

IMPROVING THE PROPERTIES OF RECYCLED SELF-HARDENING ALUMINIUM ALLOY FOR APPLICATION IN ELECTRIC VEHICLES

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Abstract: In recent years, the topic of environmental issues has become increasingly important in all areas of industry. As a result of European Union policy, there has been a significant increase in the number of electric vehicles. At the same time, there is an increasing emphasis on ecological and sustainable production. Due to their advantageous strength-to-weight ratio, aluminium alloys are widely used in automobiles and are a logical choice for electric vehicles. Aluminium recycling is a very efficient way of reducing production costs and emissions. Self-hardening aluminium alloys enable heat treatment to be omitted, leading to further energy savings. The limiting factor of secondary production is the insufficient purity of aluminium scrap, which leads to contamination with impurities. In particular, the negative impact of iron, which is found in higher content in recycled alloys after repeated recycling cycles, is well known. Its presence leads to a deterioration of the mechanical, fatigue and corrosion properties of aluminium alloys. This work examines ways to reduce iron content in AlZn10Si8Mg self-hardening alloy using a sedimentation experiment. The crystallization temperature of iron phases is higher than that of the matrix. Therefore, holding the material at a specific temperature is expected to cause iron phases to settle, reducing the iron content.

Keywords: recycled aluminium, AlZn10Si8Mg, sedimentation, Fe-rich phases, electric vehicles

1. INTRODUCTION

The increasing emphasis on environmental protection has led to an increase in the use of recycled aluminium alloys. Secondary production allows the reduction of production costs in addition to emission production (Al-Alimi et al., 2024). While commonly used foundry aluminium alloys need to be heat treated to achieve the desired properties, self-hardening alloys precipitate naturally. This saves time and energy, leading to further reductions in production costs and environmental impact (Rosso et al., 2015). AlZn10Si8Mg alloy



belongs to the group of self-hardening alloys. It is mainly used in the automotive industry due to its advantageous strength-to-weight ratio, corrosion resistance and workability, thus ensuring low weight of automobiles. For the same reason, it is a suitable material for use in electric vehicles (Dwivedi et al., 2014). The main obstacle to their wider use is the iron content, which increases with repeated cycles of secondary production due to the use of steel tooling and imperfect sorting of the input material. Since the solubility of iron in aluminium is limited, at high iron content, plate-like intermetallic Al_5FeSi phases are formed, which negatively affect the mechanical, fatigue and corrosion properties of aluminium alloys. The combination of reduced corrosion resistance and fatigue life is a potential safety risk, especially in vehicles, where components are exposed to cyclical stresses and aggressive environments (Uhrčík et al., 2023; Jakóbczak and Kowalik, 2023; Liu et al., 2024). The most widely used method to eliminate the influence of iron is manganese alloying, which causes the formation of skeletal, Chinese script or sludge iron phases, which are less harmful in aluminium alloys (Kuchariková et al., 2021). Sedimentation appears to be a promising way of reducing the iron content. Since at high iron content (above 0.85 %), the plate-like phases are precipitated at a higher temperature than the matrix, at a suitably chosen temperature, due to gravity, they sediment to the bottom of the mould, thus decreasing the iron content in most of the casting volume (Sanchez et al., 2023). The aim of this work is to compare the sedimentation efficiency as a function of iron (from 0.15 to 0.84 wt.%) and manganese content in $AlZn10Si8Mg$ alloy.

2. METHODOLOGY OF RESEARCH

The experimental material was recycled aluminium alloy $AlZn10Si8Mg$. This alloy is self-hardening, which makes it possible to omit heat treatment of castings that naturally precipitate at room temperature. The resulting, improved mechanical properties are achieved 7-10 days after casting. No heat treatment needed results in reduced production costs and emissions. We compared 4 melts of this alloy, which differed mainly in iron and manganese content (Table 1). The melts were supplied by UNEKO from the Czech Republic as round bars with a length of 300 mm and a diameter of 20 mm. They were produced by gravity casting in a sand mould at a temperature of 700-710°C.

Table 1

Chemical composition of experimental alloys [wt. %]

Alloy	Zn	Si	Mg	Fe	Mn	Cu	Ti	Al
A	10.00	8.70	0.38	0.15	0.01	0.01	0.05	Bal.
B	9.33	8.83	0.32	0.56	0.02	0.01	0.05	Bal.
C	10.35	8.80	0.33	0.84	0.03	0.01	0.11	Bal.
D	9.30	8.95	0.31	0.84	0.74	0.02	0.12	Bal.

2.1. Microstructural analysis

To analyse the Fe-rich phases, samples of each experimental melt were prepared in the initial state. They were cut from the supplied bars, pressed, ground and polished with Struers TegraPol-15 equipment. The samples were etched with 0.5% HF and documented with a NEOPHOT-32 light microscope with NIS-Elements software.

2.2. Sedimentation experiment

Sedimentation experiment was performed in TecNALIA Research & Innovation institute in Spain. All the melts investigated were molten in a VEVOR Gold Melting Furnace (Fig. 1a,

Fig. 1b) for 30 minutes until a liquid melt temperature of 740°C was reached. The temperature was then reduced, and the liquid was maintained at 600°C for 20 minutes (Fig. 1c). The temperature was selected based on CALPHAD modelling of the individual melts to be within the interval between solidification of the primary Fe-rich phases and crystallization of the matrix. After 20 minutes, the mould was removed from the furnace and cooled in air. The aim was to allow the Fe-rich phases to sediment towards the bottom of the mould under the influence of gravity. This would reduce the iron concentration at the top of the mould, thus improving the mechanical properties. For the experiment, 0.3 kg of each melt investigated was used.

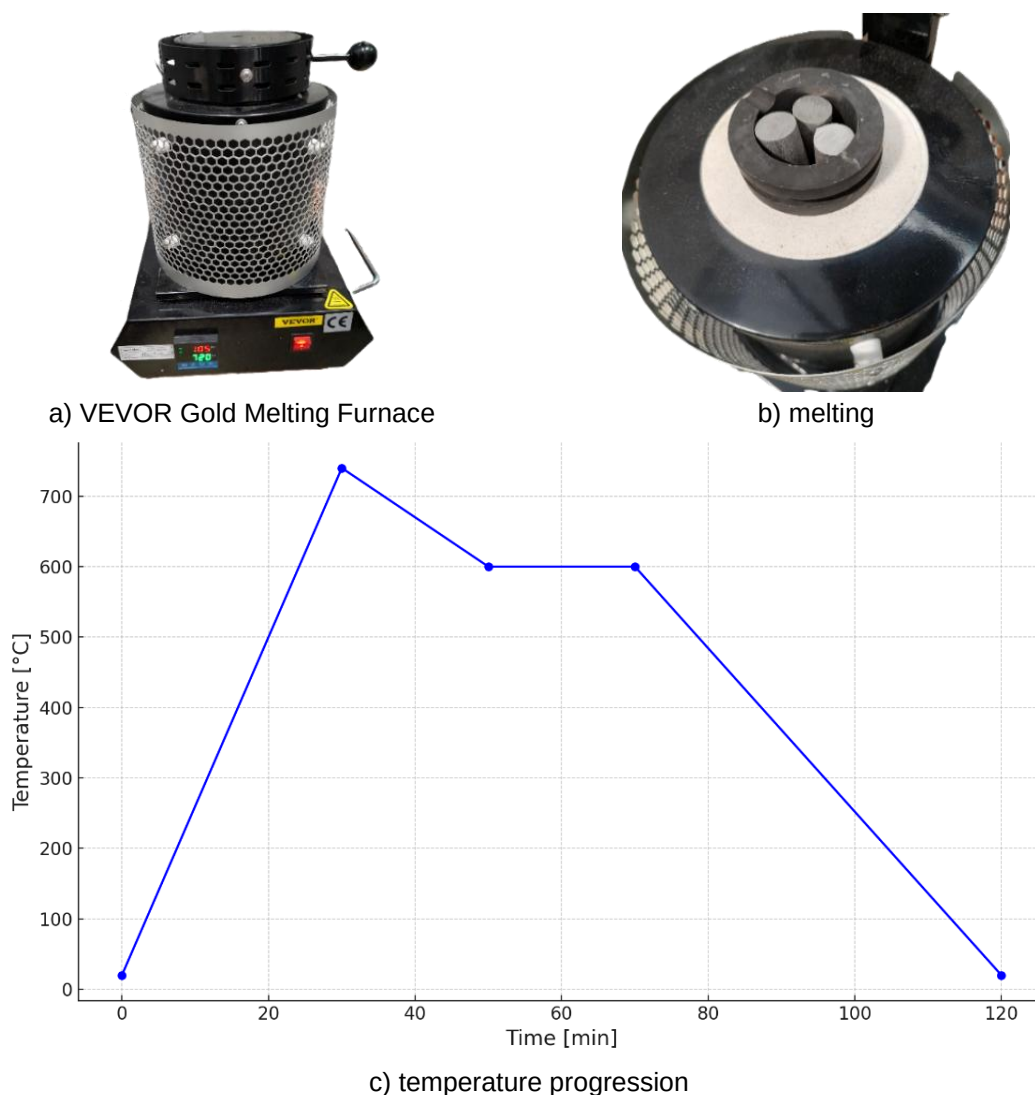


Fig. 1. Procedure of the sedimentation experiment

The final products of the process were cylindrical castings with a diameter of approximately 47 mm and a height of 57 mm. After cooling, the castings were vertically cut with a Presi Mecatech 255/300 metallographic saw, ground and polished with a Presi Mecatech 334 and analysed. Cross-sectional images of the castings were taken using a Nikon D7100 camera, and the presence of Fe-rich phases in different parts of the casting was detected using a NEOPHOT-32 light microscope and NIS-Elements software. Local variations in iron content were also detected with the SPECTROMAXx spectrometer.

3. RESULTS AND DISCUSSION

Microstructural analysis was focused on the Fe-rich phases present. The Al_5FeSi phases were found in melts A, B, and C (Fig. 2a). Their particles are visible as thin needles on the metallographic cut but have the shape of thin plates (Fig. 2c). The unfavourable morphology of the Al_5FeSi phases creates stress concentration sites, which contributes to the degradation of the mechanical and fatigue properties (Šurdová et al., 2022). A negative effect on corrosion resistance is also known, as galvanic micro-couples with other structural phases are formed (Liu et al., 2024; Piątkowski et al., 2024).

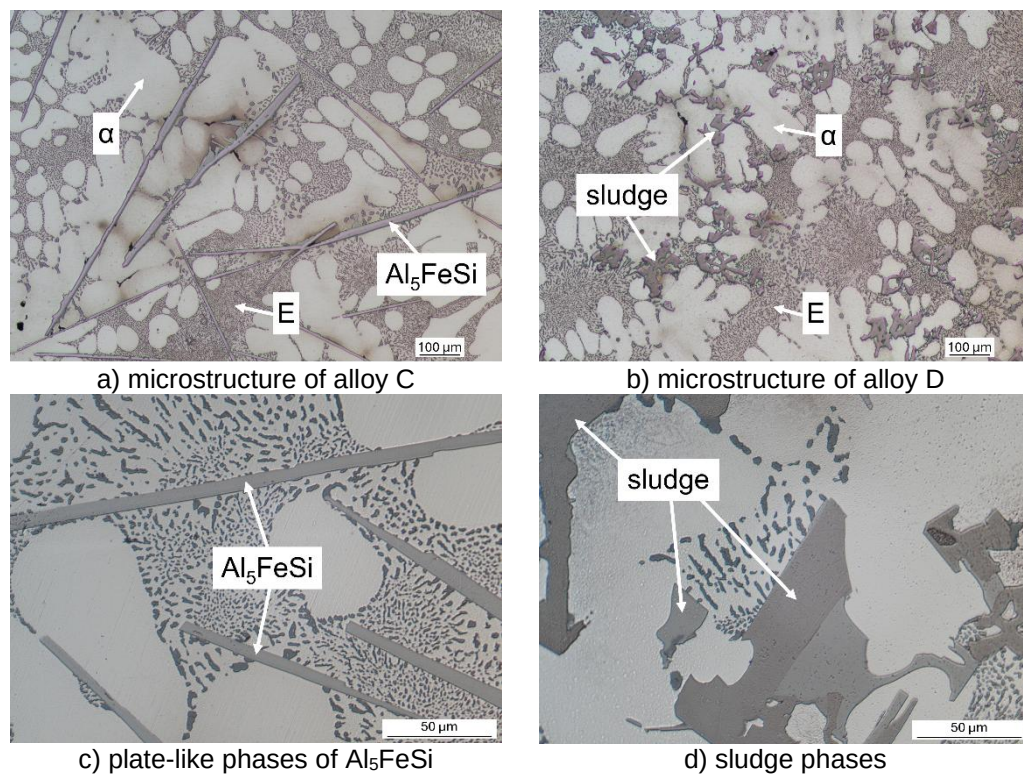


Fig. 2. Microstructure analysis of Fe-rich phases, etch. 0.5% HF

With increasing iron content, both the area fraction and the size of the Al_5FeSi phases increased in melts A, B, and C. In melt D, the formation of so-called sludge phases based on Al-Mn-Fe (Fig. 2b, Fig. 2d) occurred due to the influence of manganese (Mikolajčík et al., 2024). As these phases are formed at a higher temperature than the Al_5FeSi plates, the content of Al_5FeSi in melt D decreased significantly. Due to the more favourable morphology of the sludge phases, manganese alloyed melts have better mechanical, fatigue and corrosion properties (Fu and Cui, 2021; Cuj et al., 2023). The largest volume of the material of aluminium alloy foundries is formed by the α phase (substitutional solid solution of Zn in Al), precipitated in the dendrites. In the interdendritic spaces, there is eutectic (E), composed of eutectic silicon and the α phase.

On vertical sections of the castings, it is possible to observe the distribution of Fe-rich phases after polishing even on unpolished surfaces. The plate-like Al_5FeSi phases in low-iron alloys are precipitated secondarily - at a lower temperature than the α phase and the eutectic (Michna et al., 2024; Sanchez et al., 2023). Therefore, in melts A (Fig. 3a) and B (Fig. 3b) no sedimentation to the bottom of the mould occurred.

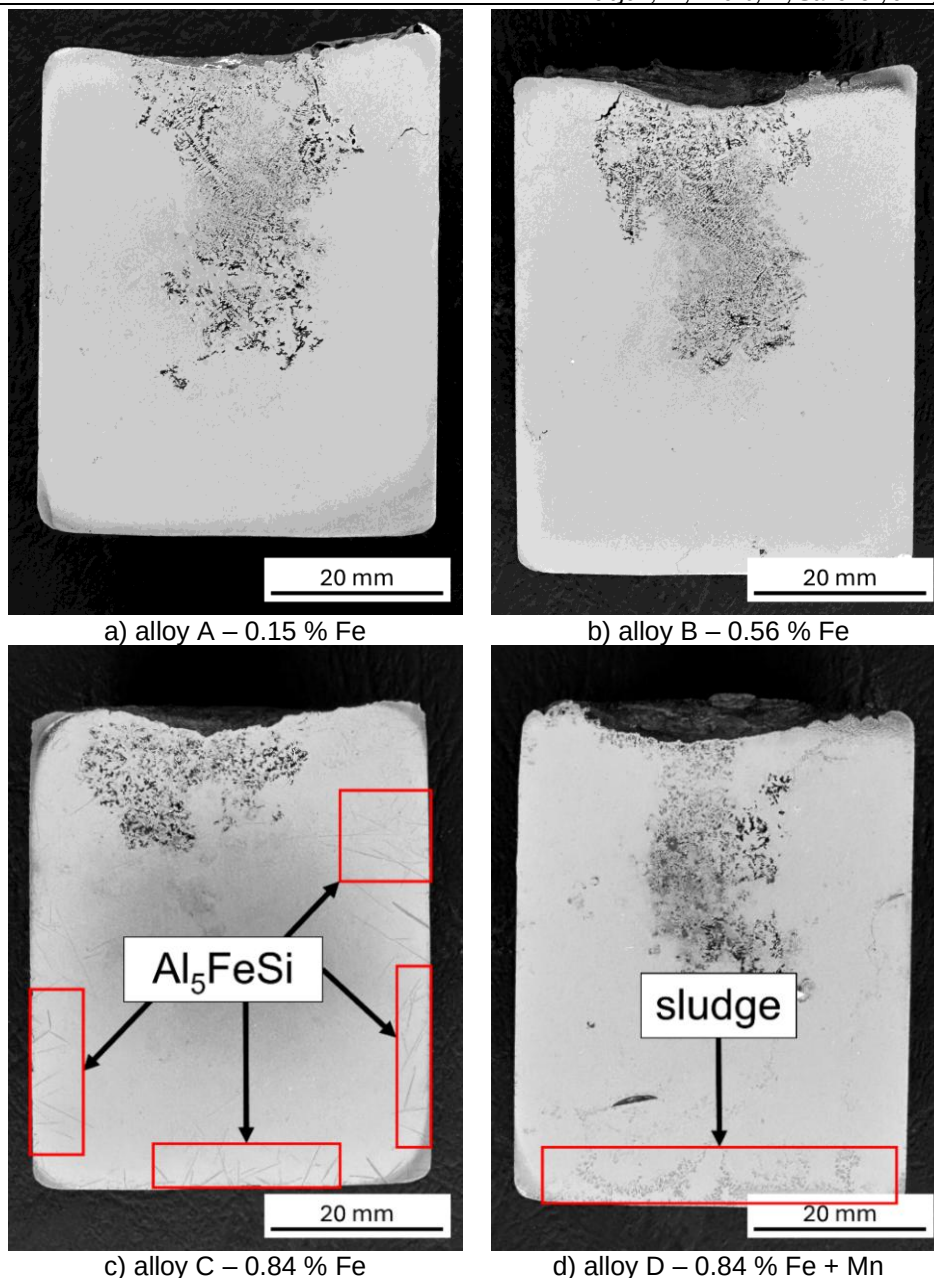


Fig. 3. Analysis of experimental castings cross-sections, unetched

At high iron contents, the plate-like ferric phases are primarily precipitated. Therefore, in melt C, a large amount of Al_5FeSi plate-like phases, exceeding 5 mm in length, are visible at the bottom and around the perimeter of the casting (Fig. 3c). However, the dimensions of these phases do not represent the real size in castings produced for industrial use, because their increase is due to the long residence time at high temperature. The reason for the formation of Al_5FeSi phases at the mould walls is probably due to the inhomogeneous temperature distribution in the casting. At the points of contact with the mould walls, the melt presumably cooled, leading to precipitation of the Fe-rich phases without sedimentation (Fig. 3c). In the cross-section of the melt D casting, the sedimentation of the Fe-rich phases was effective (Fig. 3d). There are many large sludge phases in the lower part. As in melt C, the increase in size was because of thermal residence time.

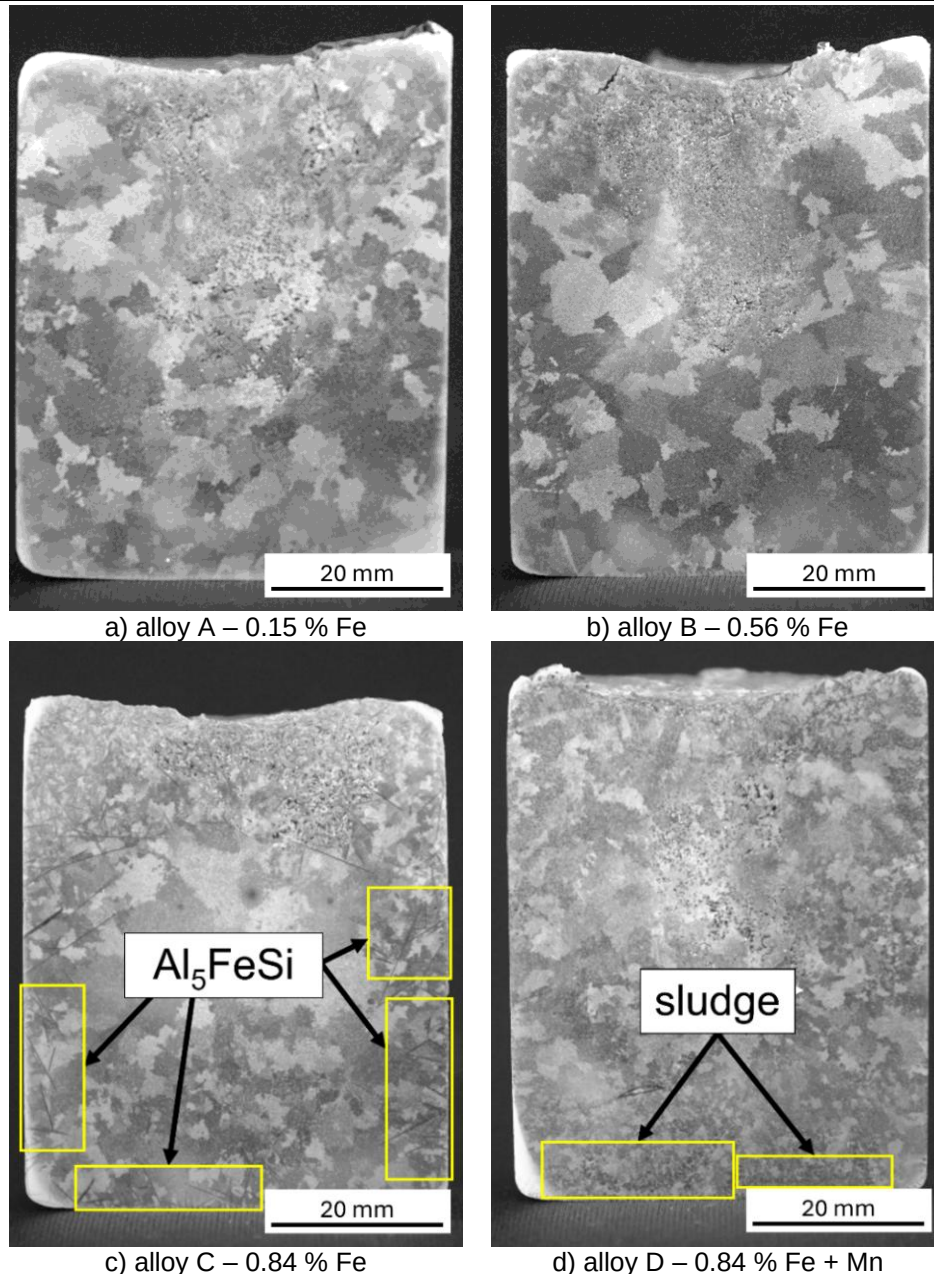
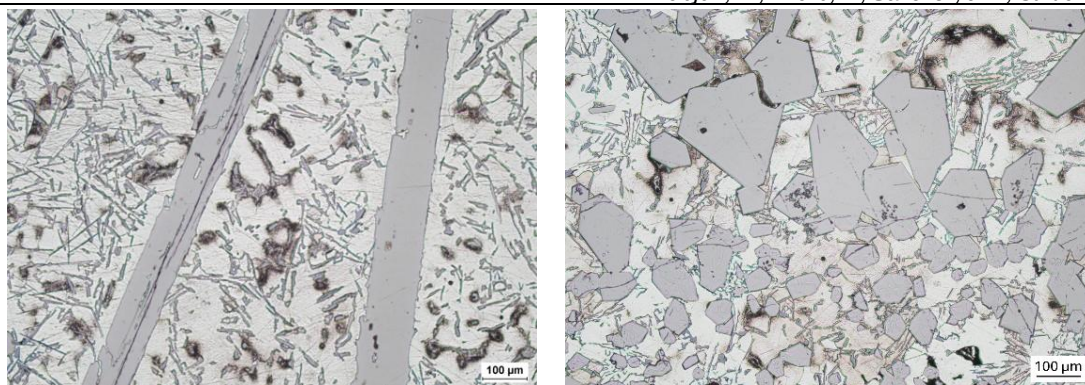


Fig. 4. Analysis of experimental castings cross-sections, etch. Dix-Keller

After etching, the castings were re-analysed and macro images confirmed that there was no sedimentation of the Fe-rich phases in alloys A and B (Fig. 4a, Fig. 4b). The Al_5FeSi and sludge phases sedimented only in alloys C and D, in which they precipitate primarily - before crystallization of the alpha and eutectic phases. No sludge phases were located higher than 10 mm from the bottom of the casting. At the given dimensions, the iron content was significantly reduced at 82% by volume. Only 18% of the casting volume could not be further processed.

The presence of Fe-rich phases in the castings of melts C and D was verified by metallographic analysis (Fig. 5). In melt C, plate-like phases with a thickness of approximately 100 μm were observed in the lower part of the sample (Fig. 5a). Sludge phases in melt D are mostly hexagonal. Their dimensions increase from the surface to the core of the casting (Fig. 5b). This is due to the lower cooling rate in the centre of the casting. In other parts of the casting, the sludge phases were not found.

c) plate-like phases of Al_5FeSi – alloy C

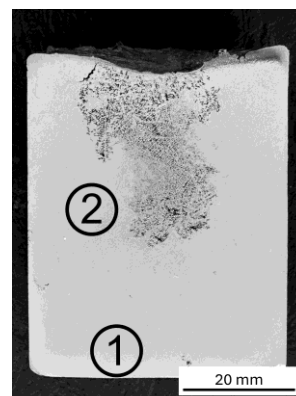
b) sludge phases – alloy D

Fig. 5. Microstructural analysis of castings vertical sections, etch. Dix-Keller

The sedimentation efficiency was verified by the SPECTROMAXx spectrometer. The iron content was detected at two locations on each casting (Fig. 6a, Fig.6b). The spectrometry results confirm the data found by observing the vertical sections. Sedimentation occurred only in melts C and D, which have a high iron content. The most effective reduction in iron content was achieved in melt D, which was contributed by the presence of manganese (Sanchez et al., 2023). Compared to the original iron content, which was verified by the supplier, the decrease in iron content in melt D is negligible and even an increase was observed for melt C. This is due to the inaccuracy of the manufacturer's data. In assessing the effectiveness of the sedimentation experiment, the difference between the point 1 and point 2 of the casting is more reliable.

Alloy	% Fe of point 1	% Fe of point 2	Initial % Fe
A	0.19	0.21	0.15
B	0.65	0.65	0.56
C	1.84	1.19	0.84
D	2.34	0.78	0.84

a) comparison of Fe content in castings [wt. %]



b) points of measurements

Fig. 6. Results of spectroscopy measurements

4. CONCLUSION

This work aimed to investigate the possibility of using sedimentation to reduce the iron content of recycled aluminium alloy castings. The effect of sedimentation at 600°C on four AlZn10Si8Mg alloy melts with different iron (0.15-0.84%) and manganese contents was assessed. The following conclusions can be drawn from the results:

- In alloys A and B, which have a lower iron content, there was no sedimentation of the Al_5FeSi plate-like phases, which are precipitated as secondary - at a lower temperature than the matrix. Therefore, the iron content in the lower part and in the core of the castings did not differ significantly.
- In alloy C, the Al_5FeSi phases sedimented to the bottom of the casting during the 600°C residence time, resulting in a decrease in the iron content in the middle part of the casting and an increase in the iron content in the lower part. The sedimentation

efficiency was limited due to the decrease in melt temperature in contact with the mould walls. Therefore, the Al_5FeSi phases also precipitated around the perimeter of the casting and only partial sedimentation occurred.

- The highest sedimentation efficiency was achieved in alloy D due to manganese alloying. A significant difference in iron content between the lower part and the centre of the casting was detected by spectrometry.
- Primary precipitated sludge phases sedimented at 600°C due to gravity and were visible in large colonies in the lower part of the casting on the metallographic section. The size of the sludge phases increased towards the centre of the casting due to the lower cooling rate.
- No sludge phases were located higher than 10 mm from the bottom of the casting. At the given dimensions, the iron content was significantly reduced at 82% by volume. Only 18% of the casting volume could not be further processed.

Sedimentation has been found to be a perspective method of reducing the iron content, thereby limiting its well-known negative effects on the properties of aluminium alloys. The results obtained in alloy with manganese addition are particularly promising. The results can improve the safety of vehicles while keeping production sustainable and environmentally friendly.

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