TALAT
Training in Aluminium Application Technologies

TALAT Lecture 1402

Aluminium Matrix Composites Materials

28 pages, 29 figures

Advanced Level 1

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Objectives:

- to obtain understanding of the state-of-the-art of aluminium matrix composite materials
- to understand the properties of aluminium matrix composite materials as a basis for materials selection
- to understand the limits of useful applications
- to understand the various types of aluminium matrix composites

Prerequisites/Target Group:

Students: Graduate education in metallurgy materials science, materials engineering
Trainers: Research or teaching experience in metallurgy, materials science, materials engineering

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1402 Aluminium Matrix Composites Materials

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1402.01 Basic Principles

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Introduction

Aluminium alloys are used in advanced applications because their combination of high strength, low density, durability, machinability, availability and cost is very attractive compared to competing materials. However, the scope of these properties can be extended by using aluminium matrix composite materials.

Aluminium matrix composites can be defined as follows :

- it must be man-made;
- it must be a combination of at least two chemically distinct materials (one being aluminium) with a distinct interface separating the constituents;
- the separate materials must be combined threedimensionally;
- it should create properties which could not be obtained by any of the individual constituents.

This definition differentiates aluminium matrix composites from aluminium alloys, which are achieved via control of naturally occurring phase transformations during solidification or thermomechanical processing.

The aluminium matrix composites may offer specific advantages (and disadvantages) compared to unreinforced Al alloys, to polymer matrix composites and to ceramic matrix composites. An overview is given in **Figure 1402.01.01.**

A list of the reinforcements for aluminium and Al-alloys is given in **Figure 1402.01.02.**

Al-matrix composites can be classified into different types, according the geometry of the reinforcement.

ADVANTAGES	DISADVANTAGES
COMPARED TO UN-REINFORCED ALUMINIUM ALLOYS:	
HIGHER SPECIFIC STRENGTH	LOWER TOUGHNESS AND DUCTILITY
HIGHER SPECIFIC STIFFNESS	MORE COMPLICATED AND EXPENSIVE PRODUCTION METHOD
IMPROVED HIGH TEMPERATURE CREEP RESISTANCE	
IMPROVED WEAR RESISTANCE	
COMPARED TO POLYMER MATRIX COMPOSITES:	
HIGHER TRANSVERSE STRENGTH	LESS DEVELOPED TECHNOLOGY
HIGHER TOUGHNESS	SMALLER DATA BASE OF PROPERTIES
BETTER DAMAGE TOLERANCE	HIGHER COST
IMPROVED ENVIRONMENTAL RESISTANCE	
HIGHER THERMAL AND ELECTRICAL CONDUCTIVITY	
HIGHER TEMPERATURE CAPABILITY	
COMPARED TO CERAMIC MATRIX COMPOSITES:	
HIGHER TOUGHNESS AND DUCTILITY	INFERIOR HIGH TEMPERATURE CAPABILITY
EASE OF FABRICATION	
LOWER COST	

TALAT Training in Aluminium Application Technologies | Comparision of Advantages and Disadvantages of Alluminium Matrix Composites | 1402.01.01

NON METALIC	METALIC
ALUMINA	BERYLLIUM
BORON	NIOBIUM
BORON CARBIDE	STAINLESS STEEL
GRAPHITE	
NICKEL ALUMINIDE	
SILICA	
SILICON CARBIDE	
TITANIUM BORIDE	
TITANIUM CARBIDE	
ZIRCON	
ZIRCINIA	
ZIRCONIUM CARBIDE	

TALAT Training in Aluminium Application Technologies | Reinforcements for Aluminium Alloys | 1402.01.02

One distinguishes (see **Figure 1402.01.03**):

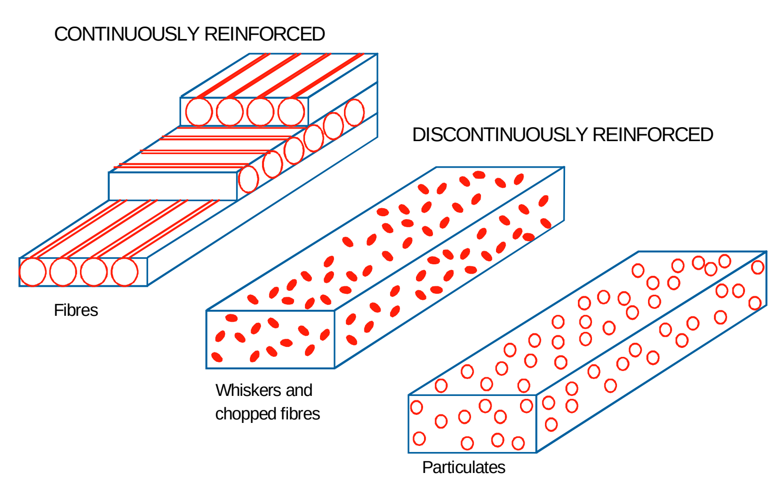
1. continuous fibre reinforced composites with monofilaments (diameter larger than 100 µm) or with tows of fibres (diameter smaller than 20 µm)
2. discontinuously reinforced composites with short fibres, whiskers or particulates.

In the following, lamellar composites, composite coatings, cermets, dispersion strengthened alloys are not considered as metal matrix composites.

The continuous fibre reinforced composites have as main features:

- improvement of stiffness and strength
- reduction of wear and creep
- anisotropic properties
- improved fatigue strength in the fibre direction
- high price and complex manufacturing techniques.

The discontinuously reinforced composites are developed, when strength is not the main objective, but when a higher stiffness, a better wear resistance, a controlled thermal expansion and a higher service temperature are expected.



TALAT | Typical Reinforcement Geometries for Metal Matrix Composites | 1402.01.03

Principles and Properties

Composite materials technologies offer a unique opportunity to tailor the properties of aluminium.This could include increased strength, decreased weight, higher service temperature, improved wear resistance, higher elastic modulus, controlled coefficient of thermal expansion, improved fatigue properties, etc.

It is of utmost importance to have rules or models in order to predict or to calculate the expected properties of the composite. As a first estimation, the rule of mixtures can be helpful. That is:

$$P_c = P_m V_m + P_r V_r$$

with P = property
V = volume fraction
and subscript c, m and r indicate resp. composite material, matrix and reinforcement.

Density (example)

The density ρ_c can accurately be predicted by the rule of mixtures :

$$\rho_c = \rho_m V_m + \rho_r V_r$$

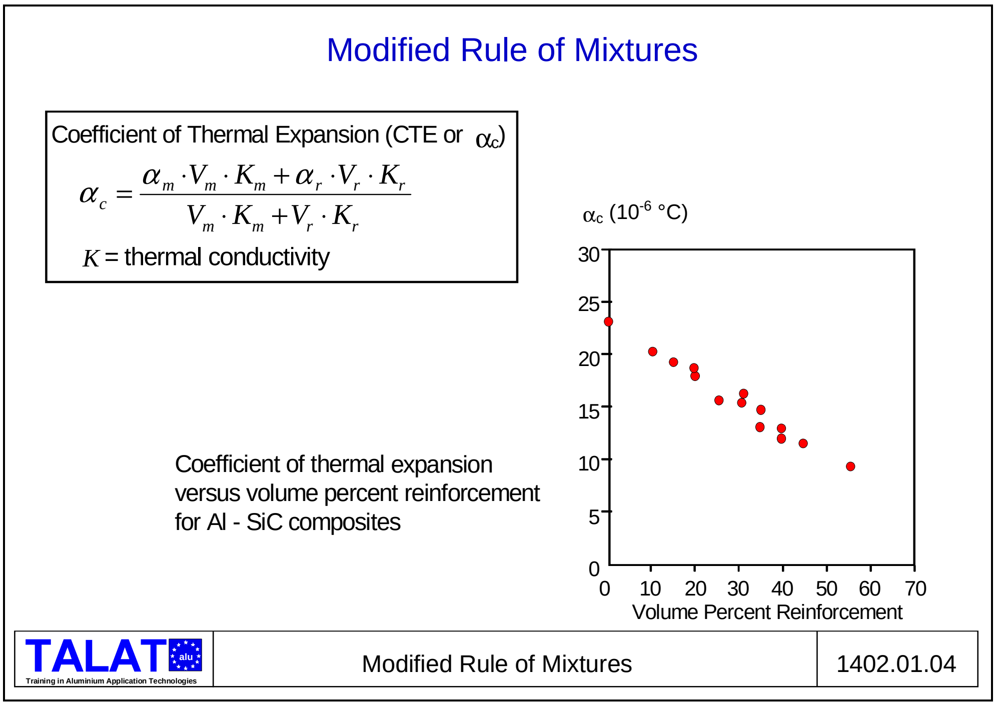
Thermal Properties

The coefficient of thermal expansion (CTE or α_c) can be approximated by the following modified rule of mixtures :

$$\alpha_c = \frac{\alpha_m V_m K_m + \alpha_r V_r K_r}{V_m K_m + V_r K_r}$$

with K = thermal conductivity.

As a consequence, by using a sufficiently high volume fraction of reinforcement, the CTE of the Al-based composite (see **Figure 1402.01.04**) can be reduced to that of steel. With carbon or graphite fibres, which have a negative CTE, Al-composites with a CTE close to zero can be produced.



Stiffness

Young's modulus (E) is an elastic property which is well bracketed by two models. **Figure 1402.01.05** illustrates the evolution of the Young's modulus of an Al-SiC composite as a function of the volume fraction of SiC. The linear upper bound (see full line in **Figure 1402.01.05**) is defined by the simple rule of mixtures:

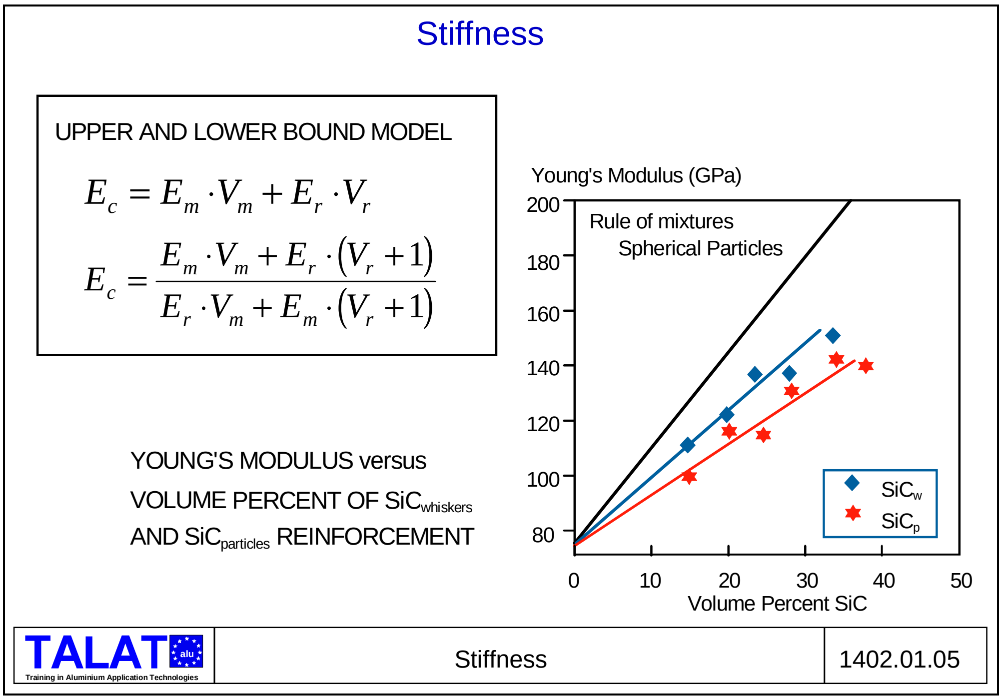
$$E_c = E_m V_m + E_r V_r$$

The non linear bound (see dotted line in **Figure 1402.01.05**) is given by a more complex expression (valid for discontinuously reinforced composite with spherical particles as reinforcement) :

$$E_c = \frac{E_m V_m + E_r (V_r + 1)}{E_r V_m + E_m (V_r + 1)}$$

For continuous fibre reinforced composites, the Young's modulus is given by the rule of mixtures.

It is clear from the above considerations that the addition of short fibres, particles or continuous fibres with high stiffness can increase the stiffness of the aluminium - matrix composites substantially.



Plastic Properties

The **strength and ductility** are difficult to predict accurately by simple mathematical expressions and are determined by the matrix alloys, the reinforcement and the processing. Two major contributions to the yield stress are matrix strengthening effects and residual thermal stresses, due to differential contraction of reinforcement and matrix.

- *Continuous Fibre Composites*

For continuous uniaxial fibre composites, the rule of mixtures can be used to predict the fracture strength (σ_c^F) of the composite in axial tensile conditions :

$$\sigma_c^F = \sigma_r V_r + \sigma_m V_m$$

with σ is tensile strength.

The properties mostly fall below the theoretically expected values, due to misalignment of the fibres and inhomogeneity in fibre distribution. The tensile properties drastically fall off with the loading direction. The ratio of transverse to longitudinal strength is for most aluminium based composites in the range of 0.12 to 0.33.

For multidirectional loading of the composite, the use of composites with different fibre ply orientation is recommended.

- *Discontinuous Fibre Composites (Whisker or Short Fibre Composites)*

The fracture strength of discontinuous fibre composites depends upon type, aspect ratio, volume fraction and distribution of the reinforcement, alloy and its heat-treated conditions, and the fibre-matrix bond.

For aligned fibres, a modified rule of mixtures predicts the longitudinal strength:

$$\sigma_c^F = \sigma_r^F \left(l - \frac{l_c}{2l} \right) V_r + \sigma_m V_m$$

where σ_m is the stress carried by the matrix at failure,

l is half the length of a fibre,

l_c is the minimum fibre length, capable of carrying the fracture stress of the fibres.

- Particulate Composites

Low strength alloys (e.g. pure aluminium) are greatly strengthened by ceramic phased e.g. SiC. For high strength alloys (e.g. 2xxx or 7xxx alloys), there is an effect of the reinforcement on the age hardening. In some alloys (e.g. 7xxx series), it is difficult to reach the same strength in the composite as in the monolithic alloy, for 2xxx, 6xxx and 7xxx based composites, the strength of the composite may be 100 MPa higher than the starting matrix alloy.

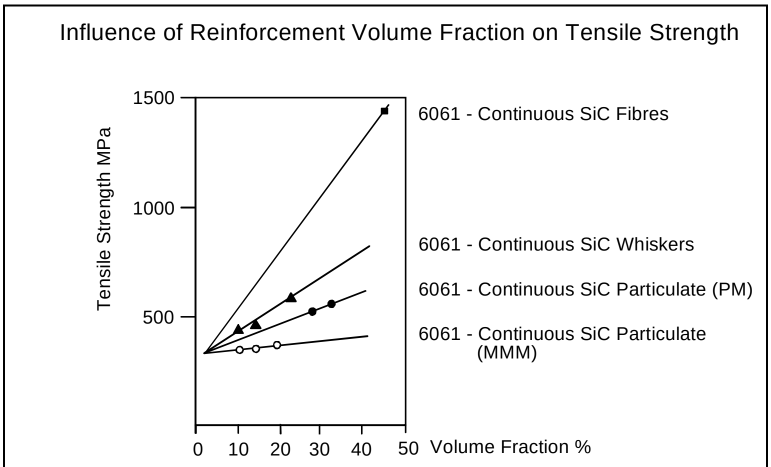
The strengthening of particulate MMCs may be due to different mechanisms:

- Orowan strengthening
- grain and sub-structure strengthening
- quench strengthening
- work hardening.

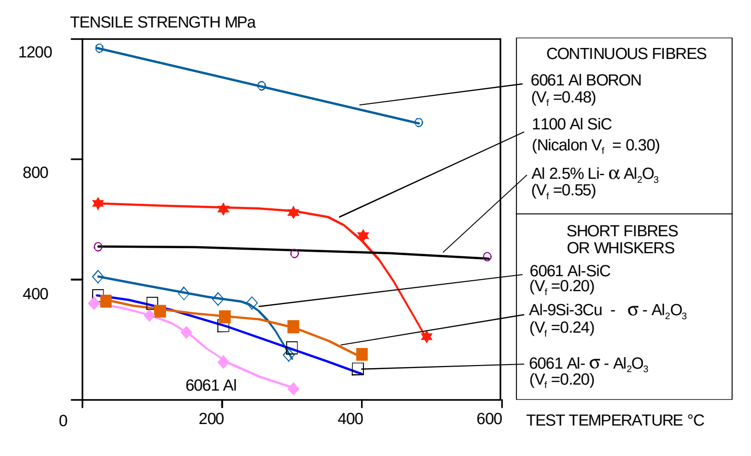
Figure 1402.01.06 illustrates the influence of the different geometries of the reinforcement on the strength. The **ductility** and the **failure toughness** is reduced as the volume fraction of the reinforcement is increased. This factor determines the upper limit

of reinforcement that can be used in a structural composite. Typical ductility values are below or equal to 5 % and typical fracture toughness values are 15 to 20 MPa $\sqrt{m}$.

Al-based composites are also very attractive for applications at intermediate temperature (200^o C - 400^o C). Indeed, conventional hardening mechanisms are not effective anymore, in contrast with fibre and particle reinforcement. **Figure 1402.01.07** illustrates this effect for the well known AA6016 alloy.



TALAT	Strength for Different Reinforcement Types and Volume Fraction	1402.01.06



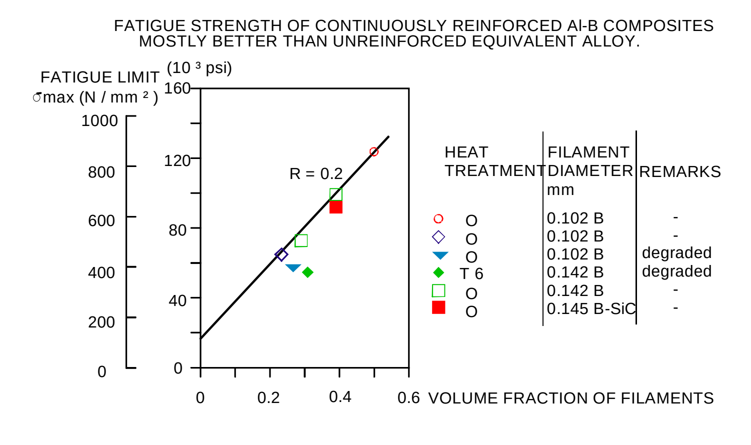
TALAT | Tensile Strength as a Fraction of the Test Temperature | 1402.01.07

Fatigue

The fatigue properties of aluminium composites are usually better than the unreinforced equivalent alloys.

- Continuous Fibre Composites

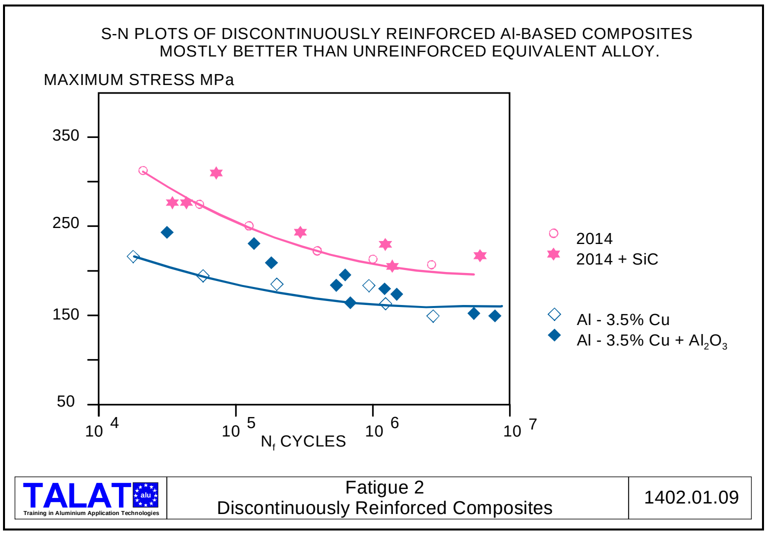
Uniaxially reinforced alloys usually possess excellent fatigue properties when loaded parallel to the major fibre axis. Values of the fatigue/tensile strength ratio (at 10^7 cycles) between 0.55 and 0.8 are not unusual. This means a doubling of the fatigue performance of unreinforced aluminium alloys. **Figure 1402.01.08** is an illustration of the effect of the volume fraction on the fatigue limit; in some cases, the fibres are slightly degraded due to chemical reaction with the aluminium matrix.



Fatigue 1
Continuous Composites
TALAT | 1402.01.08

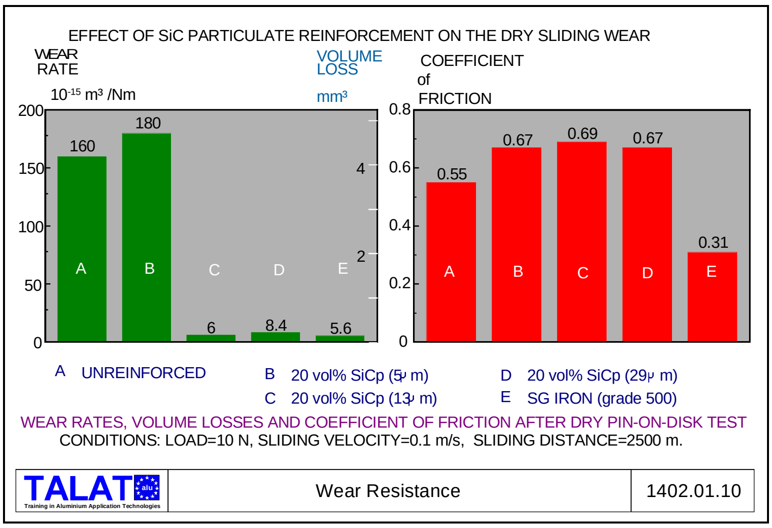
- Discontinuously Reinforced Composites

Where the reinforcement produces an increase in tensile strength, it is usual that the fatigue strength will also be improved, particularly under low cycle conditions (see Figure **1402.01.09**). However, the effect of particulate reinforcement seems to depend upon particle size and volume fraction. Also the presence of inhomogeneities and particle clusters have a negative influence on the fatigue strength.



Wear Resistance

Wear is a "system" property, rather than a "material" property. The wear of MMCs depends on the particular wear conditions, but there are many circumstances where Al-based composites have excellent wear resistance. **Figure 1402.01.10** gives the relation between the wear loss during a pin on disk test and the composition. Al-based composites are far superior to the matrix alloy.



On the Fundamental Role of Interfaces in Aluminium Matrix Composites

The success of aluminium matrix composites is highly dominated by the control and the enhancement ("management") of the interfaces between the aluminium matrix and the reinforcement phase. The three main items are :

- a good wetting is necessary to facilitate the fabrication, especially when using liquid state technique with low pressure;

- interfacial reactions between matrix and reinforcement should be very limited, in order to avoid the degradation of the reinforcement and the formation of new brittle phases.

- a correct bonding (resp. weak or strong) is required to deliver the intended property resp. high fracture toughness or good transverse properties).

For aluminium alloys as matrix, wetting may be improved by a chemical reaction with the reinforcement which lowers the interfacial energy. Also the disruption of the oxide skin covering the liquid aluminium may improve the wetting behaviour. The parameters that are further influencing the wetting of ceramics (= reinforcement) by liquid aluminium alloys are the temperature (higher temperature gives a better wettability), the contact time (wetting is improved by longer contact times), the pressure of the surrounding atmosphere (in vacuum, adsorbed gasses are removed and ameliorate the wetting behaviour). There exists chemical or mechanical means of enhancing the generally poor wetting. They can be classified into four categories, namely (a) reinforcement pretreatment; (b) matrix alloy modifications; (c) reinforcement coating; (d) mechanical means.

As a general statement, there is no given set of rules that dictates the chemical engineering of the interface for optimised properties. Contradictory demands have mostly to be fulfilled in a compromise and that at an acceptable cost.

Summary of Characteristic Properties

Continuous fibre reinforced composites:

diameter > 100 µm monofilaments
diameter < 20 µm tows of fibres

- improved strength and stiffness
- reduced wear and creep
- anisotropic properties
- improved fatigue strength in fibre direction
- complex manufacturing
- high price

Particulate, short fibre and whisker reinforced composites:

- when strength is not main objective
- improved stiffness
- reduced wear
- controlled thermal expansion
- increased service temperature

1402.02 Manufacturing Techniques

- Introduction
- Continuous fibre composites
  - Liquid state techniques
  - Solid state techniques
- Discontinuously reinforced composites
  - Solid state routes
  - Liquid state route
  - Spray methods
- In situ production methods

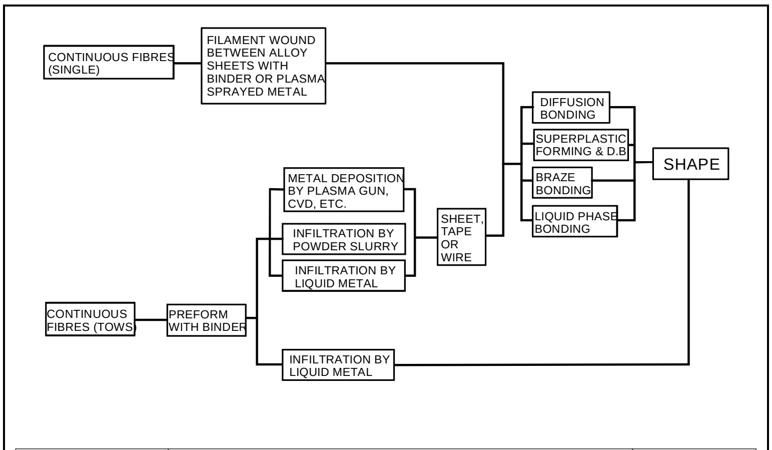
Introduction

There is a multitude of fabrication techniques of metal matrix composites depending on whether they are aimed at continuously or discontinuously reinforced MMC production. The techniques can further be subdivided, according to whether they are primarily based on treating the metal matrix in a liquid or a solid form. The production factors have an important influence on the type of component to be produced, on the micro-structures, on the cost and the application of the MMC. A special class that will be discussed, are the in situ composites.

Continuous Fibre Composites

Two groups of processes can be distinguished (**Figure 1402.02.01**):

1. processes that use liquids to infiltrate fibre bundles or preforms
2. solid-state methods which may evolve a preform stage.



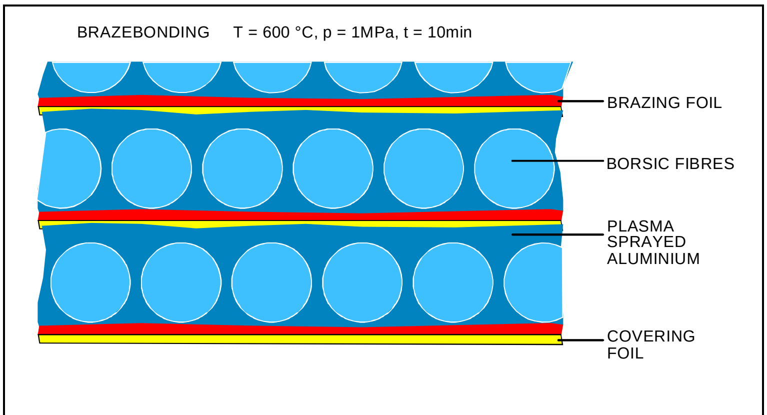
TALAT | Overview of the Different Manufacturing Routes of Continuously Reinforced Al-Composites | 1402.02.01

The production of continuous fibre reinforce Al-alloys mostly requires preforms of fibres. Therefore, arrays of single fibres or multifilament tons are infiltrated in a liquid or vapour state (e.g. plasma spraying, infiltration by a liquid matrix, electrodeposition, etc.). Also surface coatings on the fibres may be applied to prevent deterioration of the fibre mechanical properties at elevated temperatures and to enhance fibre/metal matrix wettability and adhesion (e.g. TiB_2 on C-fibres). The principal consolidation techniques are now summarised.

- *Liquid State Techniques*

Hot moulding : The reinforcements are put between foils of the matrix material and then subjected to a pressure-temperature treatment, such that both liquid and solid phases are present. The metal can be a powder or a foil and near net shape consideration is possible. This techniques includes liquid phase hot pressing.

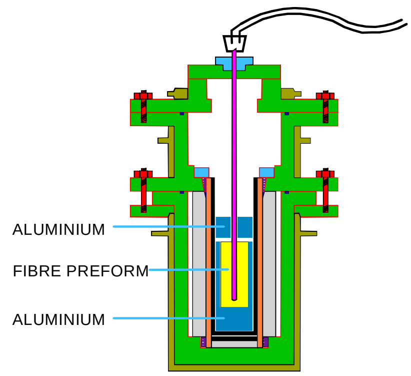
Braze bonding (**Figure 1402.02.02**): In this case a brazing alloy is employed to join and to consolidate the MMC preforms. This technique permits lower fabrication temperature and pressure, but limits also the maximum service temperature.



TALAT | Brazebonding Technique for Continuous Fibre Reinforced Composites | 1402.02.02

Liquid infiltration (**Figure 1402.02.03**): Preforms are infiltrated by liquid metal, using either gravity, vacuum or pressure.

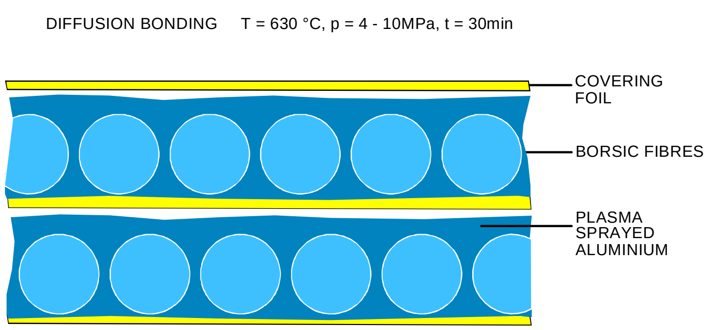
Plasma spray deposition technique: Liquid matrix droplets are sprayed with a plasma gun on reinforcement filaments, while they are wound around a core or mandrell.



TALAT | Infiltration of Preforms of Continuous Fibres | 1402.02.03

- Solid State Techniques

Diffusion bonding (**Figure 1402.02.04**) : It is probably the most widely used technique. Continuous fibres or preforms are placed between foils of the matrix material and then subjected to a pressure-temperature treatment. The bond between the matrix and the reinforcement is made by the interdiffusion between the two. The process parameters should be well controlled in order to obtain a correct bonding. Preforms can be wires, tapes or sheet that have had the metal introduced by infiltration, electrodeposition, vapour deposition, plasma spraying or by a powder slurry. A variation is the hot roll bonding, where metal matrix foils and fibre arrays are continuously fed between rollers which apply both heat and pressure.



TALAT | Diffusion Bonding of Continuous Fibre Composites | 1402.02.04

High energy rate forming: This unusual technique applies very high pressure pulses for extremely short times or preforms with foils or powder. The short processing time is avoiding fibre-matrix reaction, but the high pressure may cause excessive fibre damage.

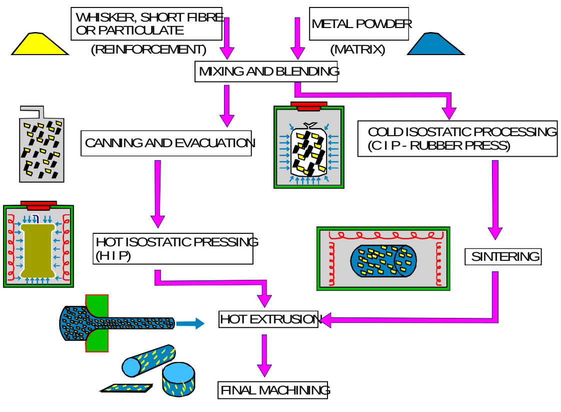
Other methods include add rolling or cold drawing of coated filaments, superplastic forming, hot isostatic pressing.

Discontinuously Reinforced Composites

Discontinuously reinforced composites can also be fabricated by either solid state, liquid state or metal spray routes. Particulate (equiaxed particles) and whisker reinforced composites are following similar routes. However, damage of whiskers should be avoided. For the handling of fine particles (diameter smaller than 5 µm) and of whiskers special health and safety precautions are necessary.

- Solid State Routes

Solid state techniques have several advantages such as a low processing temperature, leading to a low reinforcement - matrix interaction and therefore good mechanical properties can be obtained. Solidification defects (shrinkage, porosity, segregation) are avoided and generally a more uniform reinforcement distribution is obtainable. The most common solid state route is based on powder metallurgical processing. Unfortunately, the production way tends to be more expensive than liquid based routes and have to deal with health risks, pyrophoricity and/or explosivity.



TALAT | Steps of the Powder Metallurgical Processing Route | 1402.02.05

The principal processing steps are (**Figure 1402.02.05**):

- Mixing, blending (wet or dry) or mechanical alloying of the matrix powders and the reinforcements. In this step it is necessary to obtain an uniform reinforcement distribution.

- Degassing. This step is mostly essential for aluminium based composites, in order to remove adsorbed gasses, water and/or hydroxides. If this degassing is not done properly, hyrogen evolution during further consolidation may drastically degrade the composite properties.

- Consolidation. The consolidation stage may consist of cold and/or hot pressing, cold and/or hot isostatic pressing, extrusion, forging, injection moulding, hot rolling, etc.

Typical properties are given in **Figure 1402.02.06** (table)

TYPICAL AND (MINIMUM) VALUES◆

	VOLUME PERCENT Al_2O_3	ULTIMATE STRENGTH (MPa)	YIELD STRENGTH (MPa)	ELONGATION %	ELASTIC MODULUS (GPa)
6061 - T6	0	310 (262)	276 (241)	20	68.9
	10	352 (324)	296 (262)	10	81.4
	15	365 (338)	324 (290)	6	88.9
	20	372 (345)	352 (317)	4	97.2
2014 - T6	0	524 (469)	476 (414)	13	73.1
	10	531 (496)	496 (455)	3	84.1
	15	531 (496)	503 (462)	2	93.8
	20	517 (483)	503 (462)	1	101.0

NOTE: ◆ MINIMUM VALUES REPRESENT 99% CONFIDENCE INTERVAL.
ALL MEASUREMENTS MADE ON EXTRUDED BAR OR ROD (EXTRUSION RATIO ~ 20:1).

TALAT Training in Aluminium Application Technologies | Tensile Properties of Al-Matrix Composites Produced via Powder Metallurgical Route | 1402.02.06

- *Liquid State Route*

Liquid state routes involve the incorporation of reinforcement into a liquid aluminium alloy (molten metal mixing prior to casting) or the infiltration of a preform (e.g. pressure of vacuum infiltration, squeeze casting). These routes are very attractive because they are simple, cheap and can be applied for the production of complex three-dimensional compounds. It is also feasible to produce parts with local reinforcements. Basic foundry technologies can easily be adapted for the fabrication of discontinuously reinforced aluminium composites. The main drawbacks of the liquid state routes are the lack of wetting of the reinforcements (mainly ceramics) by liquid aluminium, the development of casting defects (shrinkage, gas holes) in the final product, the insufficient bonding between reinforcement and the matrix or/and the degradation of the reinforcement by excessive reaction. The most commonly used techniques are given below.

Molten metal mixing techniques (may be prior to other casting techniques). Melt mixing or stirring is an easy production route for particle reinforced aluminium alloys. Stirring can be by means of mechanical, electromagnetic methods or by gas injection. The main problems to be overcome are the agglomeration or clustering of the particles and the expulsion of the reinforcement by the liquid matrix. Also this particle redistribution affects the mechanical properties. All these problems can be solved by using several techniques such as:

- the addition of the particles into the vortex, created by a mixing impeller,
- the surface treatment of particles or the alloying of the matrix,
- preheating the particles prior to introduction,
- the use of ultrasonic or electromagnetic vibrations,
- the addition of particles and metal matrix powder as briquettes or pellets.

A typical reinforcement amount is lower than 25 vol. %.

Figure 1402.02.07 (table) gives an overview of achievable properties after molten metal mixing followed by extrusion.

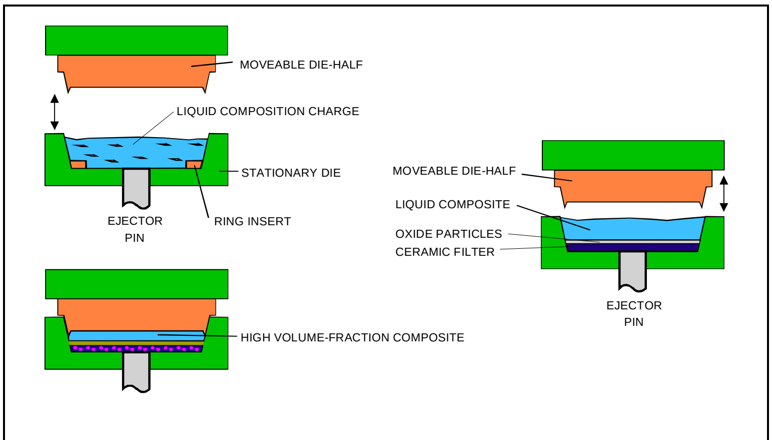
	ULTIMATE STRENGTH (MPa)	YIELD STRENGTH (MPa)	ELONGATION %	ELASTIC MODULUS (GPa)
2014 MMC PEAK-AGED	493	466	2.0	100.4
6061 MMC PEAK-AGED	364	342	3.2	91.5
7049 MMC PEAK-AGED	643	598	2.8	90.1
7075 MMC -T651	601	556	3.7	94.9
-T7651	514	435	4.7	94.0
-T7351	458	357	6.5	92.9

PRODUCTION BY MOLTEN METHOD MIXING, CASTING AND EXTRUSION.

TALAT Training in Aluminium Application Technologies | Properties of Al-Matrix Composites Produced via Casting & Extrusion Route | 1402.02.07

Sand Casting. This is a conventional foundry practise, with a low solidification rate and with segregation as main drawback. This last effect can be successfully used when a selective reinforcement is needed, e.g. for improving the abrasion resistance of the surface components.

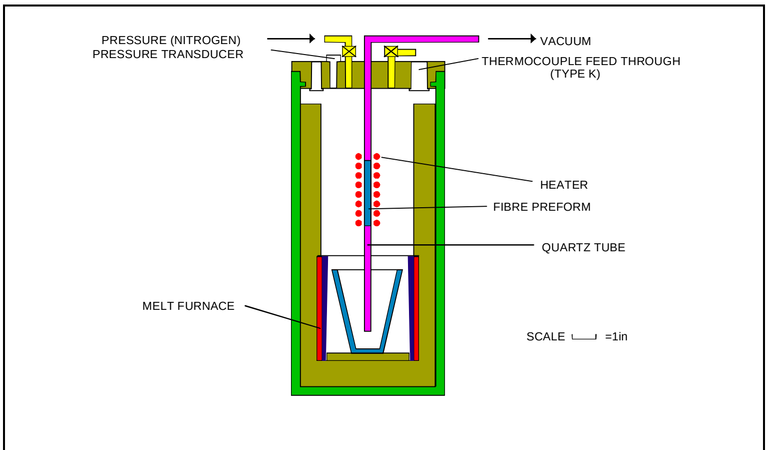
Die Casting (**Figure 1402.02.08**). This well known technique is characterised by a rapid freezing rate and may lead to a homogeneous distribution of the dispersed particles or whiskers.



TALAT | Die Casting of Discontinuously Reinforced Composites | 1402.02.08

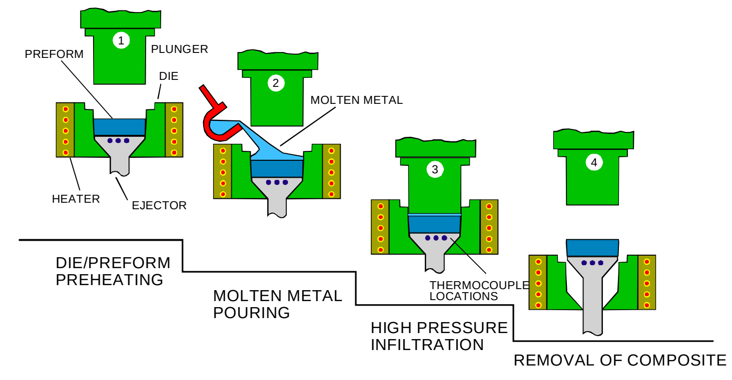
Centrifugal Casting. The segregation effect may be positively exploited in order to produce gradient materials.

Low Pressure Die Casting (**Figure 1402.02.09**). This method is well suited for the fabrication of larger sized identically shaped parts. The solidification time is short, the amount of casting defects is low and the reinforcement volume may be high. The pressures applied are usually below 15 MPa.



TALAT | Low Pressure Die Casting of Discontinuously Reinforced Composites | 1402.02.09

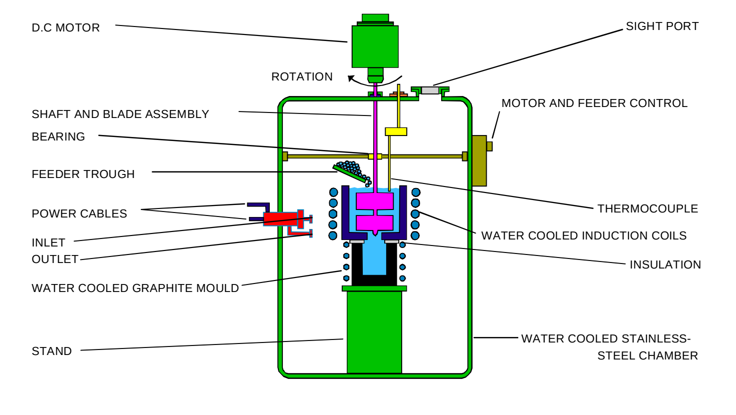
Squeeze Casting (**Figure 1402.02.10**). Squeeze casting is a popular technique for the fabrication of aluminium based composites. It is a unidirectional pressure infiltration (pressure is typically between 70 and 150 MPa). The final components are void free and have a small equiaxed grain size microstructure. It is a fast process with a good surface finish and may be used for selective reinforcement. It is most common to use preforms (exceptionally premix or pellets are used). The infiltration rate depends upon the applied pressure, the capillarity, the spacing between the dispersed particles (whiskers), the viscosity of the liquid metal, the preform permeability, the temperature of the die, preform and melt.



TALAT | Squeeze Casting of Discontinuously Reinforced Composites | 1402.02.10

Vacuum Infiltration. This technique essentially consists of a slow infiltration of a preform due to a pressure difference between the liquid melt and the evacuated preform.

Compocasting or Rheocasting (**Figure 1402.02.11**). In compocasting or rheocasting, particulates or short fibres are incorporated into vigorously agitated partially solid aluminium slurries. The discontinuous ceramic phase is mechanically entrapped between the proeutectic phase present in the alloy slurry, which is held between its liquidus and solidus temperatures. This semi solid process allows near net shape fabrication since deformation resistance is considerably reduced due to the semi-fused state of the composite slurry.

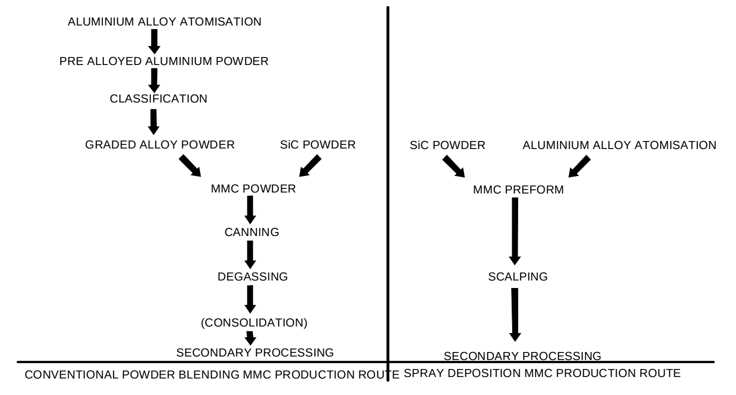


TALAT | Compocasting of Al-Based Composites | 1402.02.11

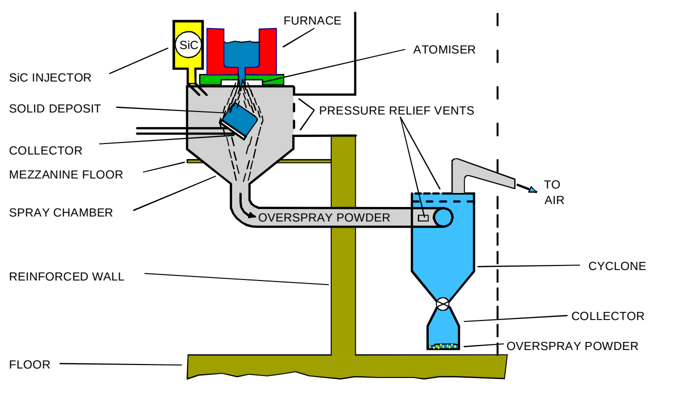
- Spray Methods

Spray methods are starting from the generation of a mixture of liquid metal droplets and reinforcement particles which are sprayed on a (removable) substrate. Advantages are the rapid solidification of the matrix leading to extra strengthening and reducing the reaction time between reinforcement and matrix. Also blending and degassing steps, which are typical for the powder metallurgical route, are avoided (**Figure 1402.02.12**).

Osprey Process (**Figure 1402.02.13**). This spray process is developed by Osprey Metals Ltd. in the UK and can be applied for particulate reinforced aluminium alloys. The essential production steps are the generation of a spray of molten droplets (in analogy with inert gas atomisation) and the impact of the liquid droplets on a cooled substrate placed in the line of flight. Reinforcement particles may be directly injected into the atomised spray, leading to the co-deposition of metal and particles. Depending on the form of the substrate collector system, a variety of shape, including sheet, can be produced. The resulting as sprayed structure has fine grains (typically 15 µm) and is quite dense (95-98 % theoretical density). It is feasible to produce ingots of 100 kg or more and a wide range of alloys has been sprayed successfully. Sprayed billets can further be hot worked (extrusion, rolling, forging). Typical properties are given in **Figure 1402.02.14**.



TALAT	Spray Methods Versus Conventional Powder Blending	1402.02.12



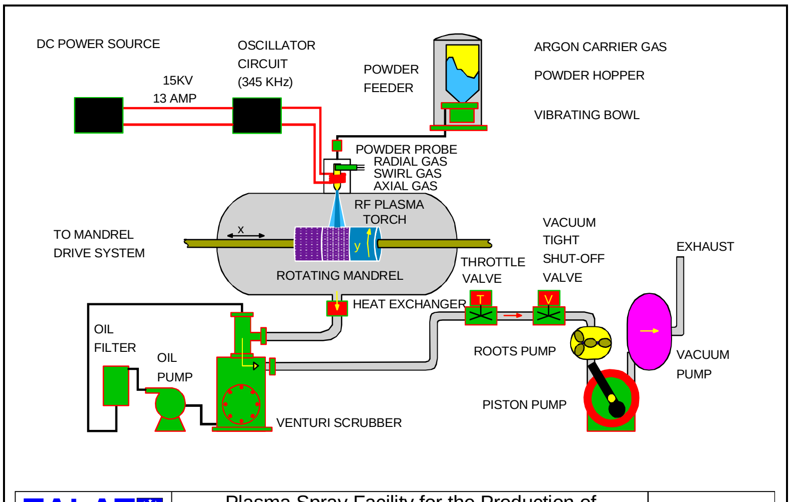
TALAT	Osprey Spray Method Modified for the Production of Particulate Composites	1402.02.13

MATRIX ALLOY	HEAT TREATMENT	SiC vol%	ULTIMATE STRENGTH (MPa)	YIELD STRENGTH (MPa)	ELONGATION %	ELASTIC MODULUS (GPa)	DENSITY g/cc
AA2124	T4	17	610	400	7	100	2.85
	T351	17	610	500	6	100	2.85
	T4	25	700	500	4	115	2.88
AA8090	T6	17	540	450	4	103	2.66
AA6013	T6	20	520	450	5	104	2.82

TALAT Typical Properties of Al-Matrix Composites (via Osprey-Process) 1402.02.14

Low Pressure Plasma Deposition (**Figure 1402.02.15**). Aluminium (alloy) powder plus reinforcement are fed into a low pressure plasma. In the plasma, the matrix is heated above its melting point and accelerated by fast moving plasma gasses. These droplets are then projected on a substrate, together with the reinforcement particles. The latter particles remain solid during the whole process if one use lower power settings or may be partially or fully melted when higher power settings are used.

By a gradual change of the feeding powder composition, gradient materials can easily be produced.



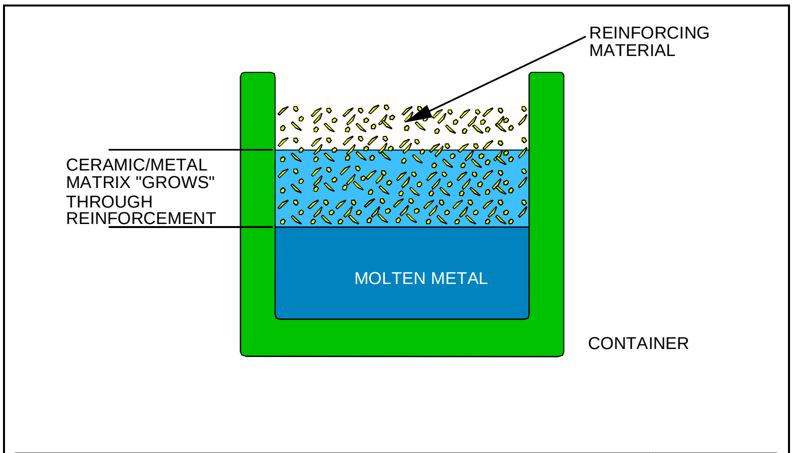
TALAT Plasma Spray Facility for the Production of Particulate Composites 1402.02.15

In situ Production Methods

The in situ production route of aluminium matrix composites is highly interesting because it avoids the need for intermediate formation of the reinforcement. Indeed, in this process the reinforcements are formed by reaction in situ in the metal matrix in a single step. A further advantage is that the interfaces between the reinforcement and the matrix are very clean, enabling better wetting and bonding between them and the matrix (no gas adsorption, no oxidation, no other detrimental interface reactions). Also costs and safety hazards are reduced, as the handling of the fine particulate reinforcement phases are eliminated.

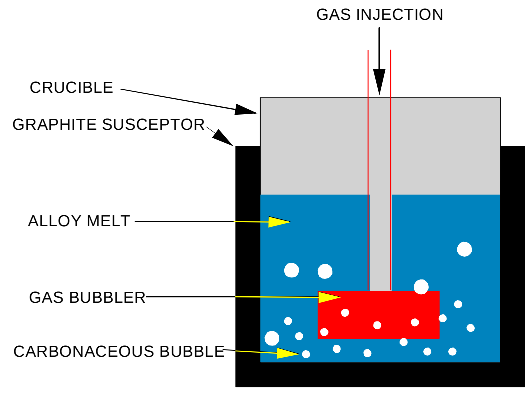
Lanxide Process (**Figure 1402.02.16**). The Lanxide process is developed by the Lanxide Corporation and involves the controlled outward oxidation or nitridation of molten aluminium alloys to form metal-ceramic mixtures (Al-Al_2O_3 or Al-AlN combinations). Other reinforcements (e.g. Al_2O_3 fibres, TiB, B_4C) may also be added to the liquid aluminium alloy.

XD-Process The XD-process is patented by the Martin Marietta Corporation. Blends of ceramic and metallic powders are heated up to a reaction temperature which is usually above the metal melting point. The components react with each other (preferably exothermically) and form a dispersion of a new ceramic phase in the matrix. Examples
are the production of aluminium composites with a dispersion of borides or nitrides.



TALAT | Principle of the in Situ Lanxide Process | 1402.02.16

Liquid, Solid or Gaseous Reactant Methods (**Figure 1402.02.17**). Controlled liquid alloy - gas or liquid alloy - solid reactions permit the generation of carbide, nitride or boride particles in aluminium matrix.



TALAT	In Situ Method with Gaseous Reactants for the Production of Al-Based Composites	1402.02.17

1402.03 Application Examples

- Introduction
- Automotive sector
- Aerospace applications
- Electronic and communication applications
- Sports and leisure market applications

Introduction

The current and potential application of aluminium based composites are concentrated on three specific areas: the automotive industry, the aerospace sector and the leisure market. However, interest is also growing in the field of mechanical applications (mostly for wear resistant or high precision applications) and in the field of electrical and electronic applications. At the present, the exploitation of improved mechanical properties (stiffening and/or strengthening of aluminium alloys), is receiving most attention, combined with a substantially improved wear resistance. But the most exiting and economically challenging area is the development of materials with tailor made properties: composites can be produced with a combination of physical, mechanical and mechanical properties, which is ideal for a given application. Typical examples are for instance components with a good thermal conductivity, a well specified coefficient of thermal expansion and good wear resistance properties (e.g. piston ring in a combustion engine). Also specific electrical properties can be tailored.

Automotive Sector

The automotive market is a high volume and a high technology market, but costs should be as low as possible. However, there are still a lot of reasons to consider the use of light aluminium composites:

- reduction of the weight of engine parts;
- increase of the operation temperature of engines;
- improvement of the tribological properties of moving and contacting components (wear resistance, lubrication);
- increase of stiffness and strength,
- matching coefficient of thermal expansion (e.g. steel or cast iron in connection with aluminium alloys);
- the use of related manufacturing techniques (especially for discontinuously reinforced aluminium alloys).

Unfortunately, ductility and fracture toughness are decreasing when compared with unreinforced alloys. There is also a lack of available design data.

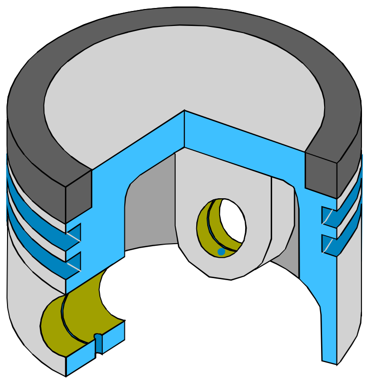
For high mass production, another important issue is recycling. At the beginning, there were some doubts about the recyclability, not only for environmental reasons, but also for cost considerations. Recent studies resulted into two approaches :

- recycling, which means reuse as composite;
- reclamation, which means the separation of the individual components (matrix and reinforcement) of the composite.

Recycling of powder metallurgical composites is the comminution of the composite to powder, which can be reconsolidated. Recycling of cast composites includes remelting and recasting, while avoiding degrading reactions or excessive agglomeration of the reinforcement. For reclamation a technology is recently developed by a major Al-company, in which the particles are "dewetted" and then separated from the matrix.

MATERIAL	APPLICATION	IMPROVED PROPERTY	FEATURE	MANUFACTURER
Al-SHORT FIBRE (SAFFIL)	PISTON RING	ABRASION RESISTANCE PERFORMANCE LOWER COST	HIGH TEMP. ENGINE	TOYOTA
Al-SHORT FIBRE (SAFFIL)	COMBUSTION BOWL OF PISTON	HIGH TEMPERATURE PERFORMANCE	IMPROVED DURABILITY	CONSORTIUM
Al-SHORT FIBRE (SAFFIL)	SELECTIVE REINFORCEMENT OF MOTOR BLOCK	HIGH TEMPERATURE PERFORMANCE	IMPROVED DURABILITY	PEUGOT
Al-SHORT FIBRE (SAFFIL)	CYLINDER LINER	IMPROVED STIFNESS WEAR RESISTANCE CLOSER TOLREANCES BETTER HEAT CONDUCTING	IMPROVED DURABILITY	HONDA
Al-SiC PARTICLES	CONNECTING ROD	SPECIFIC STRENGTH SPECIFIC STIFFNESS	HIGHER PERFORMENCE	DWA DURALCAN NISSAN
Al-ALUMINA FIBRE	CONNECTING ROD	SPECIFIC STRENGTH SPECIFIC STIFFNESS	HIGHER PERFORMENCE	DUPONT CRYSLER

Al-Matrix Composites for Car Applications 1402.03.01



TALAT | Selectively Reinforced Automotive Piston | 1402.03.02

A list of typical Al-matrix composites for car applications is given in **Figure 1402.03.01** The first high volume application is the successful aluminium Toyota-piston ring (**Figure 1402.03.02**), reinforced with short Saffil fibres and produced by squeeze casting. Both weight saving and increase wear resistance are the main reasons for the success. The production rate was more than 100,000 parts per month in 1991. Other current applications are piston parts, cylinder liners and connecting rods.

Aerospace Applications

In strong contrast with the automotive industry, weight savings are of major concern to the aerospace industry. However, the extreme demands of advanced aerospace applications also requires new materials which are stronger, stiffer and possess higher temperature capabilities. The most effective introduction of Al-based composites is not only a simple substitution of existing components, but redesigning will be required. Also, it is advantageous if one can avoid the integral machining of parts, because this fabrication route mostly attains only 10% materials utilisation. The potential of the near net shape manufacturing routes which are possible with MMCs opens possibilities for the aerospace industry. Applications can be categorised as follows:

- aircraft structural framework
- aircraft engines
- space applications.

In structural applications, the development of materials with high specific stiffness is a prime objective. Typical materials under development are Al-alloys with continuous reinforcement of SiC or alumina, high strength Al-alloys (superplastic or rapidly solidified) or Al-Li alloys with SiC particulates. The list of considered components include vertical tails, wing slat tracks, bulkheads, doors, landing gear parts, wheels, speed brakes.

The present generation of jet engines has the following requirements: higher thrust to weight ratio, increased fuel efficiencies, longer in-service lives and reduced costs.

Therefore materials with increased stiffness, higher temperature capabilities, increased reliability at higher stress levels and reduced density are required. In engines Al-based MMCs are tested for low and high pressure compressor casings, stator vanes, rotor discs.

Applications of MMCs in space are mostly motivated by weight reduction, superior specific mechanical properties or the capability of near-zero coefficients of thermal expansion. Moreover, the inherent high damping properties of most MMCs are also useful in damping out vibrations in the space satellite during launch procedures.

Electronic and Communication Applications

New generation advanced integrated circuits are generating more heat then previous types. Therefore, the dissipation of heat becomes a major concern. Indeed, thermal fatigue may occur due to a small mismatch of the coefficient of thermal expansion between the silicon substrate and the heat sink (normally molybdenum). This problem can be solved by using MMCs with exactly matching coefficients (e.g. Al with boron or graphite fibres and Al with SiC particles). Besides a low coefficient of thermal expansion and a high thermal conductivity, these Al-based MMCs also have a low density and a high elastic modulus.

Hermetic package materials are developed to protect electronic circuits from moisture and other environmental hazards. These packages have often glass-to-metal seals. Therefore, materials with an "adjustable" coefficient of thermal expansion are required. Al-based MMCs are fulfilling this condition, as the coefficient of thermal expansion is depending upon the volume fraction of the fibres or particles.

Sports and Leisure Market Applications

The already well known advantages of Al-based composites are leading to several applications in various leisure and sporting goods. Typical applications are fishing rods, tennis and squash rackets, bicycle frames, golf club heads.

1402.04 Literature

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1402.05 List of Figures