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Development of Aluminum-Lithium alloys processed by the Rheo Container Process

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Abstract. This investigation describes the development and evaluation of thixoformable alloys on Al-Li-Mg basis in the scope of the collaborative research center SFB 289 at RWTH Aachen University. Scandium and zirconium was added to Al-Li2.1-Mg5.5 (A1420) with the aid of DoE (Design of Experiments) and precursor billets were manufactured by pressure induction melting (PIM). To evaluate the thixoformability of the synthesized alloys high-quality semi solid processed demonstrators were manufactured by the Rheo-Container-Process. Subsequent heat treatment raised the mechanical properties to maximum values of tensile strength of 432MPa, yield strength of 220MPa and an elongation of 13%. The RCP-Process was designed for the special requirements of this high reactive alloy. The paper will present extraordinary benefits in terms of properties and process simpleness for the semi-solid processing of Al-Li alloys.

Introduction

The development of commercially available aluminum-lithium-base alloys was started by adding lithium to aluminum-copper, aluminum-magnesium, and aluminum-copper-magnesium alloys. These alloys were chosen to superimpose the precipitation-hardening characteristics of intermetallic Al-Cu, Al-Cu-Mg and Al-Mg precipitates to those of lithium-containing precipitates [1]. Proceeding in this manner, alloys A2020 (Al-Cu-Li-Cd), A1429 (Al-Mg-Li), A2090 (Al-Cu-Li), and A2091 and A8090 (Al-Cu-Mg-Li) evolved [2-4]. Nevertheless there are no specific casting alloys on Al-Li basis available which would offer a greater freedom of shape. Only a few research works on that topic are known [6]. Todays challenges with Al-Li alloy manufacturing and processing are:

- Hot tear susceptibility in the casting process
- High reactivity of Lithium with refractory material, moisture and atmospheric gas
- High scrap rate / high machining costs due to high rejection rate
- Corrosion susceptibility
- Recycling issues
- Al-Li alloys cost 3x as much as conventional Al alloys

Processing Al-Li alloys in the semi-solid state offers high potential to reduce the list of problems. Porosity, volume shrinkage and the hot tear susceptibility may be significantly improved by the lower liquid phase content of 40-60% during the thixoforming process. Machining and overall costs are also reduced because of the possibility to manufacture near-net shape components. With the Rheo Container Process a suitable strategy to handle the high reactivity of Al-Li alloys is provided. This was the reason to start this investigation in 2001 in the framework of Aachens collaborative research centre SFB289.

DoE supported synthesis of Al-Li-Mg-based precursor material

On the basis of the well known Al Li 2.1 Mg 5.5 (A1420) Sc and Zr additions in the range of 0-0.3 weight% were added. The other influencing parameter varied was the casting temperature (750-850°C). With the aid of DoE software MODDE 5.0© billets with variations in chemical composition have been molten and cast as precursor material for subsequent semi-solid processing. The high reactivity of Lithium with atmospheric gases and refractory material and its high equilibrium vapour pressure makes it necessary to use special melting and casting techniques. A Lithium resistant SiC crucible was installed in a 3 bar Argon overpressure furnace. The total mass of each manufactured billet was approximately 3 kg.

The strongest effects on grain size were observed when both elements (Sc and Zr) were added to the Al-Li-Mg matrix. With Sc and Zr additions, both 0.15 wt%, a minimum mean grain size of 30µm is achievable. This grain refined precursor material is used for the subsequent semi-solid Rheo-Container-Process.

RCP – Processing of Al-Li

The Rheo-Container-Process (RCP), developed at the Foundry-Institute of the Aachen University, is a rheocasting process with the consideration of the needs for processing high reactive alloy systems like magnesium or Al-Li alloys. Special characteristic of the process is the usage of a non-returnable container. After pouring the liquid alloy into an aluminium container with a wall thickness of 1mm, the alloy cools to the target processing temperature in the container. Due to the procedure on the basis of "slurry on demand" the utilisation of a reheating device is not necessary. The container is transferred together with the semi-solid billet to the shot chamber of a die-casting machine and pressed into the die, **Fig. 1**. The folded container remains completely in the biscuit. The process development, the adjustment of the mostly relevant process parameters and first investigations were executed with the, in the SSM-processing, well known aluminum alloy A356 (AlSi7Mg0.3). As a result of these investigations the cooling period into semi-solid state is supported by air cooling.

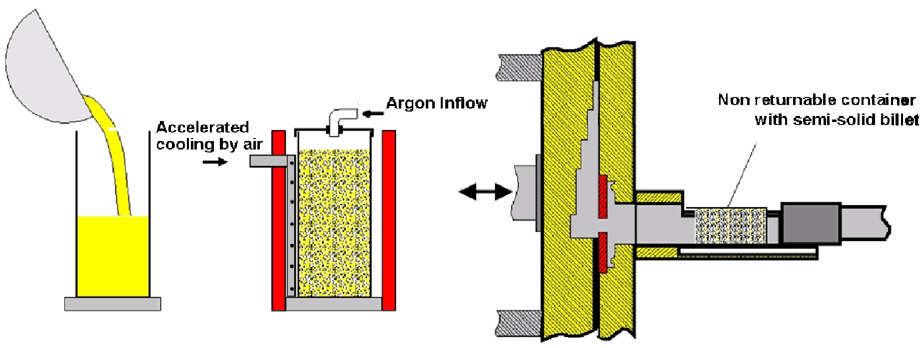


Fig. 1 Schematic illustration of the Rheo-Container-Process (RCP)

The main advantage of the process is the prevention of the oxide layer and therefore best conditions for the processing of high reactive alloys. Except of the top side of the billet, there occurs no contact of the melt or the semi-solid-material with the atmosphere. Even the top side can be easily protected from the atmosphere by using a cover with argon inflow. The use of the non-returnable container includes no further problems at the recycling, because the container material is aluminium too [5].

For the implementation of the RCP-Process for Al-Li alloys additional aspects especially for the melt handling were necessary. Due to the high reactivity of the alloy AlLi2.1Mg5.5Zr0.15Sc0.15, the melting furnace was capsuled and flooded by argon. The processing of the semi-solid Al-Li alloy was executed on a real time controlled high pressure diecasting machine of Bühler (H-630 SC).

The formfilling experiments were accomplished with a step die with wall thicknesses from 25 to 1mm. The results of the achieved step specimen indicated good formfilling properties. In spite of the distinctive hot tearing tendency of this wrought alloy the formability can be described as good. Only at a very critical section of the step specimen, at the transition from the 5mm to the 2mm part some small cracks could be recognized. Lower processing temperatures and higher fraction solid improved the results significantly, due to the lower solidification shrinkage. The mold of the test specimen was originally constructed for different experiments. One reason for the appearing hot crack can be explained by the design of the mold. The runner of the mold heating causes a hot spot in the area of the occurred hot crack. Further investigation will show that, due to construction and adjustment of process parameters, complex geometries can be produced with this Al-Li alloy.

Results

The mechanical properties of the step specimen were analysed in the as-cast and the T6-state. The as-cast properties didn't show the expected results, both, in strength and elongation. The heat treatment of the component takes an important part of this work. Primarily two different heat treatment concepts were investigated, both on the basis of a T6 heat treatment. The main difference is caused by the duration of the solution annealing. In the first concept the solution treatment time lasted 3 hours, in the second one 24 hours. Further the solution treatment temperature, the aging temperature and the aging time were raised, **Fig. 2**.

Contrary to the results of the as-cast specimen, the achieved properties of the heat treated step specimen showed very promising results. With both concepts the mechanical properties have been raised significantly, both for strength and elongation. The average tensile strength of the second concept was 383MPa, the yield strength 235MPa and the elongation 7.5%. Single results even achieved a tensile strength of 432MPa, yield strength of 220MPa and an elongation of 13%.

In **Fig. 3** the development of the microstructure can be compared as a result of the Rheo-Container-Process. The source material shows already a very fine structure. Due to the RCP-Process the primary phase appears more globular, but also a bit coarser. The distribution of the globules in the step specimen was very homogeneous with grain sizes of 65µm, **Fig. 4**.

The transformation of the microstructure, due to the T6-heat treatment show significant changes with strong influence on the mechanical properties. Shorter solution treatment times cause some agglomeration of the globules. For the solution heat treatment for 24hrs the changes in the microstructure are significant. Due to the heat treatment and higher solubility of elements in the solid solution, only a small amount of the eutectic phase remains. The very compact microstructure resembles a transformed wrought alloy, **Fig. 5**. The microstructure of the Al-Li alloy, modified in the RCP-Process shows best properties for the processing and the acquisition of light components. Both, the procedure of the process and the heat treatment, showed first results with existing concepts for further improvements. The results of this work display a high potential for the processing of Al-Li in the semi solid state.

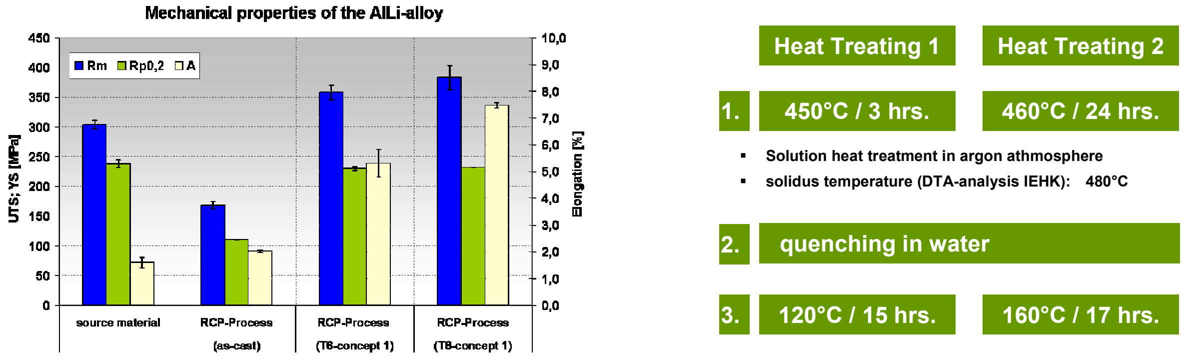
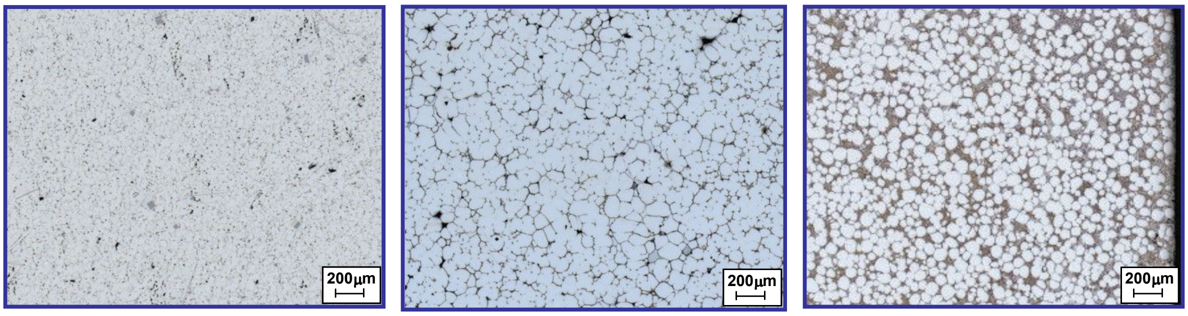


Fig. 2 Mechanical properties of the Al-Lialloy in the as-cast and the T6-state. Two heat treatment concepts for the Al-Li alloy.



source material | quenched RCP-material | RCP material after processing (step specimen, 5mm)

Fig. 3 Evolution of the microstructure of the AlLi2.1Mg5.5Zr0.15Sc0.15 in the RCP-Process

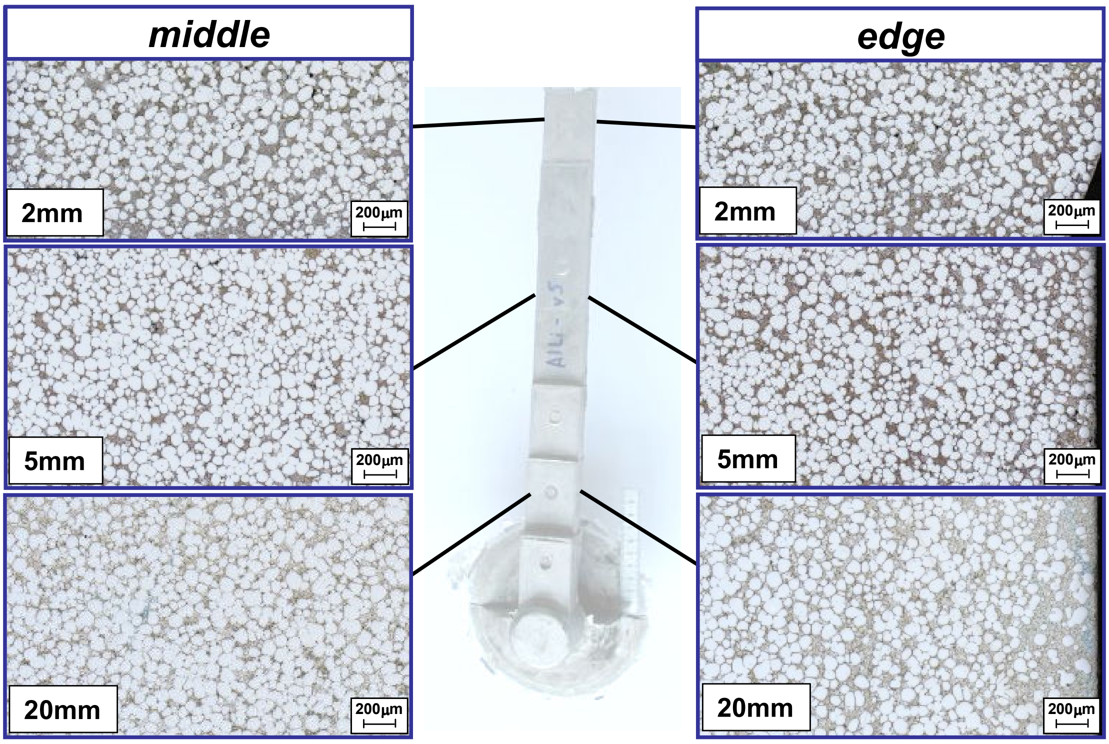
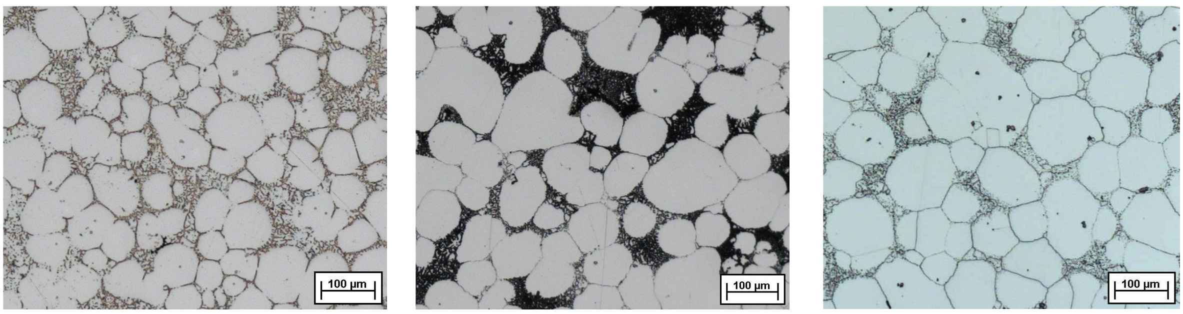


Fig. 4 Microstructure of different sections of the step specimen



as cast | 450°C / 3 Std. 120°C / 15 Std. | 460°C / 24 Std. 160°C / 17 Std.

Fig. 5 Microstructural evolution after different heat treatment concepts (5mm step specimen)

Assessment and outlook

Processing AL-Li alloys in the semi-solid state can offer a variety of improvements for this type of alloy. State of the art Al-Li alloys are generally wrought alloys which are processed by rolling, extrusion and forging. Specific Al-Li casting alloys which offer a high degree in freedom of shape are still not available for a wide spread commercial use. Challenges that have to be addressed for Al-Li alloys are their high reactivity, hot tear susceptibility, occurrence of brittle intermetallic phases, chemical corrosion, recycability and high material and processing costs. Due to the reduced liquid phase content compared to conventional fully liquid casting, it is possible to remove some of the problems occurring with conventional processing of Al-Li alloys. With the aid of a suitable heat treatment concept this research work proved that semi-solid processed near net shaped Al-Li-Mg components can reach static mechanical properties in the range of rolled A1421 (AlLi2.1Mg5.5ScZr) sheet with UTS~479MPa, TS~359MPa, A_5~11%. Future developments will focus on first AlLiMg prototypes processed by SSM and further improvement of heat treatment strategies to evaluate the feasibility of this new processing route for this type of high performance alloys.

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