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Meritve dimenzijskih sprememb med strjevanjem Al-Si zlitin

Measurement of dimensional changes of AlSi alloys during solidification

Povzetek

Namen prispevka je raziskati dimenzijske spremembe ulitka med strjevanjem. Analizirani so bili štirje vzorci. Prvi je bil iz zlitine AlSi12 brez dodatkov, drugi je bil udrobnjen s predzlitino AlTi5B1, tretji modificiran s predzlitino AlSr10 ter četrti udrobnjen in modificiran hkrati. Mikrostrukture vseh vzorcev so bile različne v smislu velikosti kristalnih zrn α_{Al} ter velikosti delcev evtektskega β_{Si}. Dilatometrijska analiza je pokazala razlike v krčenju vzorca iz zlitine AlSi12 brez dodatkov in modificiranih vzorcev, kjer je krčenje manjše. Strjevanje AlSi12 zlitine je bilo opisano z uporabo različnih metod, kot so termična analiza, dilatometrijska analiza v povezavi s termodinamskim izračunom faznih ravnotežij izvedeno s Thermo-Calc računalniškim orodjem. Metalografska analiza je bila izvedena z uporabo optične in elektronske mikroskopije (SEM). Analize mikrostrukturnih sestavin so bile izvedene z uporabo energijsko disperzijske spektrometrije (EDS).

Ključne besede: strjevanje, Al-Si zlitine, dimenzijske spremembe

Abstract

Solidification of AlSi12 alloy was described using different techniques such as thermal analysis, dilatometric analysis in accordance with thermodynamic calculation carried out by Thermo-Calc software. Metallographic investigation was made using optic and scanning electron microscopy (SEM). Phase analysis was done by energy dispersive spectroscopy (EDS). The aim of the paper is to investigate dimensional changes of a casting during solidification. Four specimens were analysed. First one was AlSi12 alloy without additions, second is grain refined with AlTi5B1 master alloy, third one modified with AlSr10 master alloy and the last one with both master alloys. Microstructures were different in terms of grain size of α_{Al} phase and size of β_{Si} particles. Dilatometric analysis has shown differences in shrinkage of basic alloy and modified alloys where shrinkage is lower.

Key words: Solidification, Al–Si alloy, Shrinkage

1 Uvod

Strjevanje zlitine AlSi12 je opisano z različnimi tehnikami, kot so termična analiza ter dilatometrijska analiza v skladu s termodinamskim izračunom faznih ravnotežij, izvedenim z računalniškim

1 Introduction

Solidification of AlSi12 alloy was described using different techniques such as thermal analysis, dilatometric analysis in accordance with thermodynamic calculation carried out by Thermo-Calc software. Metallographic orodjem Thermo-Calc. Metalografske preiskave so bile izvedene z optičnim mikroskopom in vrstičnim elektronskim mikroskopom (SEM) opremljenim z energijsko disperzivno rentgensko spektroskopijo (EDS) za določevanje mikrostrukturnih sestavin.

Cilj članka je ugotoviti dimenzijske spremembe ulitka med strjevanjem. Analizirani so bili štirje vzorci iz zlitine AlSi12. Uporabljeno je bilo tudi udrobnjevanje in modificiranje taline. Za udrobnjevanje je bila uporabljena predzlitina AlTi5B1, za modificiranje pa predzlitina AlSr10. Prvi vzorec je bil izdelan brez predzlitin, v drugega je bilo dodana predzlitina s titanom, v tretjega predzlitina s stroncijem in v četrtega obe. Mikrostrukture so se razlikovale v smislu velikosti mikrostrukturnih sestavin, predvsem dendritnih zrn α_{Al} ter delcev evtektske faze β_{Si}. Dilatometrijska analiza je pokazala razlike v krčenju vzorcev brez dodatkov in vzorcev z dodatkom stroncija, kjer je krčenje manjše.

Strjevanje Al–Si zlitin, opisano s pomočjo termične analize, je dobro dostopno v literaturnih virih [1]. Strjevanje ulitkov je povezano z dimenzijskimi spremembami oziroma krčenjem med strjevanjem, kar lahko privede do livarskih napak, kot je krčilna poroznost. Poroznost je posledica krčenja kovin med strjevanjem. Krčenje med strjevanjem aluminija je kar 7 vol. %, pri zlitinah s silicijem pa se krčenje lahko zmanjša. V literaturi je težko zaslediti poročanja o meritvah dimenzijskih sprememb ulitkov med strjevanjem. Nekateri avtorji poročajo o meritvah dimenzijskih sprememb v ulitku iz merilne celice v povezavi z deformacijami merilne celice in nastanka zračne reže med ulitkom in formo [2].

investigation was made using optic and scanning electron microscopy (SEM). Phase analysis was done by energy dispersive spectroscopy (EDS). The aim of the paper is to investigate dimensional changes of a casting during solidification. Four specimens were analysed. First one was AlSi12 alloy without additions, second is grain refined with AlTi5B1 master alloy, third one modified with AlSr10 master alloy and the last one with both master alloys. Microstructures were different in terms of grain size of α_{Al} phase and size of β_{Si} particles. Dilatometric analysis has shown differences in shrinkage of basic alloy and modified alloys where shrinkage is lower.

Solidification of aluminium alloys is well described in literature in terms of thermal analysis [1]. Solidification of castings is connected with dimensional changes or shrinkage during solidification of the castings, which can produce defects such as shrinkage porosity. Shrinkage porosity is a consequence of shrinkage of metal during solidification, which can be up to 7 % (volume fraction) in case of aluminium and is decreased with higher amount of Si in Al–Si alloys. Not many authors have reported about dimensional change measurements of castings during solidification. Some have reported about dilatometry of casting in measuring cell and relationship between casting and mould connected with gap formation [2].

2 Experimental

In order to study such phenomena the permanent measuring cell from calcium silicate brick was produced. The casting from the cell was a 220 mm long bar with the square cross-section of 295 mm^2. At the end of the bar two quartz rods were inserted into measuring cell connected to two linear

2 Eksperimentalno delo

Z namenom študija pojava krčenja ulitka je bila izdelana merilna celica iz silikatne opeke. Ulitek iz merilne celice je imel kvadratni presek z 295 mm^2 ter dolžino 220 mm. Na koncih ulitka sta bili v livno votlino vstavljeni dve kvarčni cevčici, ki sta bili povezani na induktivna merilca pomika, ki sta merila deformacije med strjevanjem in nadaljnjim ohlajanjem. Istočasno je bila v toplotnem središču ulitka izvedena preprosta termična analiza. Štirje vzorci iz zlitine AlSi12 so bili pripravljeni. Uporabljeno je bilo tudi udrobnjevanje in modificiranje taline. Za udrobnjevanje je bila uporabljena predzlitina AlTi5B1, za modificiranje pa predzlitina AlSr10. Prvi vzorec je bil izdelan brez predzlitin in je bil označen z 12, v drugega je bilo dodana predzlitina s titanom in je bil označen z 12T, v tretjega predzlitina s stroncijem in je bil označen z 12S in v četrtega obe, označen z 12TS.

3 Rezultati in diskusija

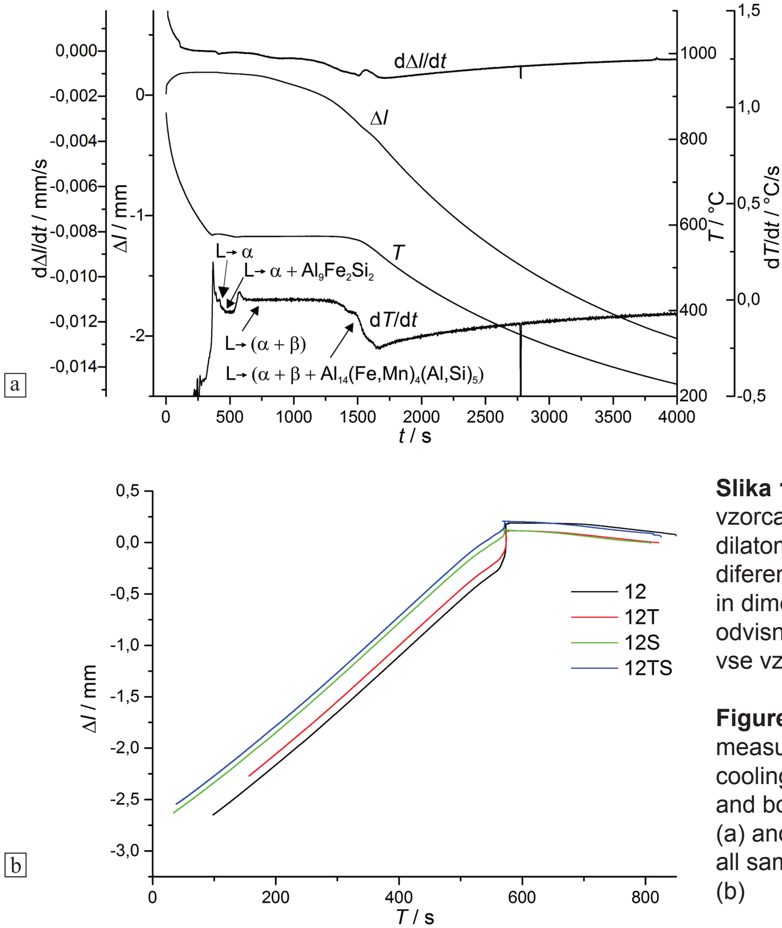
Rezultati preproste termične analize ulitka iz merilne celice so predstavljeni na sliki 1a. Ohlajevalna krivulja (*T*) vzorca 12 prikazuje potek strjevanja zlitine AlSi12. Ohlajevalna krivulja je v skladu s termodinamskim izračunom faznih ravnotežij, ki je prikazano na sliki 2, in prikazuje delež faz v odvisnosti od temperature. V prvem delu strjevanja se strjujejo dendritno izoblikovani kristali trdne raztopine α_{Al}, temu pa sledi strjevanje faze $Al_9Fe_2Si_2$. V evtektskem delu ohlajevalne krivulje se strjuje evtektik (α_{Al} + β_{Si}), strjevanje pa se zaključi s strjevanjem faze $Al_{14}(Fe,Mn)_4(Al,Si)_5$. Reakcije, ki potekajo med strjevanjem, so prikazane tudi na sliki 1a. Vse omenjene faze so bile najdene v mikrostrukturi in z EDS analizo identificirane. Mikrostrukture vzorcev 12 in

variable differential transformers (LVDT), which were measuring the dimensional changes during solidification and cooling. At the same time the thermal analysis was carried out in the thermal centre of the casting. Four samples of AlSi12 alloy were prepared. One was without additions and at others the Ti, Sr and both of additions were added simultaneously in form of master alloys AlTi5B1 and AlSr10. Samples were marked as 12, 12T for Ti addition, 12S for Sr addition, 12TS for Ti and Sr addition.

3 Results and Discussion

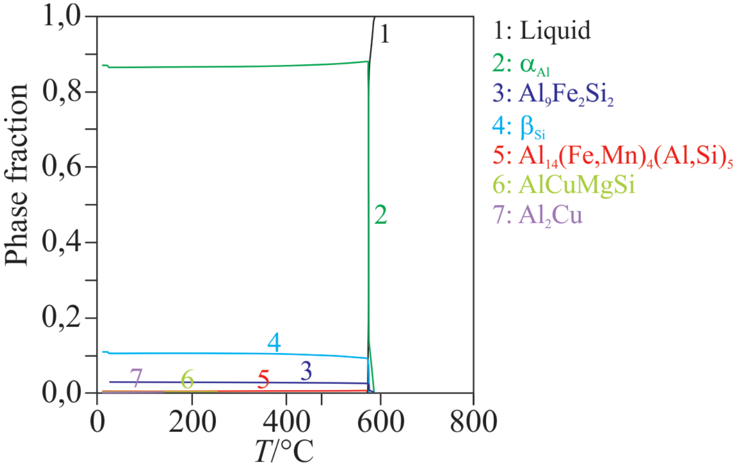
Results of thermal analysis are presented in Fig. 1a. Cooling curve (*T*) of sample 12 is showing the solidification of AlSi12 alloy. Cooling curve is in accordance with thermodynamic calculation of solidification presented in Fig. 2. In the first sequence of solidification the α_{Al} precipitates followed by $Al_9Fe_2Si_2$ phase precipitation. At eutectic part of the curve the solidification of (α_{Al} + β_{Si}) eutectic takes place and solidification is finished by $Al_{14}(Fe,Mn)_4(Al,Si)_5$ phase precipitation. The reactions of solidification are shown in Fig. 1a. All phases were detected in microstructure and analysed by EDS-analysis. Microstructure with marked phases is presented in Fig. 3. It can be seen that in modified samples the Al_2SrSi_2 phase is formed as a consequence of Sr addition [3, 4].

The measurement of dimensional changes of sample 12 is presented in Fig. 1b. It is seen on dilatometric curve (Δl) that casting is first expanding due to measuring cell expansion because of warming of a cell. Casting is still liquid at the time. When the solid skin is formed in the casting it starts to move the quartz rods and shrinkage of casting starts and takes place till the room temperature. Derivative dilatometric curve



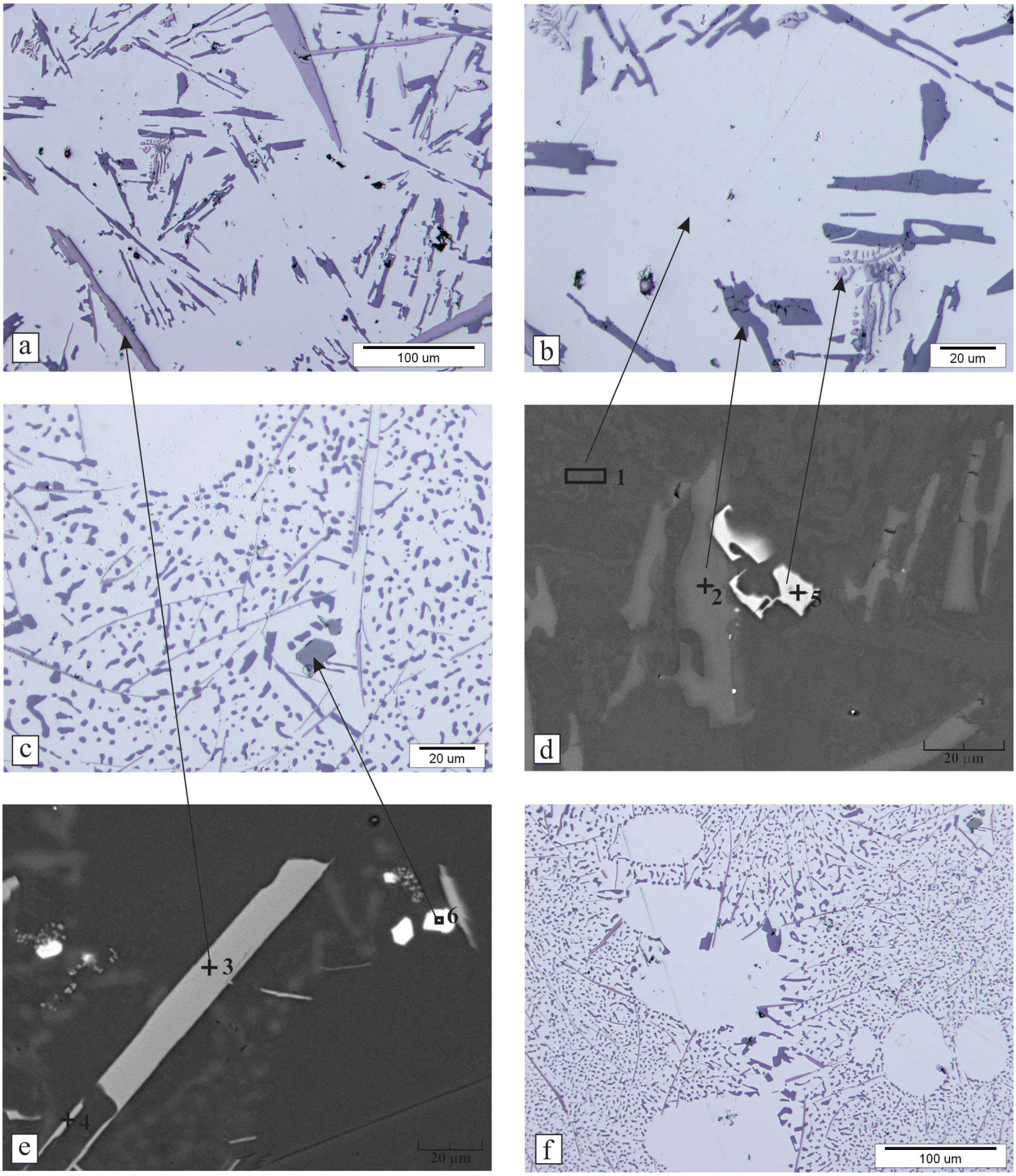
Slika 1: Rezultati meritev vzorca 12 z ohlajevalno krivuljo, dilatometrijsko krivuljo in obema diferenciranima krivuljama (a) in dimenzijske spremembe v odvisnosti od temperature za vse vzorce (b)

Figure 1: Results of measurement of sample 12 with cooling curve, dilatometric curve and both differentiated curves (a) and dimensional changes of all samples versus temperature (b)



Slika 2: Termodinamski izračun deležev faz v odvisnosti od temperature za zlitino AlSi12

Figure 2: Thermodynamic calculation of phase fractions dependent on temperature for AlSi12 alloy



Slika 3: Mikrostruktura zlitine AlSi12: svetlobnomikroskopski posnetek vzorca 12 z označenimi fazami(a, b), svetlobnomikroskopski posnetek vzorca 12S (c), SEM posnetek vzorca 12 z označenimi mesti EDS analiz (d, e) in svetlobnomikroskopski posnetek vzorca 12S (f); 1 - α_{Al}, 2 - β_{Si}, 3, 4 - $Al_9Fe_2Si_2$, 5 - $Al_{14}(Fe,Mn)_4(Al,Si)_5$, 6 – Al_2SrSi_2

Figure 3: Microstructure of AlSi12 alloy: optic micrograph of sample 12 with marked phases (a, b), optic micrograph of sample 12S (c), SEM micrographs of sample 12 with spots of EDS-analysis (d, e) and optic micrograph of 12S sample (f); 1 - α_{Al}, 2 - β_{Si}, 3, 4 - $Al_9Fe_2Si_2$, 5 - $Al_{14}(Fe,Mn)_4(Al,Si)_5$, 6 – Al_2SrSi_2

12S z označenimi fazami so prikazane na sliki 3. Opazi se, da se v vzorcu 12S pojavi faza Al_2SrSi_2 kot posledica dodatka Sr [3, 4].

Meritev dimenzijskih sprememb za vzorec 12 je prikazana na sliki 1a. Iz dilatometrijske krivulje (Δ*l*) je videti, da se ulitek najprej širi zaradi segrevanja in širjenja merilne celice. V tem času je ulitek še tekoč. Ko se v ulitku ustvari trdna skorja, le-ta začne pomikati kvarčne cevke. Krčenje se začne in poteka do sobne temperature. Diferencirana dilatometrijska krivulja (dΔ*l*/d*t*) kaže, da med ohlajanja prihaja do pojavov, kar je tudi v skladu s pojavi na diferencirani ohlajevalni krivulji (d*T*/d*t*), ki prikazuje potek strjevanja. Slika 1b prikazuje krčenje ulitka v odvisnosti od temperature. Očitno je, da z modificiranjem zlitine AlSi12 pride do razlik v krčenju ulitka. Vzorci modificirani s Sr se med strjevanjem krčijo manj kot vzorci brez dodanega Sr. Vzorec 12TS se krči za 60,9 % manj, vzorec 12S pa za 82,5 % manj kot vzorec iz zlitine AlSi12. Razlog za zmanjšano krčenje je najverjetneje spremenjena morfologija strjevanja in sposobnost napajanja ulitka. Znano pa je tudi, da dodatek St Al–Si zlitinam povečuje naplinjenost taline, kar povzroči nastanek plinske poroznosti, kompenzira krčenje med strjevanjem.

4 Zaključki

V delu je pojasnjeno strjevanje zlitine AlSi12 in določne mikrostrukturne sestavine. Ugotovljeno je, da je bilo modificiranje taline uspešno, saj so delci evtektske faze β_{Si} finejše izoblikovani. Modificiranje zlitine AlSi12 s Sr vpliva na krčenje pri strjevanju. Dilatometrijska analiza je pokazala, da je krčenje modificirane zlitine za 82,5 % manjše kot pri osnovni zlitini.

(dΔ*l*/d*t*) is showing that some effects on the curve are seen. These effects are in accordance with effects on derivative cooling curve (d*T*/d*t*) which presents the path of solidification. Fig. 1b is showing shrinkage of casting versus temperature and it is clearly seen that modification of AlSi12 alloy has an effect on shrinkage of casting. The samples with addition of Sr are shrinking less then castings without Sr addition. The shrinkage of 12TS sample is 60,9 % lower and 82.5 % lower in 12S sample than in basic alloy. The reason for lower shrinking must be found in the different solidification morphology of an alloy and ability of feeding of casting. At the same time the Sr addition can cause higher gas porosity in casting which can compensate shrinkage.

4 Conclusions

Solidification of AlSi12 alloy is described and microstructural constituents determined. It is seen that the modification was successful since β_{Si} particles are much finer in modified alloy. Shrinkage of an AlSi12 alloy is affected by modification. Dilatometric analysis showed that shrinkage of modified alloys is up to 82,5 % lower than in basic alloy.

Literatura / Literature

[1] L. Bäckerud, G. Chai, J. Tamminen. ˝Solidification Characteristics of Aluminum Alloys, Vol 2: Foundry alloys˝, AFS/Skanaluminium, (1990)

[2] P. Mrvar, M. Trbižan, J. Medved. Livarski vestnik, 48 (2001) 131

[3] C. M. Molina, A. F. Valdes, R. M. Valdez, J. T. Torres, N. R. Rosales, R. G. Estrada. Materials letters, 63 (2009) 9–10

[4] K. P. Rogers, C. Simensen. Al–Si alloys and method of casting. US patent and trademark office, 5,484,492. 1996-16-01.