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Structure Optimization of Al-Si-Type Alloys for Thermal and Mechanical High Loaded Components

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Abstract

Research and development are a very specific challenge due to the pressure to innovate, to which the automobile industry in particular is subject worldwide. For this reason the development of new materials with improved properties and process-engineering advances were the focus of this project.
The targets are to improve properties of aluminum cast alloys by refining the grain size and increasing the heat conductivity. The latter gives better material performance for all applications with local heat maxima. Due to better heat conductivity the maximal material temperature during use will be lower. This yields better local mechanical properties.
Therefore a melt treatment with boron was tested, which provides a higher heat and electrical conductivity and yields a better grain structure for improved mechanical properties.
This paper describes the development process, the experiments and the results from the examinations. Additionally it gives an outlook on the potential of such aluminum alloys.

Introduction

Usually a boron melt treatment is used for increasing the electrical and heat conductivity, [1]. This effect is caused by the removal of elements like titanium, zirconium etc. Due to the possibility to use boron as a grain refiner instead of TiB_2 [1, 2] a fine grain structure and improved mechanical properties were expected additionally.
The focus of most of the alloy developments is on increasing the mechanical properties of the component as well, just as it is in this project. The approach used in this project was to improve the mechanical properties by influencing the grain size and increasing the heat conductivity. Due to better heat conductivity the maximal temperature in the component will be lower. This yields better local mechanical properties. As a result of these facts the fatigue behavior should be increased.

Experiments

For the first experiments a common EN AC-AlSi7Mg (A356.2) was used. All tests were carried out with the boron treated alloy and a standard treated EN AC-AlSi7Mg (A356.2) for comparison.

Standard treatment

For the standard treatment primary aluminum was melted in an induction furnace and alloyed according to the chemical composition shown in Table 1. Subsequently a grain refinement with AlTiB- and a modification with AlSr10-master alloy were carried out. To avoid gas porosity in the microstructure a degassing treatment with an impeller has been applied. In all casting experiments nitrogen was used for the degassing. The density measurement resulted in a density index lower than 3.

New Treatment

Characteristically for the new treatment is that the pure aluminum is initially treated with boron. For this purpose, the aluminum was melted in an electric resistance crucible furnace and the addition of boron was carried out by using an impeller for stirring in the boron master alloy. Next step was a conditioning time for the formation of borides (TiB_2 etc.) and the sedimentation of the borides.
The purified aluminum was transferred into an induction furnace and alloyed with silicon and magnesium; as shown in Table 1. In terms of a final melt treatment only a modification with AlSr10-master alloys and a degassing treatment was done.

Table 1. Alloy composition (EN AC-AlSi7Mg (A356.2); standard and new boron treated alloy)

	unit	Standard	New
Si	%	7.3	7.1
Fe	%	0.08	0.06
Cu	%	0.004	0.005
Mn	%	0.014	0.010
Mg	%	0.33	0.30
Zn	%	0.005	0.014
Ti	%	0.12	0.0001
Zr	ppm	30	2
V	ppm	90	1
Sr	%	0.03	0.03

Casting activities/Casting of test samples

In both cases test samples were produced by pouring melt (melt temperature: 720°C-730°C) into a test mould, pre-heated to 370°C. The mould material was gray iron. The test geometry was a mould for tensile rods as visible in Figure 1. After solidification and air cooling of the test samples the risers were removed. Furthermore a T6-heat treatment was performed as well. The heat treatment parameters are:

Solution heat treatment:
535°C/6h
Water quenching,
Delay time ca. 30 min.
Artificial aging: 180°C / 6h (T6)

Figure 1. Test mould for the casting tests with the different grain refiner systems and unmachined specimen for the tensile rod

Results

Stated below the outstanding results of this investigation can be seen. The grain refinement of the boron addition is shown in Figure 2. In comparison to the TiB_2 refined alloy the boron refined alloy yields a much finer grain structure.

The dendrite arm spacing, pictured in Figure 3, is much smaller, too. In the castings with the new alloy the DAS is 23µm, while the DAS of the standard alloy is 47µm.

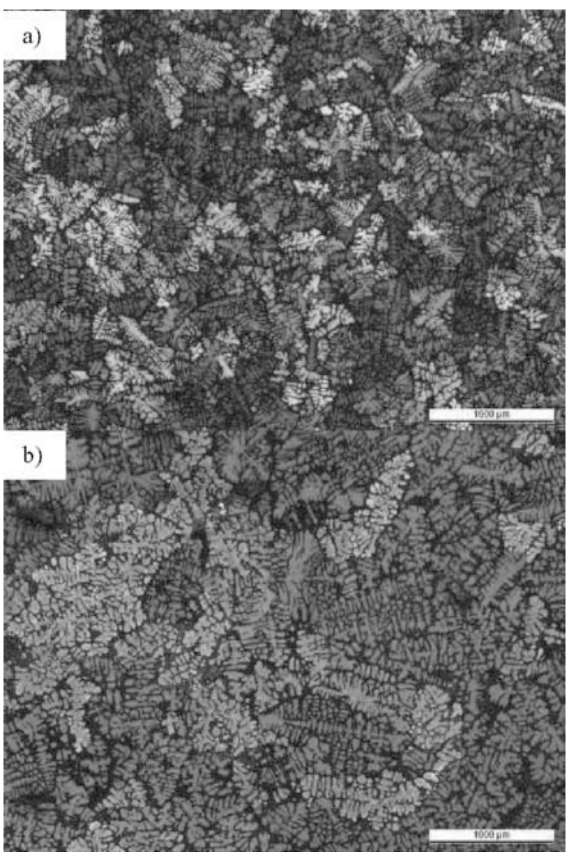

Figure 2. Examples for the grain structure of an EN AC-AlSi7Mg (A356.2) T6; a) with boron; b) with TiB2 grain refinement. All specimens are separately casted test bars.

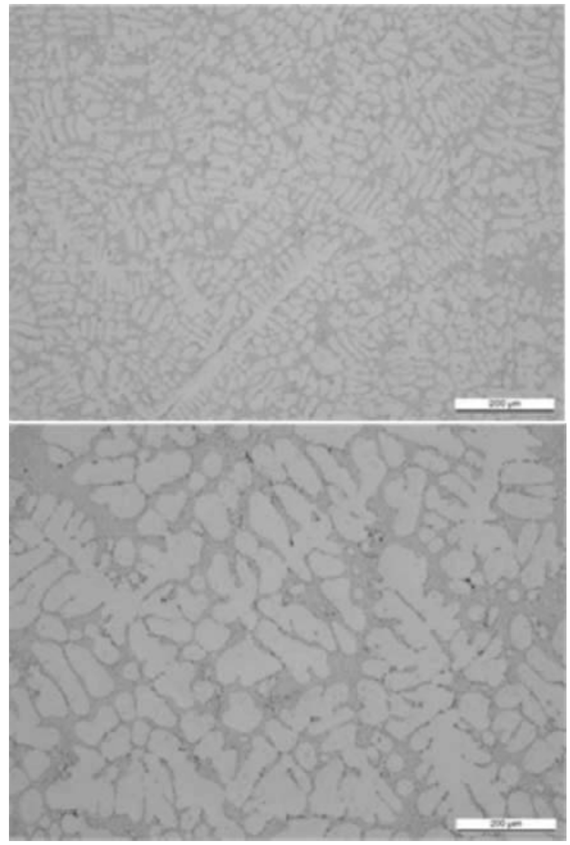

Figure 3. Examples of the dendrite structure of an EN AC-AlSi7Mg (A356.2) T6 a) with boron; DAS: 23µm; b) with TiB2 grain refinement; DAS: 47µm. All specimens are separately casted test bars.

The optimized microstructure results in significantly better mechanical properties. While the yield strength is nearly the same, the UTS is increased. But the greatest effect could be observed for the ductility. The doubling of the elongation in comparison to the TiB_2-refined material is a great benefit for multiple applications.

Table 2. Mechanical properties and grain sizes of the investigated specimen. All data are average values.

Grain refinement	**Yield strength**	**UTS**	**Elongation**	**Grain size**
	MPa	MPa	%	µm
TiB_2	252	292	4.0	500
AlB_2	250	315	8.4	250

The second main aspect in this investigation was to improve the conductivity. The well-known advantages of the boron melt treatment could be confirmed, [1]. As well as the electrical conductivity, the heat conductivity could also be increased significantly, Figure 4. For example the heat conductivity is increased at RT from 178W/Km to 203W/Km. This implies an overall increase of more than 14%.

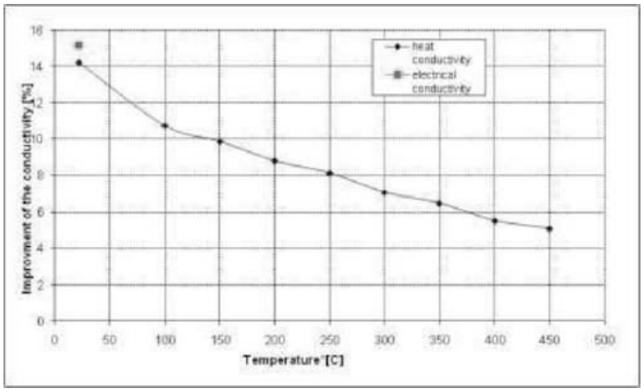

Figure 4. Improvement of the heat and electrical conductivity of the boron grain refined AlSi7Mg (A356.2) in comparison to the EN AC-AlSi7Mg (A356.2) with TiB_2.

Practical Experience

The most important purpose in developing new materials is their use in real applications. The first application area is the use of the new aluminum alloy for cylinder heads. These components are thermally and mechanically highly stressed. Additionally the requirements are rising continuously as shown in Figure 5. Increasing the mechanical properties and especially the resistance against thermal and high cycle fatigue are the targets for using the boron treated aluminum alloy. Another target is lowering the local temperature in the component due to the increased thermal conductivity. Locally lower temperature yields higher local mechanical properties in the component.
The higher thermal conductivity could be confirmed, when casting the first cylinder heads. Electrical conductivity at the surface of the fire deck of diesel cylinder heads was measured and converted into the thermal conductivity. The standard alloy shows values of 130 W/Km in comparison with the new alloy with AlB_2 grain refinement of 148 W/Km at room temperature. The elongation data show nearly a duplication. The next steps are the investigation of specific mechanical properties and real load tests of cylinder heads on a test stand.

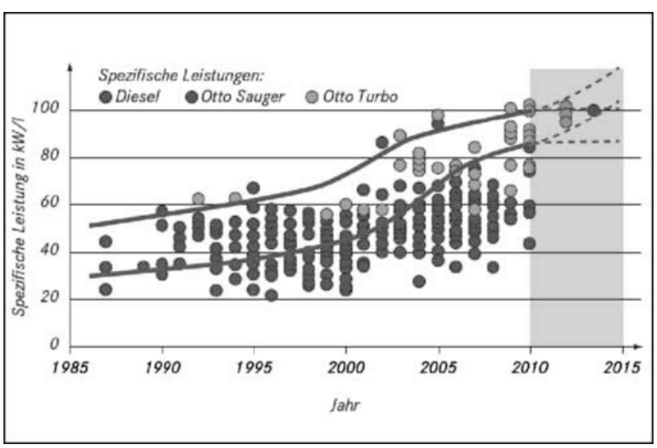

Figure 5. Specific performance of Otto- and diesel engines [3]

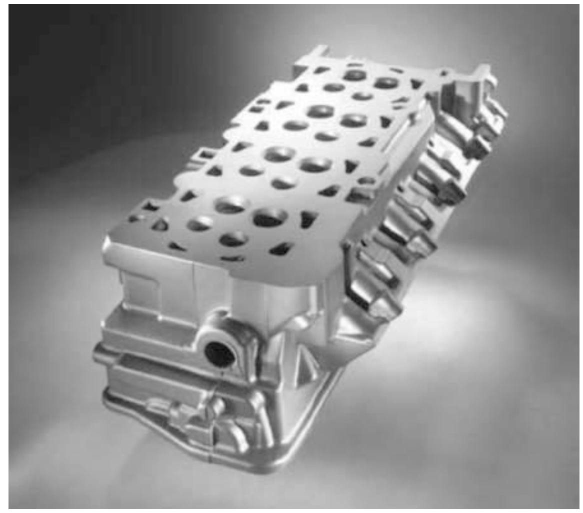

Figure 6. Cylinder head casted with EN AC-AlSi7Mg (A356.2) with boron melt treatment

Further applications of this new alloy are dynamically highly stressed components. The first casting tests with EN AC-AlSi7Mg0.3 (A356.2) were very successful. The microstructure is better than the standard alloy. The most noticeable facts are the differences in grain size and dendritic structure of the specimen.

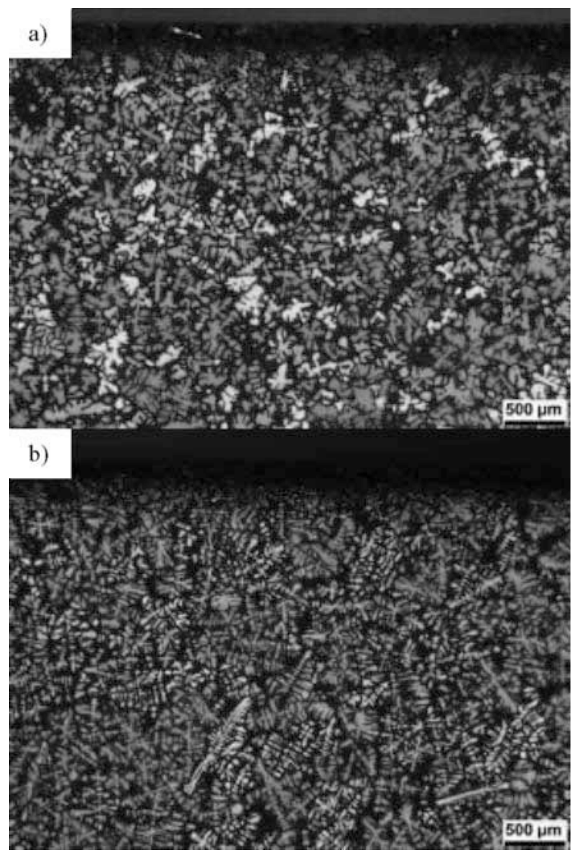

Figure 7. a) AlSi7Mg0.3 with boron melt treatment; grain size (ASTM): 0.5 b) Standard-AlSi7Mg0.3; grain size (ASTM): -0.5

The grain size of the boron treated alloy is significantly smaller in comparison to the standard alloy as perfectly visible in Figure 7. The grain size difference from -0.5 (ASTM) to 0.5 (ASTM) is significant. Figure 8 shows the grain size differences in several positions of the component.

The structure of the dendrites is pictured in Figure 9. It is clearly visible that the dendrites of the new alloy are much shorter. The dendritic structure is much more compact compared to the standard treated component.

This microstructure yields best mechanical properties. An additional effect in theses castings is that the near-surface porosity is decreased. This is an advantage for machined, decorative surfaces in many components.

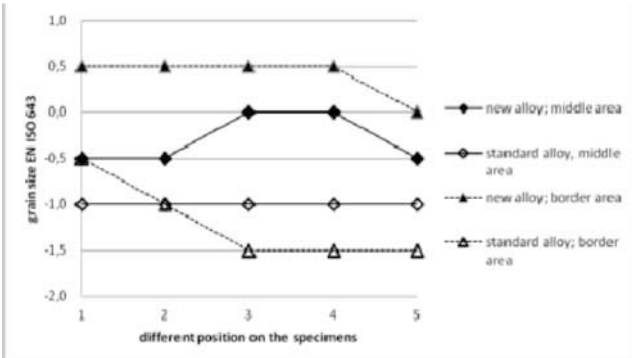

Figure 8. Grain size of the new and the standard alloy at different positions on a dynamically highly stressed component. (Grain size: ASTM; EN ISO 643)

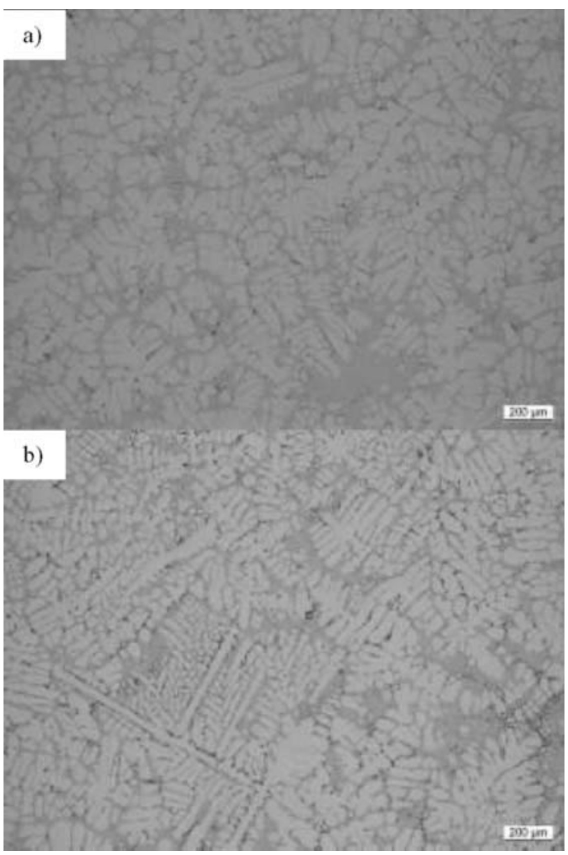

Figure 9. a) AlSi7Mg0.3 (A356.2) with boron melt treatment b) Standard-AlSi7Mg0.3 (A356.2)

Conclusions

As predicted, the boron melt treatment yields great improvements in the conductivity. Additionally the boron in the melt is an excellent grain refiner for example for AlSi7Mg. This results in an optimized microstructure therefore in improved mechanical properties. Especially the remarkable improvement of the elongation in combination with the higher heat conductivity shows great promise for a higher thermal fatigue resistance. Hence many applications in combustion engines, brakes and many other components in different areas could be optimized by this new material.

References

1. G.K.Sigworth, M.M.Guzowski, „Kornfeinung untereutektischer Al-Si-Gußlegierungen“, Gießerei-Praxis, Nr.5/1987, Fachverlag Schiele & Schön GmbH, Berlin, 1987
2. E.Nachtigall, “Kornfeinung bei Aluminiumguß”, ALUMINIUM, 42.Jahrg. 1966 . 11, Fachzeitschrift der deutschen Aluminiumindustrie. Hrsg. von der Aluminium-Zentrale, Düsseldorf, 1966
3. K., Lellig. Neue Leichtbaukonzepte in Motorenkonstruktion und -bau - Antworten auf die veränderten Herausforderungen im modernen Fahrzeugbau. *Internationales Wiener Motorensymposium.* 2010.