DOI: 10.21062/mft.2024.092 http://www.journalmt.com

Influence of Aluminium Waste Chips Content from the Machining Technology in the Batch on the Final Properties of the AlSi7Mg0.3 Alloy Casts

Tomáš Vlach (0000-0003-2326-4183), Jaromír Cais (0000-0002-1726-5326), Roman Horký (0000-0002-4451-3006)
Faculty of Mechanical Engineering, J. E. Purkyne University in Usti nad Labem. Pasteurova 3334/7, 400 01 Usti nad Labem. Czech Republic. E-mail: tomas.vlach@ujep.cz

The aim of the research was to assess the influence of additions of different proportions of aluminium waste chips from the machining technology on the melt quality and final properties of AlSi7Mg0.3 alloy casts. All casts were created using by gravity casting technology into preheated metal mold. The first cast was a pure AlSi7Mg0.3 alloy, followed by other samples with contents of 10, 30, 50, 70 wt.% of aluminum waste chips in the batches. All the samples were subjected to the Brinnel hardness and Vickers microhardness of solid solution of α(Al). Also, Density index was measured. At the end of research, the microstructures of the samples were analyzed using a Laser Confocal Microscope Olympus Lext OLS 5000. The use of chips from machining affects the gasification of the alloy. Some mechanical properties of the material deteriorate, which is confirmed by analysis in this paper.

Keywords: Al-Si alloys, casts, aluminium waste, waste chips, Density index, Dichte index

1 Introduction

Al-Si alloys are the most used materials in foundry. They have a wide range of applications due to the combination of suitable mechanical and foundry properties. These properties are mainly influenced by their chemical composition. These are alloys important for all branches of industry, mainly the automotive and aviation industries. [1, 2, 3] We can influence the mechanical properties by adding alloying elements (changing the chemical composition) or by heat treatment [4] The wide area of use of aluminum alloys also brings the necessity of machining these alloys. Chip machining is based on the principle of removing material in the form of chips, which gives the workpiece its final shape. [5] By machining, we obtain the final shape of the workpiece, but also waste in the form of the chip removed. It is necessary to continue to work with this metal waste and use the possibility of recycling and remelting. The problem with these chips is a strong thermal load during the machining process itself and subsequent oxidation during remelting. Recycling techniques are constantly being developed that can further process this small scrap. [6, 7] The experiment will bring us knowledge about the behavior of the recycled material, and subsequently we can use it again or adjust the metaurgy for processing. Aluminum alloys can be machined dry, or with the use of a process cooling liquid. Dry machining problems are caused by low melting point and high adhesion. The choice of optimal cutting conditions or the use of a suitable process liquid is necessary. [8] Process fluids improve the tribological processes of tool contact with the machined surface. Process fluids help wash away chips, cool the tool and workpiece, reduce friction and thereby improve surface quality. Some process fluids have a negative effect on the environment when they are recycled. However, in some cases they can also affect the possibility of using chip waste after machining. [9] If we recycle the scrap in the form of chips, the process is more demanding due to the small size and contamination by process fluids. Scrap in the form of chips quickly oxidizes due to moisture, and during remelting, a large proportion of the mass is burned in the furnace. Aluminum scrap recycling has several processes: Sorting, compaction, melting, degassing and refining. [10, 11, 12] The properties of casts are mainly influenced by microstructural changes during the crystallization processes of the molten alloy. Before choosing a suitable material for the required application, checking the microstructure and gasification is necessary. [13, 14] The Density index is measured using a special devices such as the 3VT Plus and the MK 3000 special scale. [15, 16] The use of waste chips for remelting is limited in industry. The recycling process is very important. The experiment will verify the possibilities of using the material obtained in this way and provide information about the properties of the remelted materiál.

2 Materials and methods

AlSi7Mg0.3 alloy was used for the experiments. This alloy is characterized by good toughness and ductility, with a minimum number of alloying elements and impurities. It is a foundry alloy that has good foundry properties, machinability, corrosion resistance and weldability. It is most often casting into metal or sand molds, using low pressure or gravity casting. This alloy finds application not only in the automotive industry, but also in the aviation and rocket industries. The alloy has a small tendency to shrinkage during casting, for this reason it is advisable to refine the grain by inoculating with B, Ti. [14] Chemical composition of AlSi7Mg0.3 alloy according to standards is in the Tab 1.

***Tab. 1** Chemical composition of AlSi7Mg0.3 (EN 42100) [14]*

Chemical el.	Al	Si	Mg	Ti	Fe	Mn	Zn	Cu
wt [%]	91.3-93.3	6.5-7.5	0.25-0.45	0-0.25	0-0.19	0-0.1	0-0.07	0-0.05

2.1 Sample preparation

First of all, it was necessary to prepare a cast from the AlSi7Mg0.3 alloy for turning and the production of chips for their subsequent remelting in different contents together with the AlSi7Mg0.3 alloy. The batch was melted in a graphite crucible at a temperature of 740 °C. Metal mold was preheated to 200 °C. Before casting, the oxide layer was removed from the surface of the melt (see Fig. 1).

***Fig. 1** Oxide layer removal before casting*

After removal of the oxide layer from the surface of the melt, gravity casting began (see Fig. 2). Casting was at a temperature of 730 °C and the cast weighed 3 kilograms.

***Fig. 2** Casting of pure AlSi7Mg0.3 alloy*

After casting the real chemical composition was measured by Q4 Tasman Spectrometer. determined chemical composition of the cast is in the table below (Tab. 2).

***Tab. 2** Measured chemical composition of AlSi7Mg0.3*

Chemical el.	Al	Si	Mg	Ti	Fe	Mn	Zn	Cu
wt [%]	base	7,03	0.31	0.21	0.09	0.08	0.02	0.04

Then there was the production of chips. AG COOL B 553 process fluid was used during turning. This process fluid is semi-synthetic and miscible with water. It contains a moderately high content of mineral oil, which forms a stable emulsion together with water. It is characterized by very low foaming, both in hard and soft water with excellent rinsing and cooling effects. [17, 18] After the cast was clamped, the revolutions were adjusted so that the cutting speed corresponded to the parameters defined by the tool manufacturer and material removal began. The lathe was cleaned before use to avoid contamination with chips from previous machining. For the designed weights of the batches for subsequent melting, it was necessary to create at least 1600 grams of Al chips.

After obtaining the aluminium chips from machining, it was necessary to prepare the amount of pure alloy in the crucible. Five melting crucibles were prepared, into which the pure alloy was subsequently weighed. The first crucible contained only pure alloy to allow comparison of the other samples. Another four melting crucibles were used to weight the chips. The 100 g, 300 g, 500 g and 700 g of chips were successively prepared in the crucibles with different concentrations of pure alloy (see Tab. 3). All crucibles contained 1 kilogram of material.

Fig. 3 *Machining of the cast of the AlSi7Mg0.3 alloy*

Tab. 3 *Overview of input raw materials for individual pouring crucibles*

Cast / crucible	Weight of pure AlSi7Mg0.3 [g]	Weight of AlSi7Mg0.3 chips [g]
Sample 1	1000	0
Sample 2	900	100
Sample 3	700	300
Sample 4	500	500
Sample 5	300	700

The melting crucibles were placed in the furnace, where they remained for about 4 hours until the material melted. The run-up to the melting temperature was realized gradually from the ambient temperature (21 °C). During melting, a sample was taken from each melt to measure the Density (Dichte) index.

A part of the melt was removed with a stainless steel ladle, which was then poured into pre-prepared cups that were heated to 200°C. One of the crucibles was cooled in air. The second crucible was placed in the vacuum chamber. For the analysis was used the Vacuum Density Tester 3VT plus (see Fig. 4).

From each melt with a different percentage content of chips, two casts were created, which were used to measure the gas concentration in the alloy. An Electronic Density Index Balance MK 3000 was used for this measurement (see Fig. 5), which is used to evaluate and determine the gassing rate of aluminum alloys in percent.

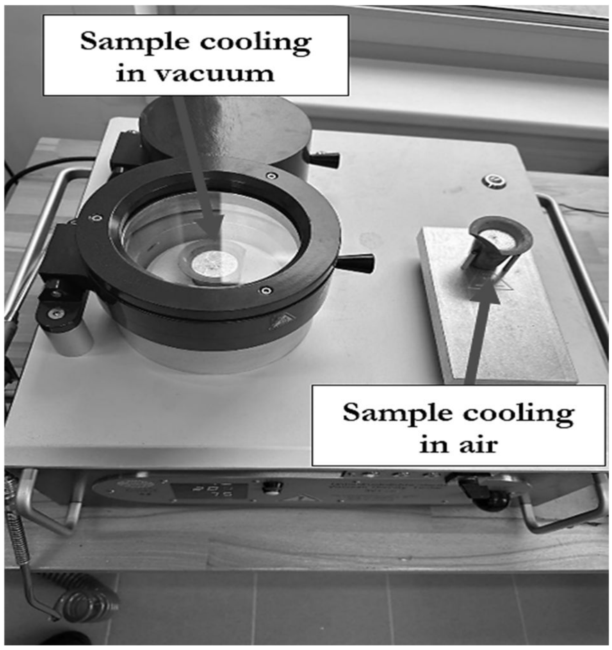


Fig. 4 *Vacuum Density Tester 3VT plus*

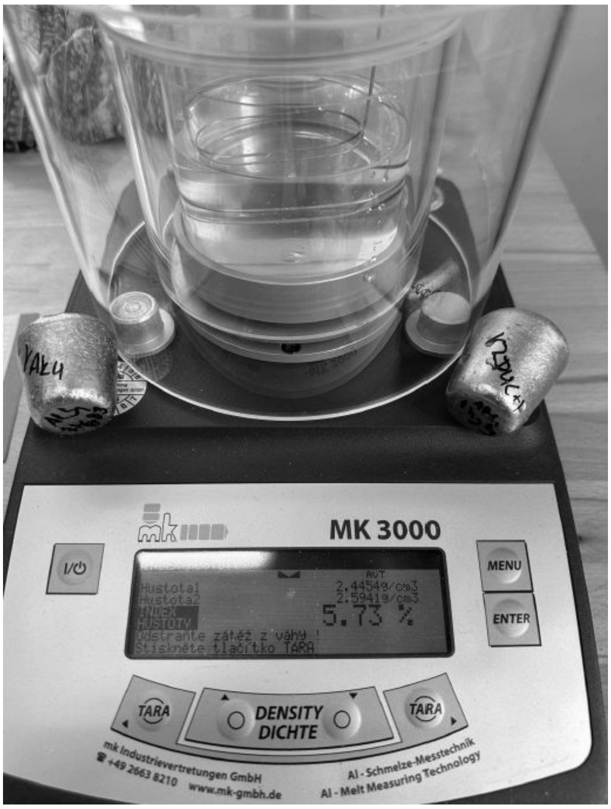


Fig. 5 *Electronic Density Index Balance MK 3000*

The rest of the melt was always by gravity casting into a metal mold, followed by weighing. For the next hardness, microhardness of solid solution measuring and microscopy analyses the samples were cutted. The cutting and sampling scheme is shown in the figure below (see Fig. 6). Each of the samples was measured and observed under an optical microscope.

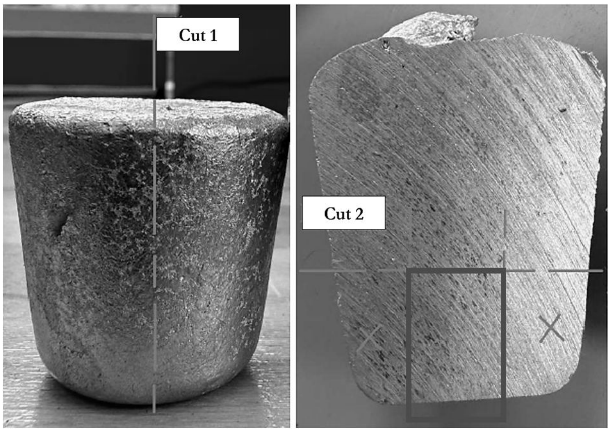
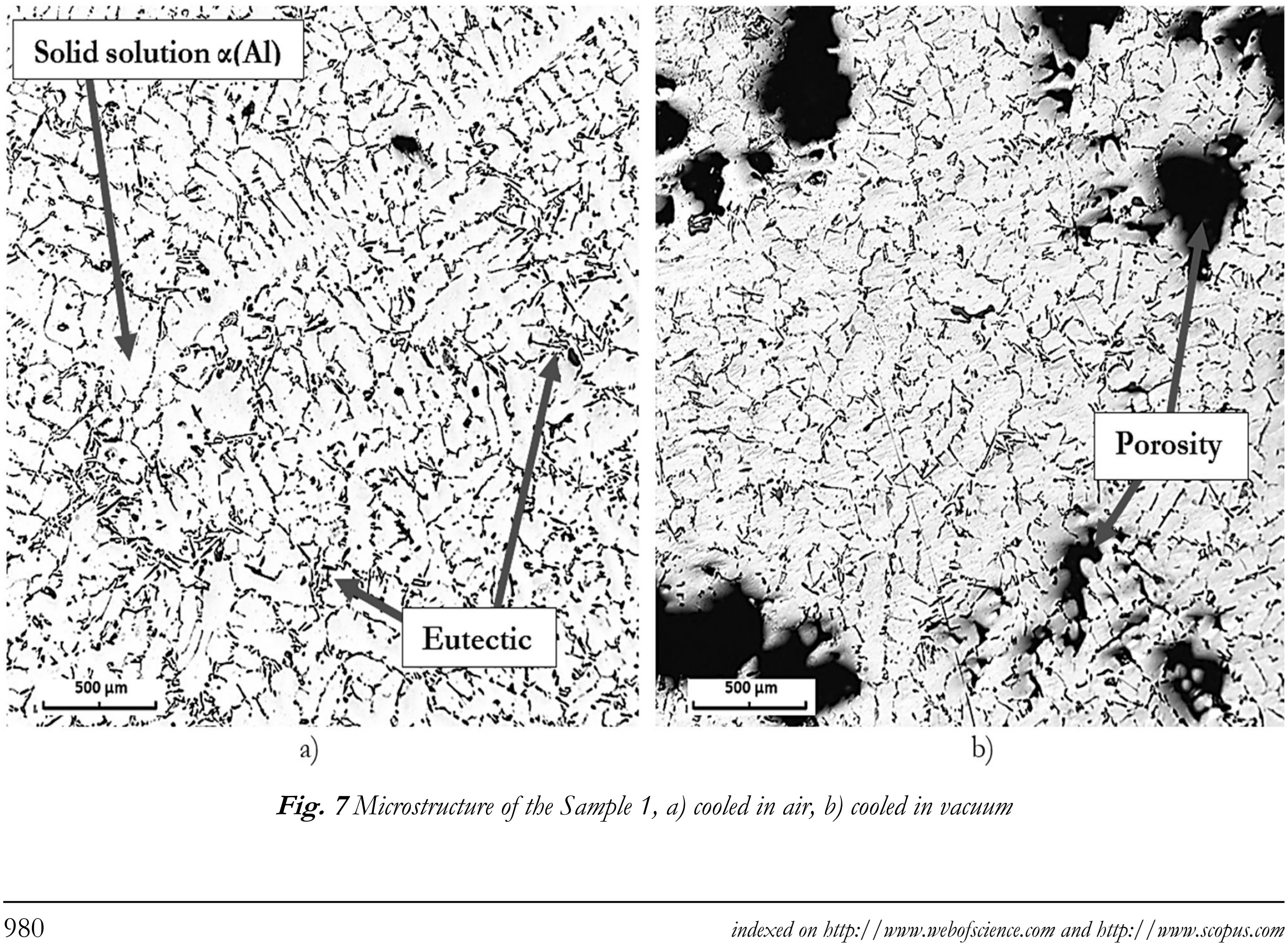


Fig. 6 *Preparing of the samples for next measuring and analyses*

3 Results

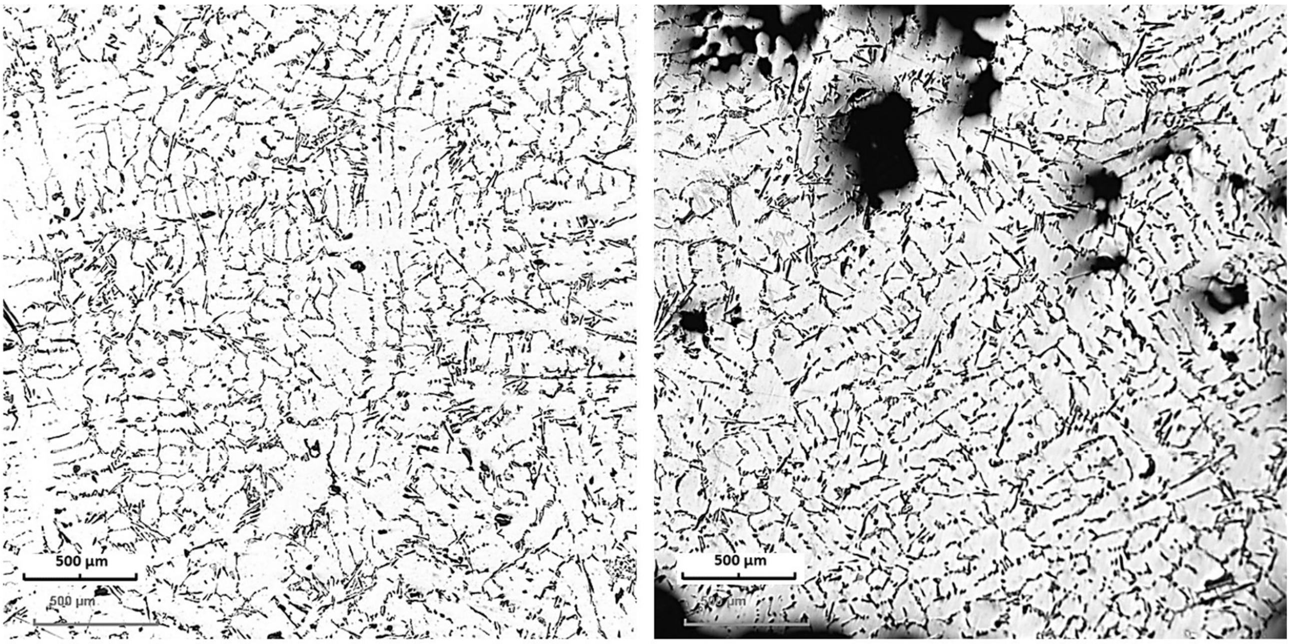
3.1 Microscopy observation

The images of microstructure of the samples 1 and 5 were selected for comparison. The samples in Fig. 7a and Fig. 8a were cooled in air and samples in Fig. 7b and Fig. 8b were cooled in vacuum. Due to observation, the microstructure all samples contains solid solution α(Al) and eutectic. Eutectic is in the interdendritic spaces. The samples, that have cooled in vacuum contain porosity and that affects mechanical final properties. For observation and analysis was used a Laser Confocal Microscope Olympus Lext OLS 5000.



a) b)

Fig. 7 *Microstructure of the Sample 1, a) cooled in air, b) cooled in vacuum*

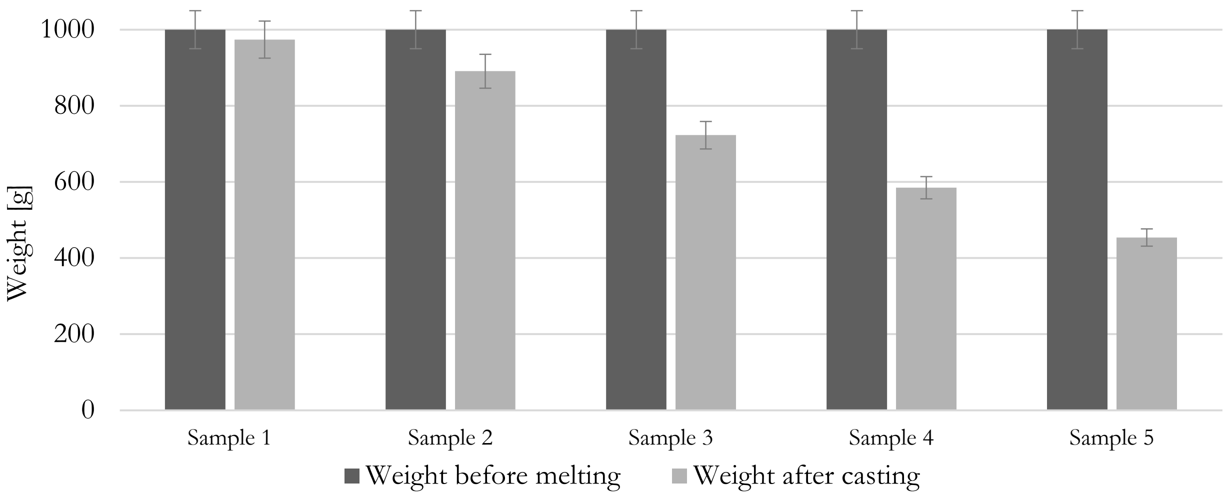


a) b)

Fig. 8 *Microstructure of the Sample 5, a) cooled in air, b) cooled in vacuum*

3.2 Weight loss during remelting

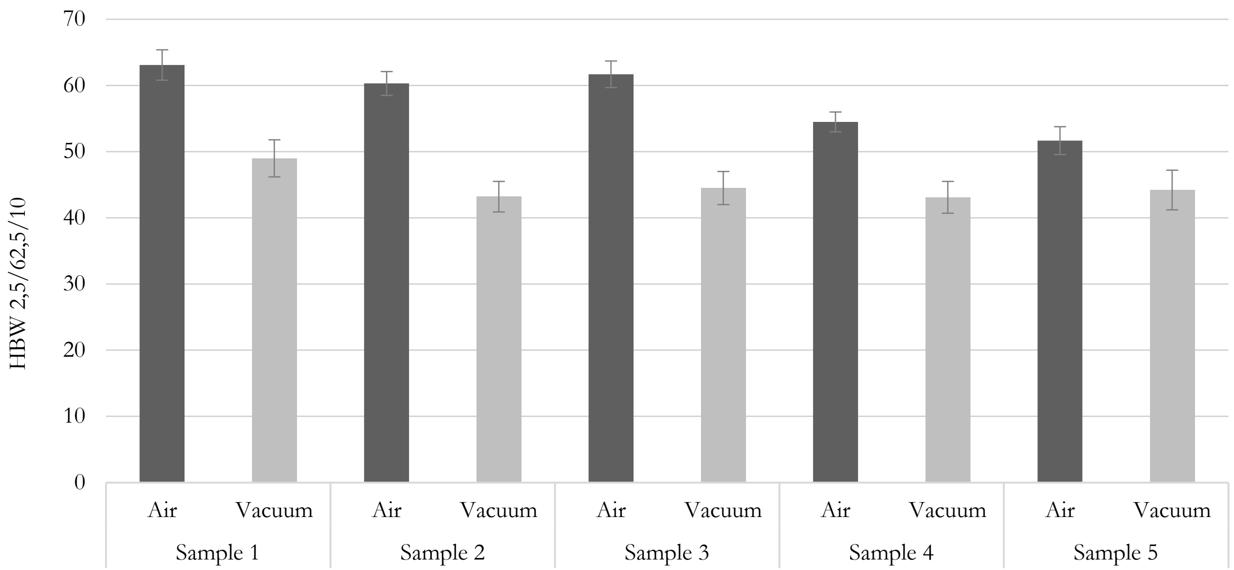
Graph 1 shows the amount of cast mass for individual samples, i.e. the usable part, and how much waste and dross was created during remelting. It is obvious that with the increasing percentage of chips from machining, much more waste is produced in the form of smear than when remelting pure alloy. The smallest difference in weight between the input and output weights (2.6 hm. %) was found for sample 1, when it was a pure alloy. For sample 5, where the ratio of pure alloy and chips was the same, when exceeding more than 50 wt. % of waste occurs and the waste is greater than the weight of the pure alloy.



Graph 1 *Weights of casts before and after remelting with aluminium chips*

3.3 Hardness

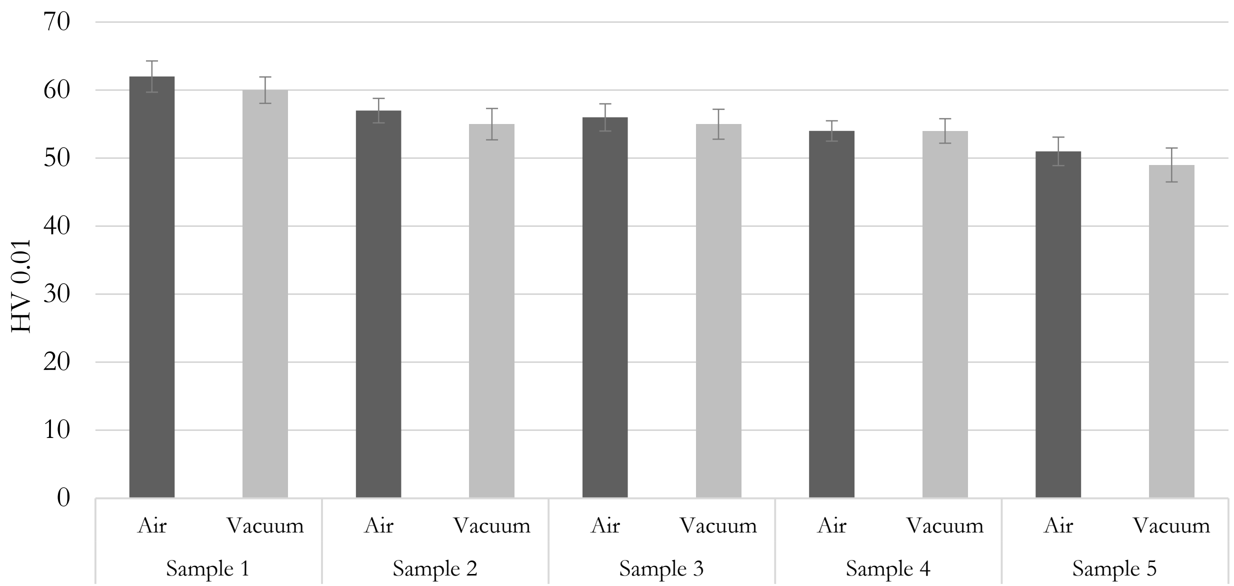
All of the samples were subjected to Brinell hardness measurement according to standards. Each of the sample was measured 10x. ERNST AT 250 DR-NX Tester device was used to measurement. The obtained median values are shown in the graph below (see Graph 2). Due to the large porosity, some measurements had to be repeated. The measured values for samples that were cooled in air are higher than for samples that were cooled in vacuum. The highest values were obtained for sample 1. The lowest values were for sample 5. It is true that the greater the content of chips (waste) in the alloy, the lower the Brinell hardness.



Graph 2 *Brinnell hardness of the samples of AlSi7Mg0.3 alloy*

3.4 Microhardness

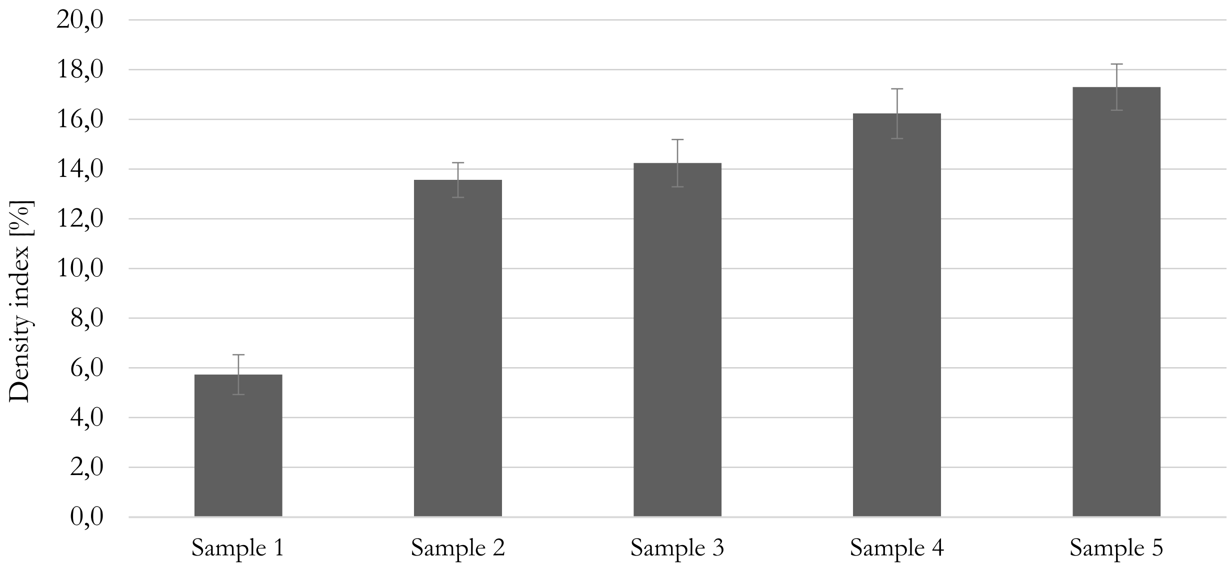
Microhardness analysis was performed on each of the sample. For the measurements were used digital FM-300 MicroHardness Tester. The medians of the values of microhardness of solid solution α(Al) are shown in the Graph 3 below. Samples were taken from the bottom of the casts (see Fig. 6) As with Brinell hardness measurements, some measurements had to be repeated due to high porosity. Solid solution α(Al) was measured 10x for each sample. The highest microhardness was found for the sample 1, that cooled in air. The lowes value was found for the sample 5, that cooled in vacuum. It can be seen from the graph that the higher the concentration of chips (waste) in the alloy, the lower the microhardness of the solid solution α(Al).



Graph 3 *Vickers microhardness of the samples of AlSi7Mg0.3 alloy*

3.5 Density index

Graph 4 show differences between measured Density indexes. As you can see, the lowest values were measured for sample 1, which did not contain any concentration of waste aluminum chips. This sample was pure alloy and was used to compare the results. The highest values were found for sample 5, which contained 70 wt. % waste aluminium chips in the batch. The difference between sample 1 and 5 is almost threefold in the density index value. Samples 2, 3 and 4 had similar values. A density index value in the order of tens of % is a negative phenomenon, and when choosing such a material for a given application, there may be problems in terms of strength etc.



Graph 4 *Density index of the samples*

4 Conclusion

Analyzes prove that the content of waste chips reduces the mechanical properties of the AlSi7Mg0.3 alloy. The higher the percentage content of chips in the alloy, the worse the mechanical properties, especially hardness and microhardness. The difference of Brinell hardness of alloy between sample 1 and sample 5 was 17 %. The difference of Vickers microhardness of solid solution α(Al) between sample 1 and sample 5 was 22 %.

Significant porosity was observed in the microstructure of the alloy, and thus the gassing value increases. In one sample (sample 5), the wight of slag was greater than the weight of the pure alloy. The difference of Dichte index values between samples 1 and 5 a was more than threefold. Value increased from 5,7 % to 17,3 %. Samples with higher concentrations of waste aluminum chips had a large amount of burn-through. The gases produced during this phenomenon influence the internal structure of the casts and thus its final properties.

It is clear from the analyzes that the use of waste chips affects the internal structure of the casts and the final properties of the material. The results and appearance of the microstructure give us information that can be used in further processing. By adjusting the metallurgy, which can be the goal of further research, we can obtain a better material. Recycling and sustainability is important in all industries. Whether it is worthwhile to use waste chips depends on the required quality of the material in terms of chemical composition or the area of application of the aluminum alloy. The results help us to modify the metallurgy and consider the possibilities of mechanical processing of chips from machining before melting. If we are going to use recycled material for casting, it is necessary to always monitor the mechanical properties in order to meet the requirements for the quality of the casting.

Acknowledgment

This research was supported by the internal UJEP Grant Agency (UJEP-SGS-2024-48-008-02).

References

[1] MICHNA, Š., MICHNOVÁ L. (2014). *Neželezné kovy*, PrintPoint s.r.o., Praha, ISBN 978-80-260-7132-7

[2] SVOBODOVA J, LUNAK M, LATTNER M. Analysis of the Increased Iron Content on the Corrosion Resistance of the AlSi7Mg0.3 Alloy Casting. (2019) *Manufacturing Technology*.;19(6):1041-1046. doi: 10.21062/ujep/415.2019/a/12132489/MT/19/6/1041.

[3] HREN I, SVOBODOVA J, MICHNA Š. Analysis of Microstructure Changes for AlSi7Mg0.3 Alloy Caused by Modification. (2019) *Manufacturing Technology*.;19(5):767-771. doi: 10.21062/ujep/369.2019/a/12132489/MT/19/5/767.

[4] VLACH T, CAIS J. The Effect of Casting Mold Material on Microstructure of Al-Si Alloys. *Manufacturing Technology*. (2022) ;22(5):617-623. doi: 10.21062/mft.2022.072.

[5] AYUBA, SAMUEL & ARAOYINBO, ALABA & ELEWA, R & BIODUN, M. (2021). Effect of Machining of Aluminium Alloys with Emphasis on Aluminium 6061 Alloy – A Review. *IOP Conference* Series:

Materials Science and Engineering. 1107. 012157.doi:10.1088/1757899X/1107/1/012157.

[6] TEKKAYA, A.E., et al. (2009). Hot profile extrusion of AA-6060 aluminum chips. In: *Journal of Materials Processing Technology*, Vol. 209, No. 7, pp. 3343-3350, doi: https://doi.org/10.1016/j.jmatprotec.2008.07.047

[7] MURRAY, JAMES & SPEIDEL, ALISTAIR & JACKSON-CRISP, ALEXANDER & SMITH, PETER & CONSTANTIN, HANNAH & CLARE, ADAM. (2021). Unprocessed machining chips as a practical feedstock in directed energy deposition. *International Journal of Machine Tools and Manufacture*. 169. 103803.
doi: 10.1016/j.ijmachtools.2021.103803.

[8] BAMBULA, M. *Hodnocení obrobitelnosti slitin hliníku - kritéria hodnocení*. (2008) Brno: VUT, Fakulta strojního inženýrství, Ústav strojírenské technologie. 27 s., [online], [cit. 23.5.2024] Available: http://hdl.handle.net/11012/7035

[9] P.S. SREEJITH, Machining of 6061 aluminium alloy with MQL, dry and flooded lubricant conditions, (2008) *Materials Letters*, Volume 62, Issue 2, Pages 276-278, ISSN 0167-577X, https://doi.org/10.1016/j.matlet.2007.05.019

[10] S.N.A. RAHIM, M.A. LAJIS, S. ARIFFIN, A review on recycling aluminum chips by hot extrusion process. (2015) *Procedia CIRP 26*, 761–766, doi: 10.1016/j.procir.2015.01.013

[11] R. GALLO, I. SOTO, Improving competitiveness through in-house aluminum chip melting: a case study. *AFS Trans*. 119, 1–8 (2011)

[12] H. PUGA, J. BARBOSA, D. SOARES, F. SILVA, S. RIBEIRO, Recycling of aluminium swarf by direct incorporation in aluminium melts. (2009) *J. Mater. Process. Technol*. 209, 5195–5203 https://doi.org/10.1016/j.jmatprotec.2009.03.007

[13] UHRÍČIK M, PALČEK P, CHALUPOVÁ M, KUCHARIKOVÁ L, PASTIEROVIČOVÁ L, MEDVECKÁ D, et al. (2023) Structural and Fractographic Analysis of Aluminum Alloy before and after Fatigue Loading. *Manufacturing Technology*. 23(5):725-731. doi: 10.21062/mft.2023.067.

[14] ROUČKA J., (2004). *Metalurgie neželezných slitin*, CERM s.r.o., Brno, ISBN 80-214-2790-6

[15] COMBI PACKAGE plus. (2024) www.mk-gmbh.de [online], [cit. 23.5.2024] Available: https://www.mk-gmbh.de/fileadmin/user_upload/produktbilder/Produkte/DichteIndex/Stationaere_Messstation_plus/Brochure_Combi-Package_plus_EN.pdf.

[16] *Zařízení podtlakové zkoušky indexu hustoty*. (2024) Vysoká škola technická a ekonomická v Českých Budějovicích. [online], [cit. 23.5.2024] Available: https://www.vstecb.cz/laboratore-1551-htm/.

[17] Kovonástroje s.r.o. [online]. Copyright © Kovonástroje s.r.o [online], [cit. 23.5.2024] Available: https://www.kovonastroje.cz/chladici-kapalina-ag-cool-friguo-b-553-5-kgkoncentrat/

[18] Chladící kapalina AG COOL B553 [online], [cit. 23.5.2024] Available: https://www.svarecky-kukly.cz/chladici-kapalina-ag-cool-b-553-aknel-5-kg

[19] SAPIETA, M., ŠULKA, P., SVOBODA, M.: Using a numerical model to verification of thermoelastic analysis of flat specimen, In: *Manufacturing Technology*, Vol. 18, No. 3 (2018) pp 482-486, ISSN: 1213-2489, DOI: 10.21062/ujep/125.2018/a/1213-2489/MT/18/3/482

[20] CAMPBELL, F. C., (2008). *Elements of metallurgy and engineering alloys*. Materials Park, Ohio: ASM International ISBN 978-0-87170-867-0. [cit. 23.5.2024] doi: https://doi.org/10.31399/asm.tb.emea.9781627082518

[21] SAPIETA, M., ŠULKA, P., SVOBODA, M.: Localization of delamination in composite test specimens. In: *MATEC Web of Conferences* 157, 01015 (2018) doi.org/10.1051/matecconf/20181570101

[22] SVOBODA, M., SOUKUP, J., SAPIETA, M.: Improving the quality of cutting flat glass. in *MATEC Web of Conferences* 157, 04004 (2018) https://doi.org/10.1051/matecconf/201815704004

[23] LICHÝ P., KROUPOVÁ I., RADKOVSKÝ F., NGUYENOVÁ I.: Possibilites of the controlled gasification of aluminum alloys for eliminating the casting defects (2016) METAL 2016 - 25th Anniversary International Conference on Metallurgy and Materials, *Conference Proceedings* ISBN: 978-808729467-3