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P/M Aluminium Structural Parts for Automotive Application

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Abstract

In recent years there has been a resurgence of interest in development of P/M aluminium alloys and components, especially for automotive applications. These light weight materials are expected to replace sintered iron and steel parts in automobiles in order to reduce weight, increase fuel efficiency and also reduce exhaust emission. The presentation will give an overview of the objectives of the current joint research project sponsored by the BMBF. Hypereutectic Al-Si-alloys produced by powder metallurgy are most promising because of their superior properties (hardness and strength, low thermal expansion, wear resistance) and the ability to tailor these properties for particular applications (e.g. oil pump rotors). However, it must be shown that each application is technical feasible as well as cost effective in order to introduce mass production of P/M Al-Si-alloys. In this context, the press-and-sinter P/M offering net shape and inexpensive manufacturing will be considered

1 Introduction

The challenge for achieving high volume automotive applications of P/M aluminium products lies in achieving the desired properties at sufficiently low cost. Net shape processing routes, i.e. the manufacturing of complex formed structural parts with no or small amounts of waste material, are the key to cost reduction (1)

P/M aluminium alloys have the potential for application in automotive components, particularly for sliding and friction parts. Most of the structural P/M aluminium alloys used today are based on wrought or cast alloy compositions; most are based on the 2000 and 6000 alloys and contain Cu, Mg and/or Si. More recently, also considerable work has been invested into AlZnMgCu sintered alloys (2, 3); noticeable activities have been reported especially in the 1990s (4, 5). Also here the alloy elements have been introduced as elemental powders or rich masteralloys since prealloy powders are virtually incompressible and do not exhibit sufficient sintering activity (6).

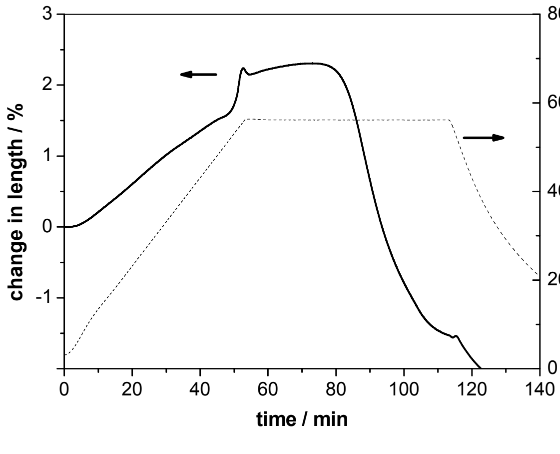
Applications in pulleys, rod guides, shock absorber piston, oil and transmission gears are envisioned. These are examples for parts with different geometry and complexity which are manufactured using uniaxial pressing. Apart from wear and strength problems which are still an issue, these components require extremely tight control of dimensions (7, 8). One component that has elevated the position of P/M aluminium in the automotive market is the camshaft bearing cap produced by the conventional press-and-sinter P/M. The alloy that is used for this component is the P/M equivalent of wrought 2014 alloy (AlCuMgSi).

An area of intensive interest is the development of AlSi alloy products by P/M processing. Typically, Si additions are made to aluminium casting alloys to increase the fluidity of the molten alloy as well as to improve the wear resistance of the cast product. P/M processing offers some significant advantages over casting, particularly in its ability to produce hypereutectic alloys with relatively fine Si particles, which can provide a wear-resistant and machinable product.

3 Al-Si-alloys

Microstructure

The challenges for the P/M AlSi alloys reside primarily in processing, as the prealloyed AlSi powders are hard and difficult to compact. Approaches involving blending of high and low Si powders as well as additions of sintering aids are under investigation (9). In addition, a mix of plain aluminium powder and a masteralloy containing all alloying elements has been developed by ECKA for this type of sintered alloys (10). The Si content of these AlSi-based alloys may vary from 14 to 35% by e.g. changing ratio Al-masteralloy. These further possibilities of alloy design should be used to achieve the target properties of some aforementioned automotive components.
After sintering in the optimum temperature range of 550-560°C, materials with good dimensional stability, sufficient strength and excellent wear resistance can be obtained. In Fig. 1 typical shrinkage curve of powder compacts of an AlSi-based powder blend and a optical micrograph of the sintered material are shown.



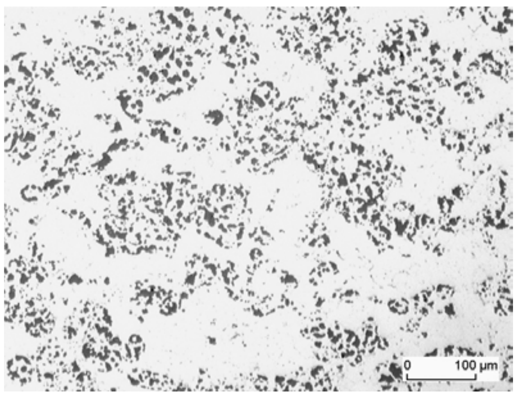


Fig. 1: Typical dilatometric graph during sintering of AlSi14CuMg powder blend and the corresponding microstructure of P/M aluminium.

The green compacts possess about 93% total density (TD) and a heterogeneous microstructure of masteralloy particles embedded in the plastically deformed plain aluminium powder. The initial swelling effect beginning at about 520°C can be explained by the formation of a small amount of supersolidus liquid phase from the masteralloy. This liquid phase activation supports the densification process. The final density is about 99,8% TD during isothermal sintering for at least 60 minutes at 550 – 560°C. Simultaneous Si coarsening has occurred and a silicon grain size of 2-30 µm is measured.

Mechanical and thermal properties

The mechanical properties of Alumix 231 (supplied by ECKA) with the nominal composition AlSi14Cu2,5Mg0,6 are given in table 1 in comparison to Alumix 123. Quite attractive strength and hardness levels have been attained by age hardening, but at the expense of a reduced ductility.

ECKA Alumix	*Composition*	*State*	*Tensile strength MPa*	*hardness HB2,5*	*Elongation %*
231	AlSi14CuMg	T1 T6	230 340	100 140	1 0,5
123	AlCu4,5MgSi	T1 T6	190 320	60 100	5 1

Table 1: Mechanical properties of sintered Alumix 231 compared to Alumix 123 (17).

The main phase determining the value of the coefficient of thermal linear expansion (CTE) of aluminium alloys is silicon. Fig. 2 illustrates the decrease of CTE with increasing Si level for P/M aluminium alloys. This capability to change physical properties is important in applications where CTE matching is critical in part design (e.g. oil pumps).

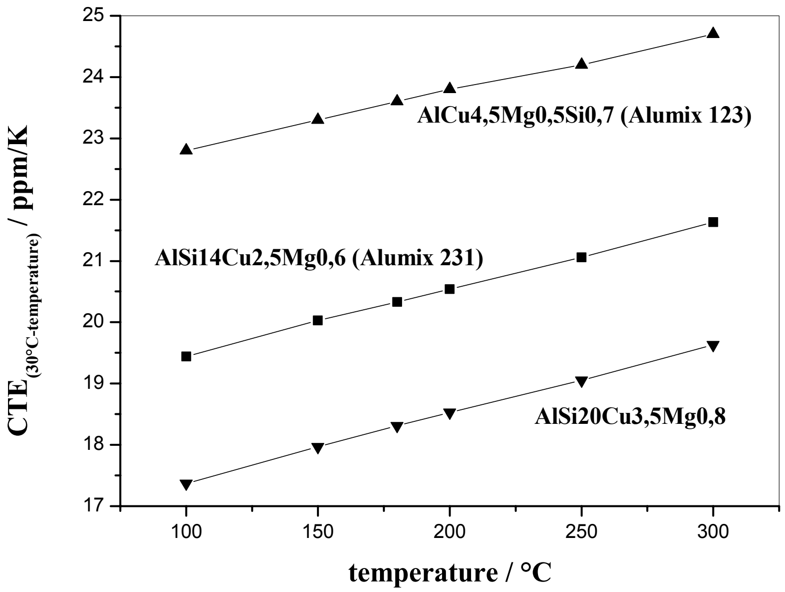


Fig. 2: Coefficient of thermal expansion vs. temperature for different sintered AlSi alloys.

Tribological properties

The tribological behaviour of sintered AlSi alloy was investigated by ring-on-disk tests against a typical die-cast AlSi9 alloy (Fig. 3). The samples were tested at a temperature of 110°C, fully immersed in oil, with a constant normal load between 240N and 640N. The sliding speed changes cyclically between 0m/s and 6m/s in periods of seven seconds. For comparison the sintered AlCuMgSi alloy (Alumix 123) was also evaluated. The friction coefficient is calculated from the measured tangential force. During the tests, the temperature of the system and the total linear wear were recorded (Figs. 4 and 5).

Negligible wear occurred in case of Alumix 231 disk against the die-cast AlSi ring during experiments performed at 240N. At the beginning of the tests, the increase of temperature causes a pretended wear effect by thermal expansion of the specimens. After this running-in period of about 10^4 m, a stable wear condition is reached.

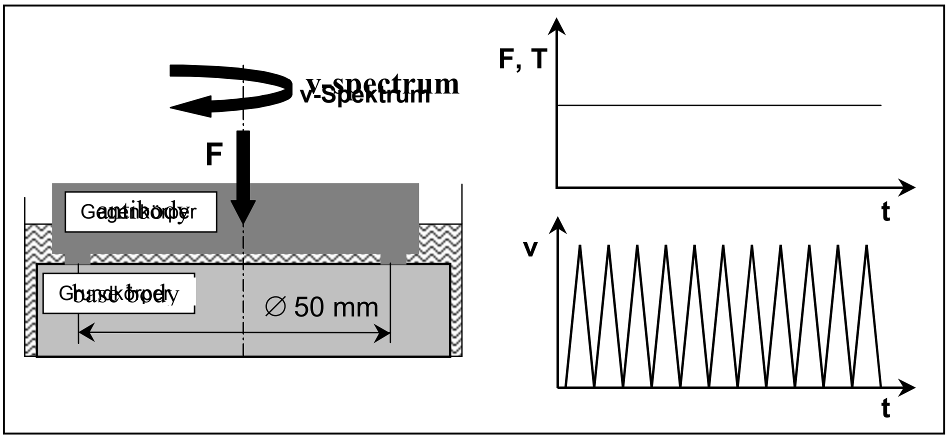
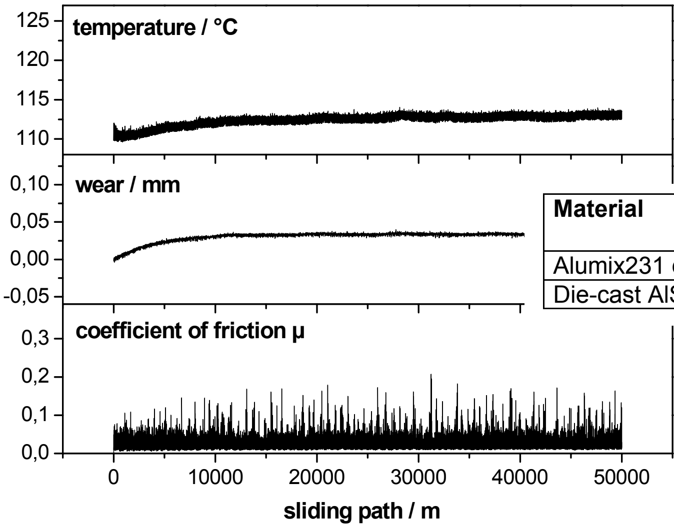
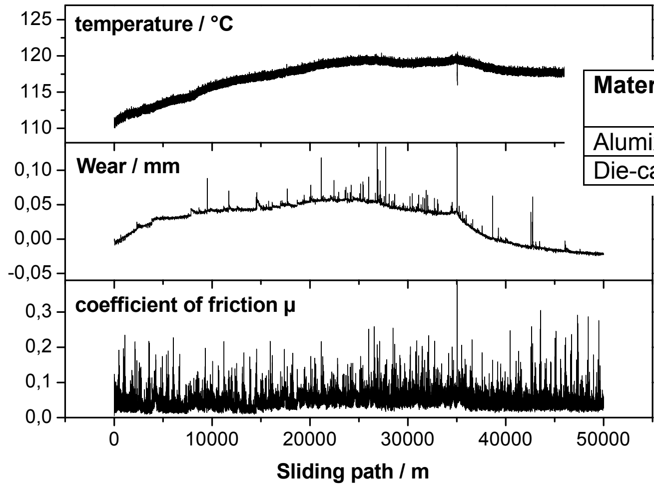


Fig. 3: Schematic view of the wear test setup and the loading configuration with load F, system temperature T, sliding time t and sliding speed v.



Material	HB2,5	Surface condition und roughness (µm)
Alumix231 disk	140	turned, Rt=7,8, Rz=5,9
Die-cast AlSi ring	105	blasted, Rt=6,5, Rz=6,4

Fig. 4: Temperature, total linear wear and calculated coefficient of friction during ring-on-disk tests with disks of sintered Alumix 231 (AlSi14Cu2,5Mg0,6).



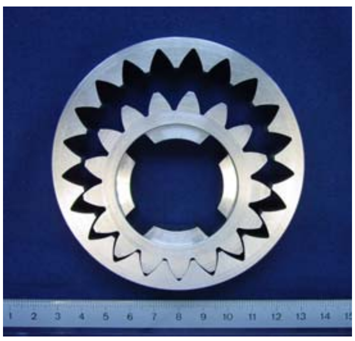
Material	HB2,5	Surface condition and roughness (µm)
Alumix123 disk	115	turned, Rt=7,2, Rz=4,5
Die-cast AlSi ring	105	blasted, Rt=6,5, Rz=6,4

Fig. 5: Temperature, total linear wear and calculated coefficient of friction during ring-on-disk tests with disks of sintered Alumix 123 (AlCu4,5Mg0,5Si0,7).

This is reflected by the stable evolution of the friction coefficient and the constant wear value. The dynamic friction coefficient depends on the sliding speed and varies between 0,02 and 0,08. Values of μ up to 0,2 were measured during static test conditions. In addition, there is a Si enrichment in the contact zone compared to the starting compositions of ring and disk, as proven by EDX investigations. In the steady-state a constant amount of this debris obviously remains in the contact, keeping the friction coefficient low. A sliding distance dependent transition to severe wear occurs within the load range of 560-640N. Both, strong spots of seizure and massive surface damage by abrasion were observed for these test conditions.
When a disk of Alumix 123 (AlCu4,5Mg0,5Si0,7) is used (Fig. 5), the wear signal already reveals the early occurrence of seizure and stick at the contacting surfaces at the lowest load of 240N. All of these effects were recorded during restarts of the disk rotation. After a strong seizure at about 35000 m with a measured peak friction coefficient of μ = 1,28, a pronounced increase of weight loss occurred. Both disk and ring showed a final linear wear of about 25-30 µm in the wear track.
Therefore, silicon is essential for wear properties because these particles control the direct contact between the matrices. The addition of silicon with controlled Si particle size increases the wear resistance of Al alloys (e.g. Alumix 231) by improving the seizure resistance of these materials.

4 Application

Durability tests of oil pump rotor sets made from P/M aluminium were performed in the 6-gear shift automatic transmission "myTronic6" (Fig. 6) supplied by ZF Getriebe GmbH for car application. Using P/M aluminium pump components, the thermal expansion of the



Oil pump gear set

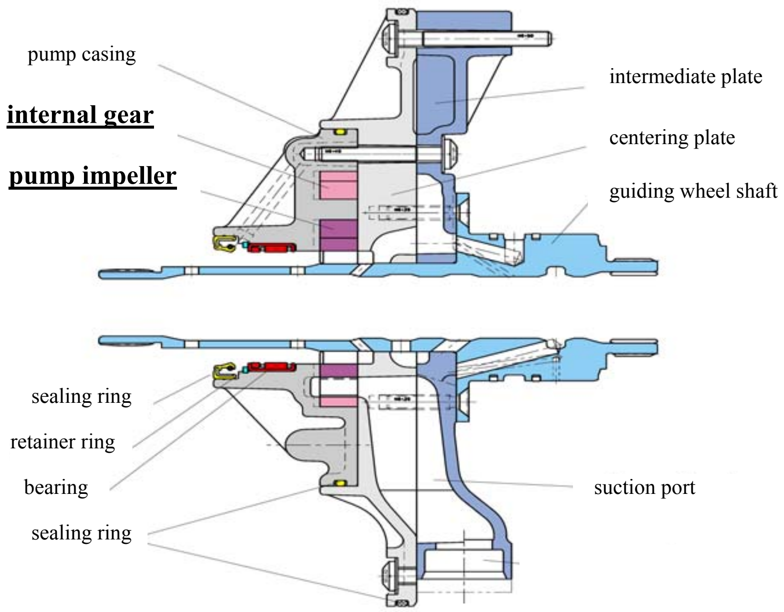


Fig. 6: Oil supply with oil pump of an automatic transmission by ZF.

housing and rotors are matched. Optimised, reduced clearance may be designed resulting in less leakage and greater pumping efficiencies.
Significant abrasive wear occurred with an oil pump gear set made from Alumix123 (AlCu4,5MgSi). At the front faces of the rotors scoring was presumably caused by non filterable dirt particles in the oil. In contrast, negligible wear and no changes in pump performance parameters were found in case of Alumix231 (AlSi14CuMg) during testing.

However, sintered pump rotors with microstructures containing small silicon particles < 10µm tend to some adhesive wear and seizure in combination with a housing made from die-cast GD-AlSi9Cu3. Therefore, testing trials showed the need for a careful adaptation of the microstructures and the hardnesses of the single pump components.

5 Conclusions

For the manufacturing of aluminium based P/M precision parts by pressing and sintering, suitable powder mixtures have been developed. In the last years, considerable work has been done on Al-Si base sintered alloys of near- and hypereutectic composition. These alloys are attractive for wear loaded components but also offer good mechanical properties and tailorable CTE`s.

Oil pump rotors are heavily loaded under operating conditions. Durability testing of P/M aluminium rotors performed in a transmission test stand showed that Alumix231 can meet the main demands on material properties (density > 95%, hardness > 130HB, strength > 250MPa, high wear resistance). In addition, the P/M aluminium pump rotors would allow to replacing previous cast iron pump housing by cast aluminium for significant weight savings of about 1 kg.

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