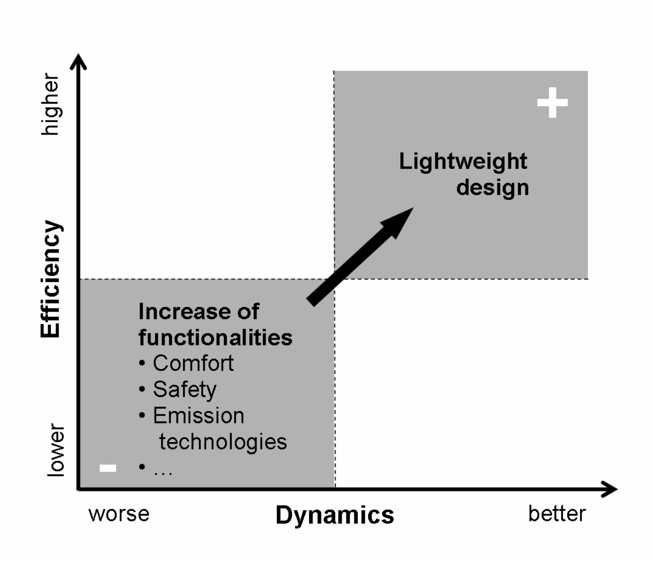

Figure 2: Efficient Dynamics by lightweight design

Increased emphasis on lightweight construction is required to ensure a high standard of driving dynamics. Along with the gross vehicle weight, the distribution of mass is extremely important. Optimum weight distribution is the genetic precondition for superior overall driving dynamics, since the determinants of longitudinal and transverse dynamics (axle load distribution, center of gravity height, ratio sprung to unsprung mass) are directly associated with weight distribution.

Well directed lightweight measures are therefore a key element to ensure efficient dynamics and to provide 'sheer driving pleasure' to automobile drivers.

TARGETS FOR MATERIAL DEVELOPMENT

Two types of lightweight design are particularly relevant in automotive material development: weight reduction by material design and conceptual weight reduction.

Weight reduction by material design means the substitution of materials with high density, in first instance steel and cast iron, by materials with lower density, primarily light metals and polymers. The composite Mg/Al crankcase, the aluminum front-end, the thermoplastic side panel and the carbon fiber reinforced plastic roof show the great progress that could already be reached in this sector. Material lightweight construction definitely continues to be a field of work in automobile engineering, but in terms of weight, properties and cost it becomes more and more sophisticated to develop solutions suited for high volume application. In first instance new developments are expected to be launched in high technology low volume series or in case of high functional benefit.

Conceptual weight reduction denotes weight optimization by tailoring components as exactly as possible to existing loads and other requirements. Three approaches achieve improvements:

1. Tapping further potential at recording and specification of design relevant loads
2. Exhausting full capacity of materials by development and use of more exact material models in virtual integration of vehicle function
3. Stronger adjustment of material concepts to functional requirements of components

Generally the stronger adjustment of material concepts to requirements can be realized on three routes. A traditional approach involves the variation of the currently used alloys. Due to processing and cost aspects, this approach is limited, and new developments in this sector often involve strenuous efforts. Nevertheless, the development of the AJ62 magnesium alloy [2] cast in the composite Mg/Al crankcase shows that significant improvements are possible in this field of research.

An alternative way to weight and strain optimized components is the combination of different materials in one component – for example magnesium with aluminum or steel with polymers. Such a configuration is able to create parts with new functional spectrums on the basis of present-day available materials. But as with every material mix, they often entail joining, corrosion and recycling problems.

The third approach is demonstrated by composite materials. These consist of at least two chemically and physically distinct phases. For automotive applications, the combination of low density polymer or light metal matrices with ceramic or carbon phases is very interesting, as such composites offer promising mechanical characteristics with respect to the matrix material and at the same time similar low weight. Polymer matrix composites (PMCs) typically feature lower density compared to metal matrix composites (MMCs) whereas MMCs show higher strength and stiffness, higher service temperatures, better transverse properties and higher thermal and electrical conductivity [3]. As PMCs and MMCs strongly differ in application range and processing routes, this paper focuses on light metal matrix composites.

Regarding reinforcement of light metals, there exist basically two alternatives – global and local. Global reinforcement means identical build up of the composite throughout the entire part. Beside common improvement of properties in relation to unreinforced polymers or metals, this type of reinforcement is also interesting because of its diversification potential. By omitting or including the strengthening phase, parts with identical geometries but different mechanical properties can be produced. This allows low weight component design because the lower loaded vehicle models inside one series do not have to be dimensioned for the loads of the highly equipped models.

Local reinforcement represents another kind of material adjustment to component requirements. Heavily loaded zones, which usually exclude the usage of light metals, can be selectively reinforced by ceramic structures, thereby allowing the use of these low-density materials. Local reinforcement also has the potential to provide new solutions in terms of diversification.

The following section outlines which matrix alloys and reinforcement phases are considered for automotive application, how the strengthening mechanisms work and what potential for reinforced light metals one can expect. Further progress on the computational modeling of such composite materials is also discussed.

REINFORCEMENT OF LIGHT METALS

MATRIX ALLOYS

The manufacturing of MMC components has to be suitable for high volume output for the automotive industry. Therefore, processes related to established casting technologies are researched and developed. For automotive applications, reinforced light metals are especially interesting because of their high strength to weight ratio. The following aluminum and magnesium cast alloys are employed for development of MMCs.

AZ91 represents the standard magnesium die cast alloy, used due to its excellent castability in various components, such as in convertible top covers, intake manifolds, cylinder head covers or instrument panel carriers. Like most other magnesium alloys, the application of AZ91 is limited by its relatively low temperature strength, which prohibits usage beyond 120℃. A great improvement was achieved by development of the AJ62 alloy, which is able to sustain service temperatures up to 150℃. AJ62 was introduc ed in the new composite Mg/Al crankcase.

Higher mechanical and thermal loadings still require the use of aluminum cast alloys. For the purpose of this research, subeutectic Al-Si-Cu alloys are employed due to their wide field of application, for instance in engine components. Table 1 gives an overview of characteristical mechanical and physical properties of the investigated matrix materials.

	Density [g/cm³]	CTE [10^{-6}*K^{-1}]	Young's Modulus [GPa]	Tensile strength [MPa]
AZ91	1.8	25	45	220 - 260
AJ62	1.8	27	45	239
Al-Si-Cu alloys	2.8	22	70	240 - 310

Table 1 : Typical mechanical and physical properties of light metal cast alloys. For a reasonable comparison, the characteristics are listed as cast by pressure die casting. [1,2,15]

One strives for the enhancement of the mechanical characteristics of these alloys by inserting stronger and stiffer ceramic and carbon structures. The aim is to significantly improve the strength and stiffness characteristics at room and elevated temperature, while retaining the low density of the light metals.

REINFORCEMENT

All of the prevalent types of hard ceramics are basically suited as reinforcement material: oxides, borides, nitrides and carbides. As metallurgical melt processes require chemical resistance between the ceramic phase and the liquid metal, carbides such as SiC could be successfully employed in light metal matrix composites. Alumina, or aluminum oxide, is another option, but there is the risk of reaction with molten magnesium under the formation of magnesia and spinels. Nitrides are already decomposed at lower temperatures. [4]

Along with ceramics, carbon fibers are also valued as reinforcement material due to their excellent strength and stiffness characteristics. Table 2 gives an overview of typical mechanical and physical properties of prevalent hard ceramics and carbon fibers used in MMCs:

	Density [g/cm³]	CTE [10^{-6}*K^{-1}]	Young's Modulus [GPa]	Tensile strength [MPa]
SiC particles	3.2	4.7	430	-
Al_2O_3 particles	3.8-3.9	8.5	380	-
Carbon-fibers	1.8	(-0.4) - (-0.1)	210-379	3200 - 4680

Table 2: Typical mechanical and physical properties of ceramics and carbon fibers used in light metal matrix composites [5,6,7]

The volumetric content of the reinforcement phase usually varies from 5 to 30 percent. Depending on the application, the reinforcement phase can exist in a variety of shapes, ranging from particles and short fibers to long fibers and porous inserts. Each form has its advantages and disadvantages:

- Continuous long fiber reinforced MMCs show the highest yield strength. In [8] more than 1000 MPa could be reached along the fiber direction in a composite of AZ91 and 63 vol-% high modulus carbon fibers. On the other hand, transverse strength is much lower, as demonstrated in [9], when these values for a similar composite ranged between just 5 and 20 MPa. As a result of this strong anisotropy, the field of application for long fiber reinforced light metals is strongly limited [6].
- Discontinuous short fibers offer lower anisotropy in the composite. Depending on the manufacturing process for example planar isotropic properties can be produced. Compared to long fiber MMCs, the volume fraction of the short fibers is generally lower, but unfortunately, so are the mechanical property values. Nevertheless, temperature strength characteristics as high as those of aluminum can be reached by short fiber reinforced magnesium. Further on creep behavior may be improved by the insertion of short fibers. [6]
- Particles represent a very promising reinforcement structure for automotive application. The effect is nearly isotropic. The availability of various shapes allows a wide spectrum of adjustable properties. The lower mechanical property values in relation to fiber reinforced MMCs are balanced by lower costs and better processability, especially in high volumes.
- Whereas the first three structures provide global reinforcement of an entire component, porous inserts, or preforms, are typically used locally. The preforms are manufactured by sintering or weaving particles and fibers individually. Taking economic efficiency into account, only simple geometries can be produced by this process, ruling out reinforcement of complexly shaped parts. But as preforms posses a continuous structure and make high ceramic volume fractions processable they are well suited for local reinforcement of highly loaded zones.

To meet the requirements deduced from weight reduction by material design and conceptual weight reduction, BMW Group researches the insert of short fibers, particles and preforms in light metal matrices.

MICROMECHANICS

This section gives an introduction of how stiffness and strength characteristics of light metals are improved by the insert of reinforcement phases.

<u>Stiffness</u>

The most common approach to predict the stiffness of a composite material is the rule of mixture (ROM)

$$E_{comp} = v_{matrix} \cdot E_{matrix} + v_{reinf} \cdot E_{reinf} \ .$$

Here, E is the Young's modulus and v is the volume fraction of composite, matrix and reinforcement respectively. This linear dependence results from the consideration of an isostrain condition to a unidirectional continuous fiber reinforced composite loaded along the fiber direction. Applying an isostress condition to the same composite, the modulus transverse to fiber direction is given as the inverse rule of mixture (IROM)

$$\frac{1}{E_{comp}} = \frac{v_{matrix}}{E_{matrix}} + \frac{v_{reinf}}{E_{reinf}} \ . [3]$$

In both cases, the stiffness of the composite increases with higher volume fraction of the reinforcement material as the modulus of the reinforcing phase is significantly higher than the modulus of the light metal matrix alloys (see Table 1 and 2). ROM and IROM give accurate results for the longitudinal and transverse modulus of continuous long fiber reinforced composites, whereas for short fiber and particulate MMCs, stiffness of the composite is overestimated by ROM and underestimated by IROM. Short fiber and particulate composites can be well described by the empirical approach of Halpin and Tsai, an extension of the IROM with the geometrical parameter ξ. [10]

$$E_{comp} = E_{matrix} \cdot \frac{1 + \xi \cdot \eta \cdot v_{reinf}}{1 - \eta \cdot v_{reinf}} \quad \text{with}$$

$$\eta = \frac{E_{reinf} / E_{matrix} - 1}{E_{reinf} / E_{matrix} + \xi}$$

ξ represents a kind of reinforcement effectiveness measure. The longer the aspect ratio of the fiber is, the higher ξ is. $\xi = 0$ and $\xi \rightarrow \infty$ provide upper and lower bounds, the ROM and the IROM (see figure 3).

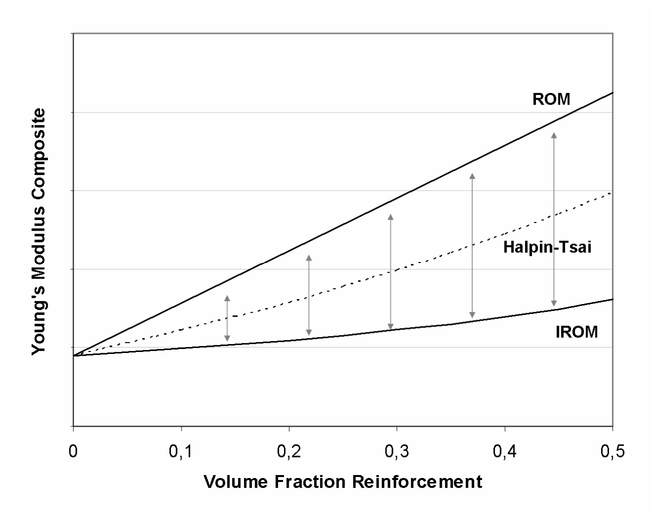

Figure 3: ROM, IROM and Halpin-Tsai Model

Outside of ROM, IROM and Halpin-Tsai, there is a series of techniques that can describe composite properties on the basis of matrix and reinforcement characteristics [3]. The series includes self-consistent field methods [11], variational calculus methods [12] and the equivalent homogeneous inclusion technique [13].

Direct strengthening

The strengthening mechanisms of MMCs can be divided in two categories: direct and indirect strengthening. Direct strengthening means that a significant amount of the applied load is carried by the reinforcement, typically characterized by greater stiffness and strength. If one assumes that the reinforcement isn't directly loaded itself, the load is transferred from the matrix across the matrix/ reinforcement interface to the reinforcement.

With a fiber, the more load that can be transferred by shear strains across the interface, the bigger the size of the fiber's shell. For given fiber diameter, this implies that a critical length is required to transfer the applied load completely to the fiber. Consequently, direct strengthening is particularly relevant for continuous and long discontinuous fibers. [3]

In particulate MMCs, load transfer is not as efficient due to the lower aspect ratio, but still important in providing strengthening [3]. Nardone and Prewo [14] proposed a modified shear lag model for particulate materials, where the load transfer takes place at the particle ends. Attributable to the high aspect ratio this effect is neglected in fiber reinforced composites. Generally load transfer decreases as particle size is reduced.

Indirect strengthening

E. Orowan, M. Polanyi and G. I. Taylor recognized roughly simultaneously in 1934 that plasticity can be explained by theory of dislocations. According to this theory, dislocations (linear crystallographic defects) move under applied stresses within atomic slip planes through the crystal. A dislocation passing along an atomic slip plane leads to a shift of one atom's diameter between the two adjacent atom layers (see figure 4). Because of this mechanism, plastic deformation of crystalline metals occurs far below the theoretical shear strength of the perfect crystal.

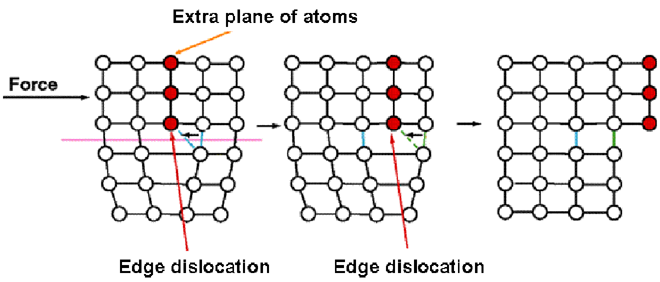

Figure 4: Plastic deformation by dislocation motion [16]

During plastic deformation, new dislocations are formed and the dislocation line length is increased, amplifying dislocation density. Escalating dislocation density leads to stronger resistance to dislocation motion, since adjacent dislocations often hinder one another. This effect is known as work hardening, and it results in higher strength.

Other crystallographic defects can hinder dislocations, as well. Grain boundaries and precipitates, for instance, also constrict dislocation mobility and thereby influence the strength characteristics of the metal.

Humphreys et al. [17] developed a micromechanical model to explain the strength of particulate composites on the basis of dislocation theory. The increased flow stress of particulate MMCs, compared to that of unreinforced metal, is quantified by four terms based on the following microstructural effects:

- Residual dislocations and internal stresses:
  Due to differential thermal contraction between matrix and reinforcement (Table 1 and 2), high thermal stresses occur during cooling. The misfit strain is partly relieved by the generation of dislocations, causing a hardening effect. The remaining misfit strain produces internal stresses, by which the flow stress may also be affected.
- Grain boundary strengthening:
  During thermomechanical processing, particulate MMCs may recrystallize. If the particles are larger than about 1µm, they may stimulate nucleation of new grains. This usually results in a grain size considerably smaller than that in the unreinforced alloy. The smaller grain size means an increase of grain boundaries per unit volume. As a result dislocation mobility is reduced and strengthening occurs (Hall-Petch relationship).
- Substructure strengthening:
  In certain circumstances, for instance when the particle size is fairly small and a critical ratio of volume fraction to particle size is exceeded, recrystallization is prevented. The material will then retain a dislocation substructure that causes a similar but weaker strengthening effect than grain boundary strengthening.
- Work hardening:
  The initial work hardening rate of particulate MMCs is often much higher than that of the unreinforced matrix. This is because different strains occur in the matrix material and the particles for a given stress. Hence, under certain deformations of the composite, the matrix will show plastic deformation while the particles will still behave elastically. As dislocations created by plastic relaxation accumulate near the particles, the local flow stress increases and relaxation becomes progressively more difficult.

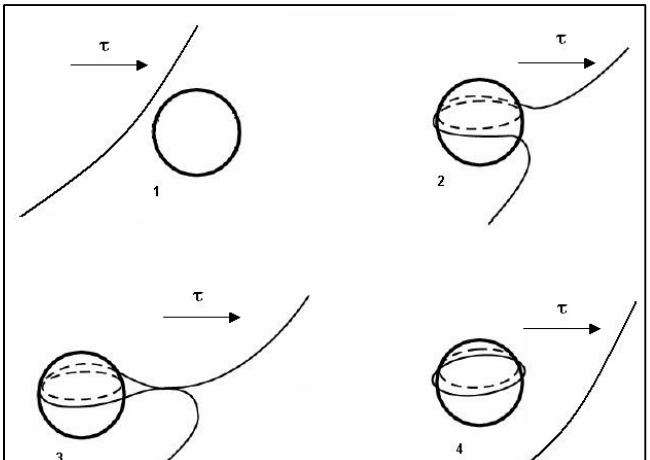

Figure 5: Orowan mechanism [18]

When employing particles with a distance of 1µm or smaller, another strengthening mechanism has to be taken into account. In the Orowan mechanism, the particle itself may behave as an obstacle for dislocation motion. A moving dislocation can only overcome the obstacle if a specific minimum stress is applied. The necessary shear stress is inversely proportional to the distance between the obstacles. In the case of homogeneous particle distribution and constant particle volume fraction, the inter-particle spacing decreases with the downscaling of particle diameter. For that reason, nanoscale particles present huge potential for strengthening light metals. Figure 5 schematically shows the Orowan mechanism leaving behind a dislocation loop around the obstacle. [4]

MODELLING

The physical and mechanical properties of a metal matrix composite depend on a variety of factors, such as the volumetric content, shape or distribution of the reinforcement. Analytical models, as mentioned in micromechanics section, are able to provide reasonable predictions for relatively simple configurations of the phases. Numerical models can extend the realm of problems that can be modelled. [3] This extension can be significant, since materials with heterogeneous, hierarchial, graded or localized microstructures often posses much higher strength and damage resistance than materials with homogeneous, simple microstructures. [20]

Numerical micro- and mesoscale material models are an essential scientific tool for studying and understanding microstructural effects. In addition, and particularly important from the industrial point of view, numerical models can serve as instrument for the optimal design of material microstructures. Numerical models enable the variation of a wide range of parameters with comparatively low effort. Even if they will never substitute for the production and testing of material samples, they are well suited for defining the parameter range for sensible further investigation.

A crucial factor for the use of MMCs in automotive components is the applicability of virtual methods of functional integration on such materials. Material models have to be able to describe stiffness and strength characteristics, elastoplastic and creep behavior, thermal expansion, failure and the lifetime of MMCs. For these purposes numerical micro- and mesoscale material modelling is a promising approach. Still, a model has to able to deduce significant correlations while requiring low computational and experimental effort. Further, it should be based on or at least compatible to CA software tools standard in the automotive engineering environment. Implementation into the virtual functional component and vehicle integration process is also a crucial requisite.

Under these circumstances, the application of the Finite Element Method seems well suited for a micro- or mesoscale volume element representing the material's microstructure. The following section outlines some approaches of this type.

The simplest models use a two-dimensional, rectangular, axisymmetric representative volume element (RVE) consisting of elastic matrix and round or quadratic elastic inclusions for ceramic particles. Boehm investigated a comprehensive model to predict the microscale and the overall macroscale response to uniaxial tensile loading [21]. Twenty round inclusions are distributed in the quadratic cell element by a random sequential adsorption algorithm. Overlapping inclusions are cut, and the remaining part is moved to the opposite edge to achieve translational symmetry. The inclusions still behave elastically, but the matrix offers continuum plasticity in combination with a modified Ludwik hardening law. In spite of the improvements Boehm achieved, this two-dimensional model under- or overpredicts overall stiffness and strain-hardening, depending on whether plane stress or plane strain constraints are applied.

A more realistic approach to incorporate microstructure into Finite Element Modelling is described by Chawla [22]. Through image processing, a MMC micrograph is transformed into a Finite Element Mesh. Figure 6 shows an example of this procedure. Numerical experiments were conducted on such RVEs for Al/SiC- and WC/Co-composites. The computational results of Young's modulus and CTE coincided well with experimental values - more so than theoretical predictions did.

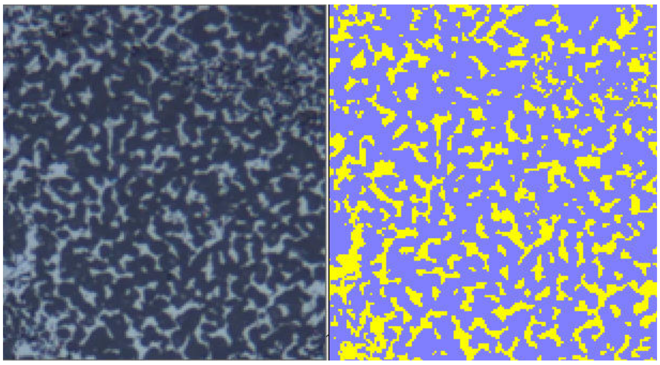

Figure 6: Micrograph of a MMC (left) and deduced FE-Mesh (right)

Descriptions of further aspects of two-dimensional microstructure modelling can be found in works by Wolf [23] and Pandorf [24]. Here, methods are proposed to simulate the creep and failure behavior of particulate aluminum matrix composites.

In spite of promising results using two-dimensional models, realistic analysis of MMCs, in particular the prediction of elastoplastic microscale and overall behavior requires the development of three-dimensional models [21]. Chawla [25] generated a RVE based on a realistic three dimensional microstructure. The geometric structure and orientation of some particles of an Al/SiC-composite were detected by a combination of serial sectioning and image processing. Figure 7 gives an overview of this approach. The effort involved in this method was comparatively high, but the results demonstrated that the 3D microstructure based model fits the experimental elastoplastic stress-strain-curve and the Young's modulus well - much better than rectangular or spherical inclusions did.

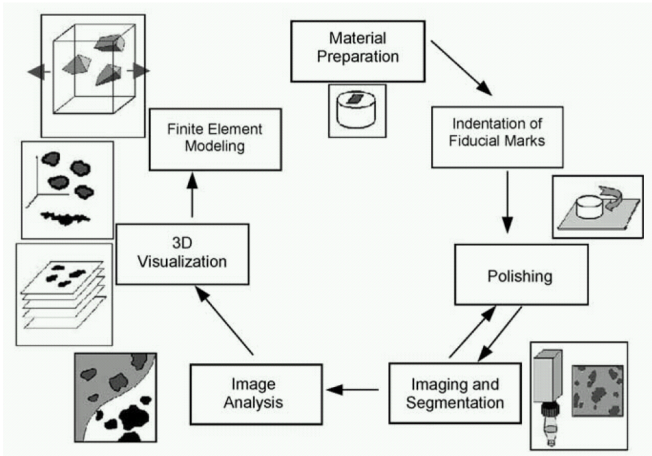

Figure 7: Serial sectioning process [25]

Due to their reliable predictability of MMC characteristics, BMW Group utilizes three dimensional microscale material models to support MMC development and to introduce MMCs into the virtual process of function integration.

POTENTIAL

In order to identify the strength potential of MMCs, particulate reinforced magnesium samples were produced in laboratory scale by melt bath stirring and ingot casting at Neue Materialien Fürth GmbH. Samples without reinforcement were cast under similar conditions to serve as a reference.

The magnesium cast alloy AZ91 D is used as matrix metal in the present work. The reinforcement consists of silicon carbide particles from the abrasive industry. The particles own grade F600 according to FEPA-F standard, which means an average particle size of 9.3 µm.

Figure 8 shows a characteristic microstructure with a volumetric content of 10 vol.-% silicon carbide. It can be seen that the non-optimized laboratory process results in a high porosity in the MMC. The compression test is therefore utilized to identify strength characteristics to estimate the potential of the composite. For this purpose cylindrical samples with a diameter of 5 mm and a height of 7 mm were prepared out of the ingots. In the following diagram the mechanical properties at room temperature of the Mg/SiC composites are presented for different particle contents. For practical reasons, the particle content is determined as the ratio of the reinforcement area to the entire area of a micrograph section.

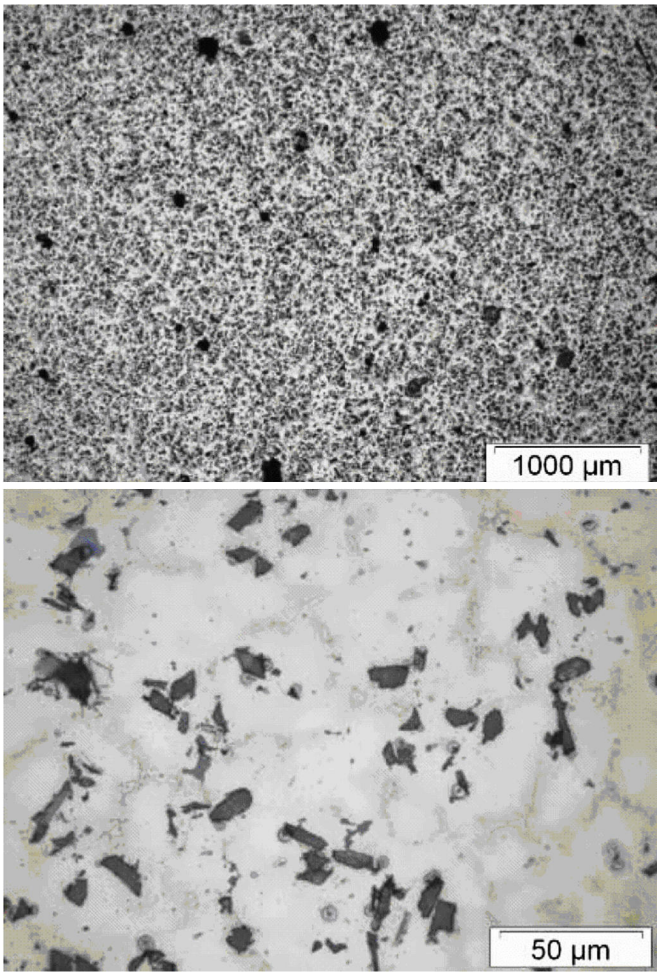

Figure 8: Micrographs AZ91/SiC-Composite

Figure 9 compares the values of the Young's modulus *E*. As predicted by micromechanical considerations there is a strong increase in Young's modulus with higher particle content. *E* increases approximately 50% from 40 GPa (reference) to 60 GPa in the measured range. With lower porosity and higher particle content the level of aluminum is reachable (compare table 1).

Just as the Young's modulus does, the strength characteristics of the Mg/SiC-composite improve with higher particle content. Figures 10 and 11 show that the yield strength under compression and the ultimate compressive strength increase by up to 120 MPa in the measured range. In spite of the relatively high ceramic content of the highly reinforced samples, the Mg/SiC-composites exhibit no brittle failure. The compressive strain at failure is reduced from approx. 18% (reference material) to a minimum value of 13%.

The high potential for improvement of mechanical properties by particulate reinforcement as presented above corresponds to similar results in the literature, see for instance [3,4,17,19]. The challenge for the automotive industry is now to realise the potential of these materials, so far demonstrated only on a laboratory scale, in high volume applications.

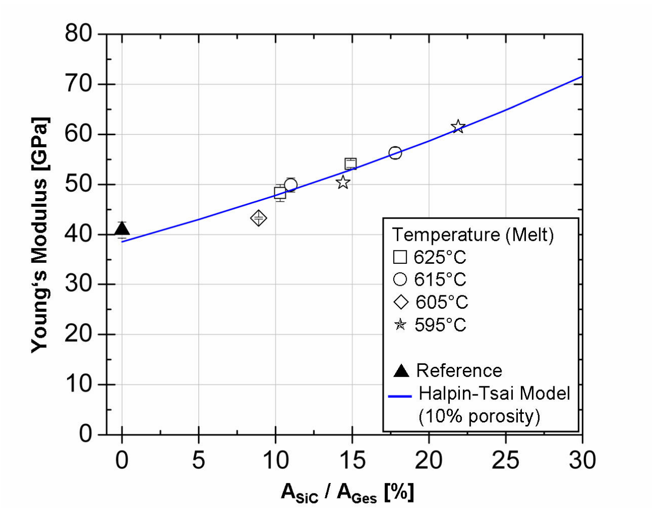

Figure 9: Young's modulus at room temperature of AZ91/SiC-Composites

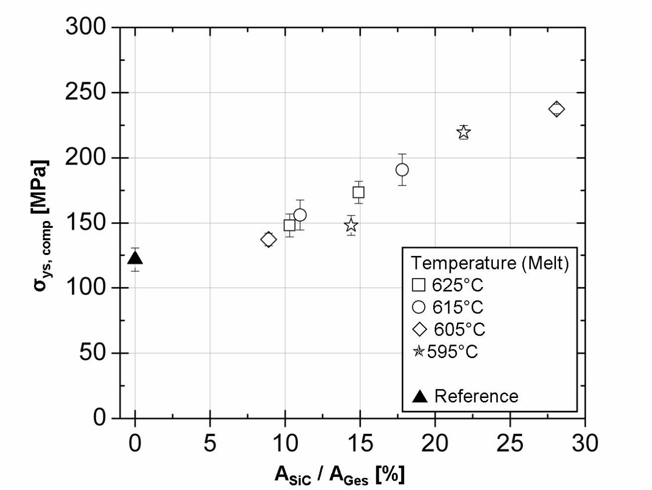

Figure 10: Compressive yield strength at room temperature of AZ91/SiC-Composites

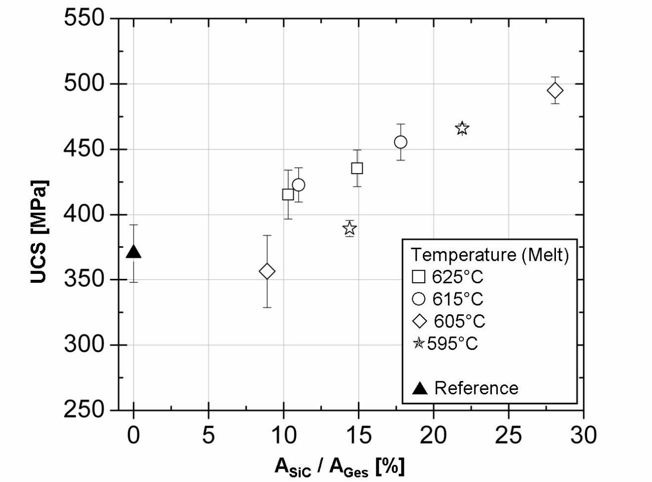

Figure 11: Ultimate compressive strength at room temperature of AZ91/SiC-Composites

CONCLUSION

- Augmenting comfort, safety and emission functionalities denote a great challenge for lightweight design targets and thus also for efficiency and dynamics of a vehicle.
- Reinforced light metals are able to provide solutions for lightweight design by material substitution and for conceptual lightweight design by more precise adjustment of material concepts to functional requirements of a component.
- For automotive applications ceramic particles are well suited for global reinforcement of light metal components whereas porous ceramic inserts can provide local reinforcement of highly loaded zones in components.
- Basic relations between structure and characteristics of a metal matrix composite can be described by analytical models. For further investigation and optimization of such composite materials three-dimensional FE-based material models are used.
- The potential to significantly improve the strength and stiffness characteristics of light metal cast alloys by ceramic reinforcement was shown on a laboratory scale. Further research is presently being done to realize the potential of these materials in high volume automotive applications.

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CONTACT

BMW Group, 80788 Munich

Prof. Dr. rer. nat. Rudolf Stauber

Email: Rudolf.Stauber@bmw.de

Dr.-Ing. Peter Fallböhmer

Email: Peter.Fallboehmer@bmw.de

Dipl.-Ing. Florian Bechmann

Email: Florian.FB.Bechmann@bmw.de