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Influence of silicon concentration on linear contraction process of Al-Si binary alloy

J. Mutwil [a,*], K. Kujawa [a], P. Marczewski [b], P. Michajłow [b]
[a] Department of Mechanical Engineering, University of Zielona Góra, ul. Podgórna 50, 65-246 Zielona Góra
[b] Mechanical Engineering Student, University of Zielona Góra, ul. Podgórna 50, 65-246 Zielona Góra
*Corresponding author. E-mail address: j.mutwil@iizp.uz.zgora.pl

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Abstract

Investigations of shrinkage phenomena during solidification and cooling of aluminium and aluminium-silicon alloys (AlSi5, AlSi7, AlSi9, AlSi11, AlSi12.5, AlSi18, AlSi21) have been conducted. A vertical shrinkage rod casting with circular cross-section (constant or fixed: tapered) has been used as a test sample. By constant cross-section a test channel mould was parted and allowed a constrained contraction to examine. No parted test channel mould was tapered and allowed an unconstrained contraction to investigate. In the experiments the dimensions changes of solidifying test bar and the test mould have been registered, what has allowed to explain a mechanism of pre-shrinkage extension of solidifying metals and alloys. Registered time dependence of the test bar and the test mould dimension changes have shown, that so-called pre-shrinkage extension has been by mould thermal extension caused. The investigation results have also shown that time- and temperature dependences of shrinkage of Al-Si alloys have been on silicon concentration depended.

Keywords: Linear contraction, Shrinkage, Pre-shrinkage expansion, Al-Si alloys

1. Introduction

In parallel paper [1] a new version of an experimental set-up for examination of linear contraction and shrinkage stresses progress of metals and alloys during– and after solidification has been described. The new version is significant development of the early design [2]. In both cases of the designs it was possible to measure the linear displacement of the sample (shrinkage rod casting) and the mould wall. Already the investigations conducted by the first version of design [3,4,5] shown that so-called pre-shrinkage extension might be caused by thermal elongation of the test mould. This not agreed with opinion of professional literature [6,7,8], that the pre-shrinkage expansion is mainly due to the evolution of gases and depends on the amount of dissolved gas in the melt. Usage in the new design of a displacement sensor with a return spring gave a possibility to easy measurement not only the thermal expansion of the test channel mould but also her thermal contraction. This should help to judge what opinion is correct.

In order to proof an effectiveness of the new setup to investigation of the shrinkage phenomena in Al-Si alloys some experiments have been conducted on aluminium and AlSi5, AlSi7, AlSi9, AlSi11, AlSi12.5, AlSi18, AlSi21 alloys. Some results have been presented below.

2. Experimental

Aluminium and Al-Si alloys were in resistance furnace melted using clay -graphite crucible. The binary alloys were alloyed by silicon introducing into melted aluminium. For each alloy and each test sample five experiments have been carried out: 1) cold mould, 100°C melt superheat; 2, 3, 4) 130°C mould temperature and 100°C melt superheat, 5) as in 2-4, but 150°C superheat.

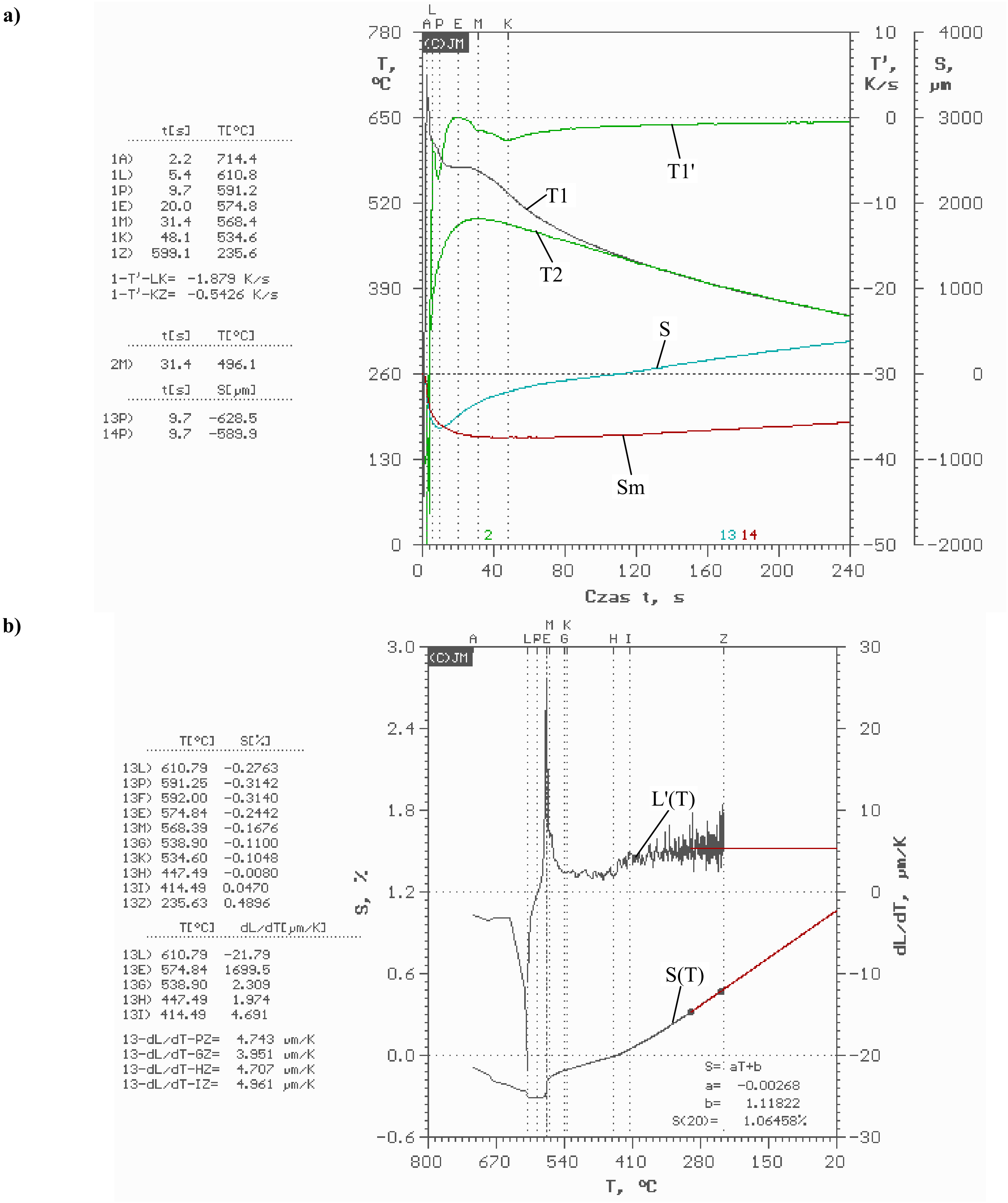
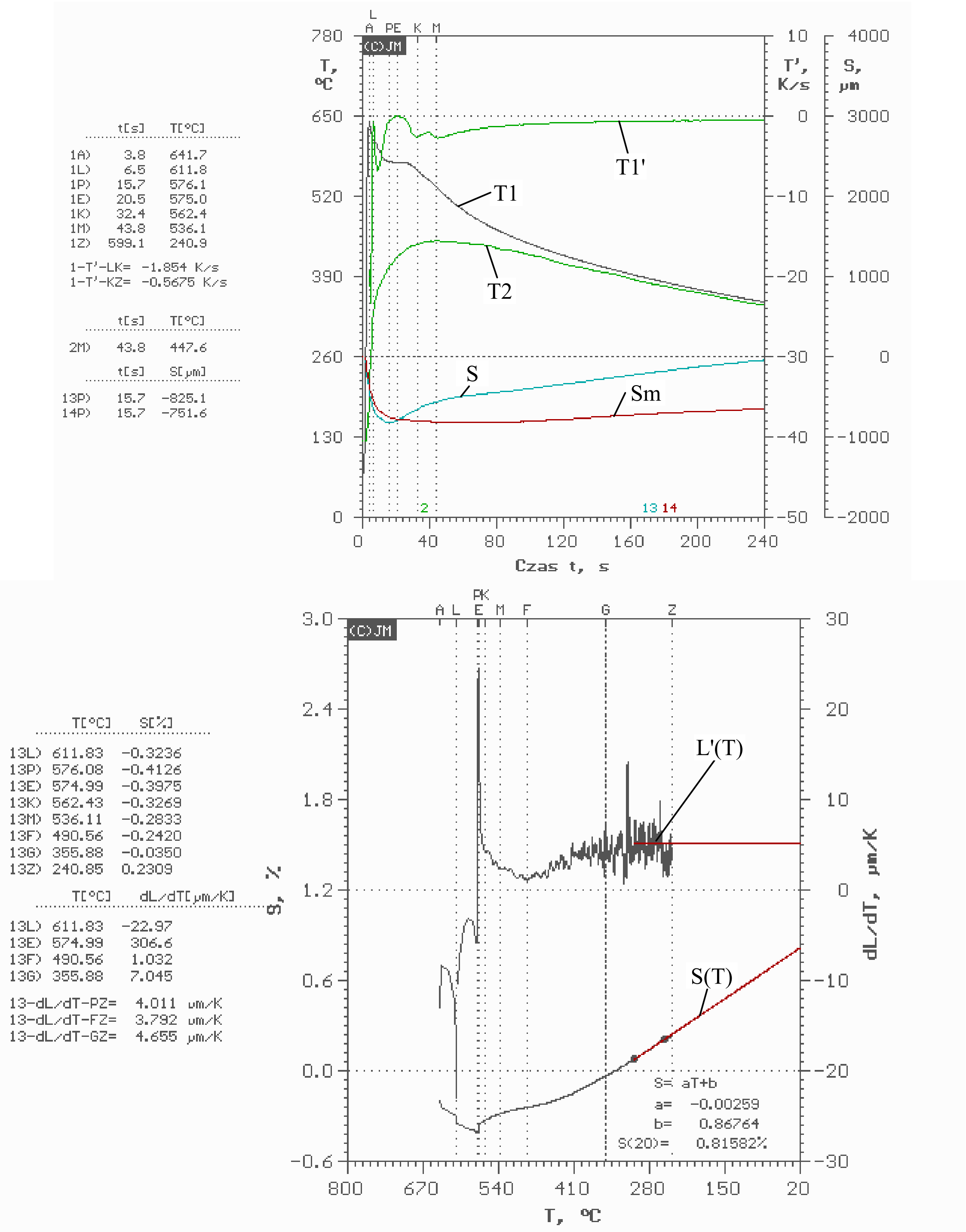


Fig. 1. Linear contraction of the AlSi7 alloy in pre-heated to 130 °C tapered mould: a) first 240 second time dependence of: metal (T1) and mould (T2) temperatures, temperature time derivative (T1'), test sample (S) and mould (Sm) length changes, b) temperature dependence of relative contraction S(T) and length of sample temperature derivative L'(T)



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        t[s]    T[°C]
    ..............................
 1A)     3.8    641.7
 1L)     6.5    611.8
 1P)    15.7    576.1
 1E)    20.5    575.0
 1K)    32.4    562.4
 1M)    43.8    536.1
 1Z)   599.1    240.9

 1-T'-LK=  -1.854 K/s
 1-T'-KZ=  -0.5675 K/s

        t[s]    T[°C]
    ..............................
 2M)    43.8    447.6
        t[s]    S[μm]
    ..............................
13P)    15.7   -825.1
14P)    15.7   -751.6
```

```
        T[°C]    S[%]
    ..............................
13L) 611.83  -0.3236
13P) 576.08  -0.4126
13E) 574.99  -0.3975
13K) 562.43  -0.3269
13M) 536.11  -0.2833
13F) 490.56  -0.2420
13G) 355.88  -0.0350
13Z) 240.85  0.2309

        T[°C]    dL/dT[μm/K]
    .......................................
13L) 611.83  -22.97
13E) 574.99   306.6
13F) 490.56   1.032
13G) 355.88   7.045

13-dL/dT-PZ=   4.011  μm/K
13-dL/dT-FZ=   3.792  μm/K
13-dL/dT-GZ=   4.655  μm/K
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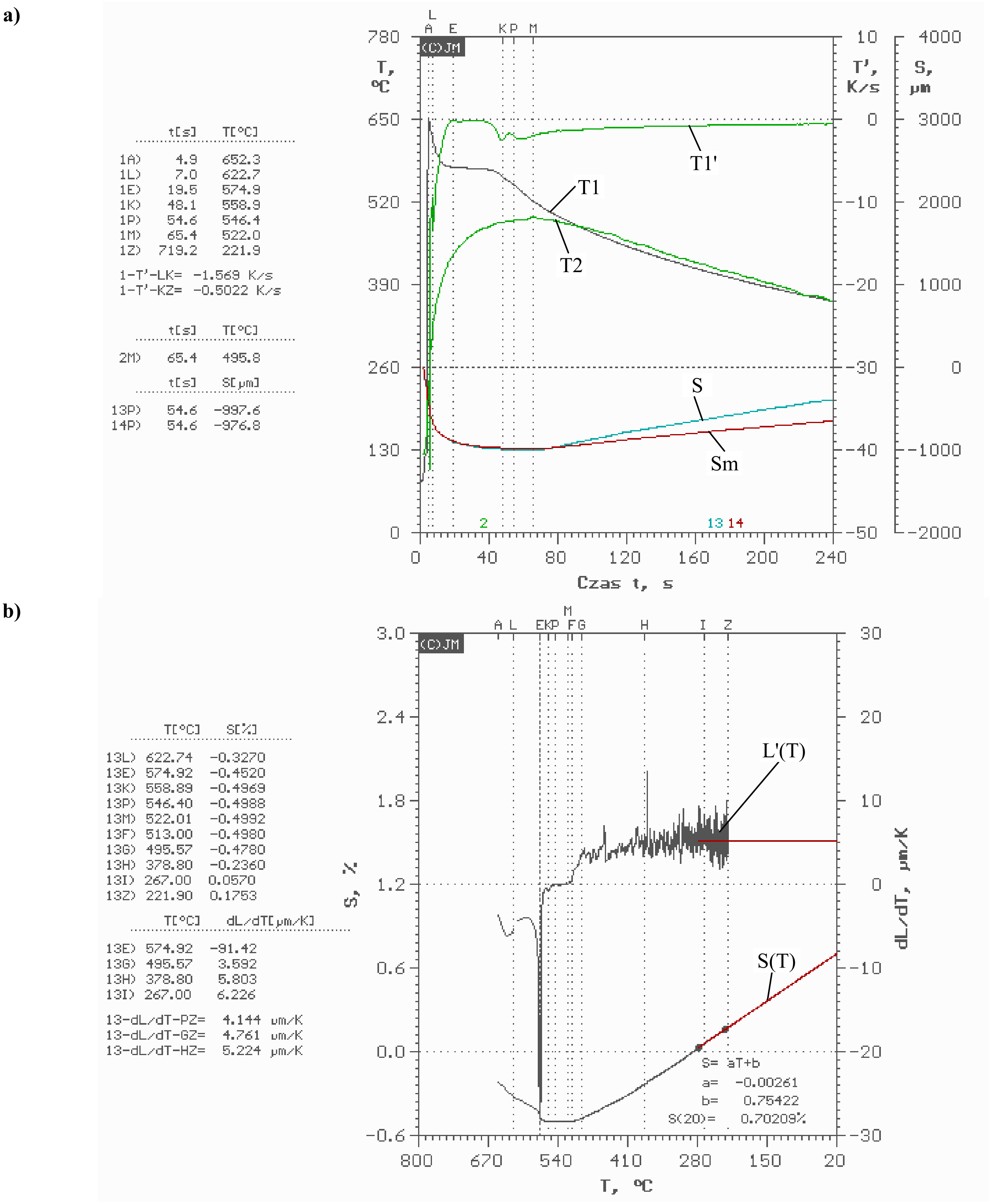
Fig. 2. Linear contraction of the AlSi7 alloy in pre-heated to 130 °C no tapered mould: a) first 240 second time dependence of: metal (T1) and mould (T2) temperatures, temperature time derivative (T1'), test sample (S) and mould (Sm) length changes, b) temperature dependence of relative contraction S(T) and length of sample temperature derivative L'(T)



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         t[s]    T[°C]
    ...............................
 1A)      4.9    652.3
 1L)      7.0    622.7
 1E)     19.5    574.9
 1K)     48.1    558.9
 1P)     54.6    546.4
 1M)     65.4    522.0
 1Z)    719.2    221.9

 1-T'-LK=  -1.569 K/s
 1-T'-KZ=  -0.5022 K/s

         t[s]    T[°C]
    ...............................
 2M)     65.4    495.8
         t[s]    S[μm]
    ...............................
13P)     54.6   -997.6
14P)     54.6   -976.8
```

```
        T[°C]    S[%]
    ...............................
13L)  622.74   -0.3270
13E)  574.92   -0.4520
13K)  558.89   -0.4969
13P)  546.40   -0.4988
13M)  522.01   -0.4992
13F)  513.00   -0.4980
13G)  495.57   -0.4780
13H)  378.80   -0.2360
13I)  267.00   0.0570
13Z)  221.90   0.1753
        T[°C]    dL/dT[μm/K]
    ...........................................
13E)  574.92   -91.42
13G)  495.57     3.592
13H)  378.80     5.803
13I)  267.00     6.226

13-dL/dT-PZ=   4.144  υm/K
13-dL/dT-GZ=   4.761  υm/K
13-dL/dT-HZ=   5.224  μm/K
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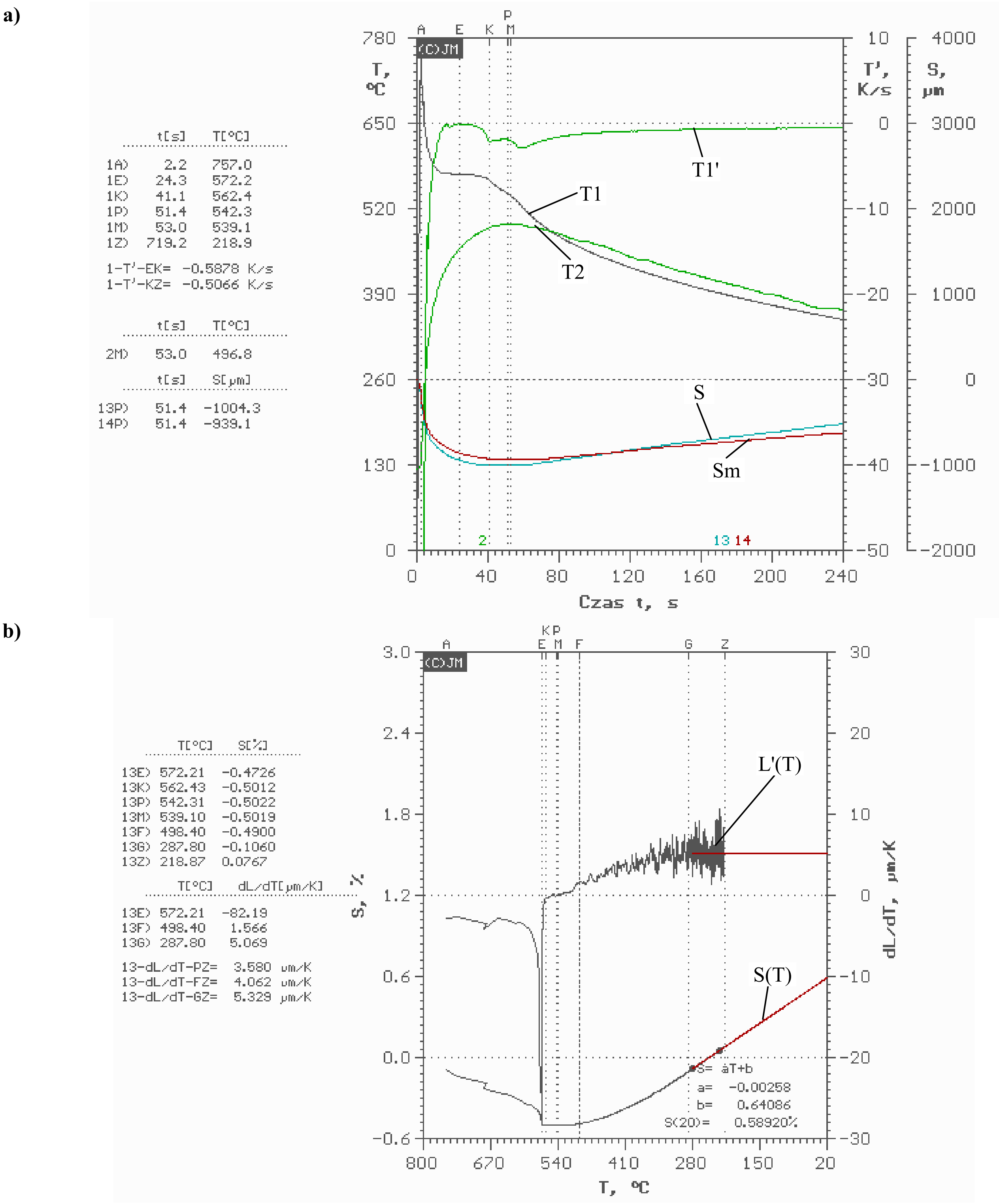
Fig. 3. Linear contraction of the AlSi21 alloy in pre-heated to 130 °C tapered mould: a) first 240 second time dependence of: metal (T1) and mould (T2) temperatures, temperature time derivative (T1'), test sample (S) and mould (Sm) length changes, b) temperature dependence of relative contraction S(T) and length of sample temperature derivative L'(T)



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         t[s]    T[°C]
  ...................................
 1A)      2.2    757.0
 1E)     24.3    572.2
 1K)     41.1    562.4
 1P)     51.4    542.3
 1M)     53.0    539.1
 1Z)    719.2    218.9

 1-T'-EK=  -0.5878 K/s
 1-T'-KZ=  -0.5066 K/s

         t[s]    T[°C]
  ...................................
 2M)     53.0    496.8

         t[s]    S[µm]
  ...................................
13P)     51.4  -1004.3
14P)     51.4  -939.1
```

```
        T[°C]    S[%]
  ...................................
13E) 572.21   -0.4726
13K) 562.43   -0.5012
13P) 542.31   -0.5022
13M) 539.10   -0.5019
13F) 498.40   -0.4900
13G) 287.80   -0.1060
13Z) 218.87   0.0767

        T[°C]    dL/dT[µm/K]
  ............................................
13E) 572.21   -82.19
13F) 498.40    1.566
13G) 287.80    5.069

13-dL/dT-PZ=   3.580 um/K
13-dL/dT-FZ=   4.062 um/K
13-dL/dT-GZ=   5.329 µm/K
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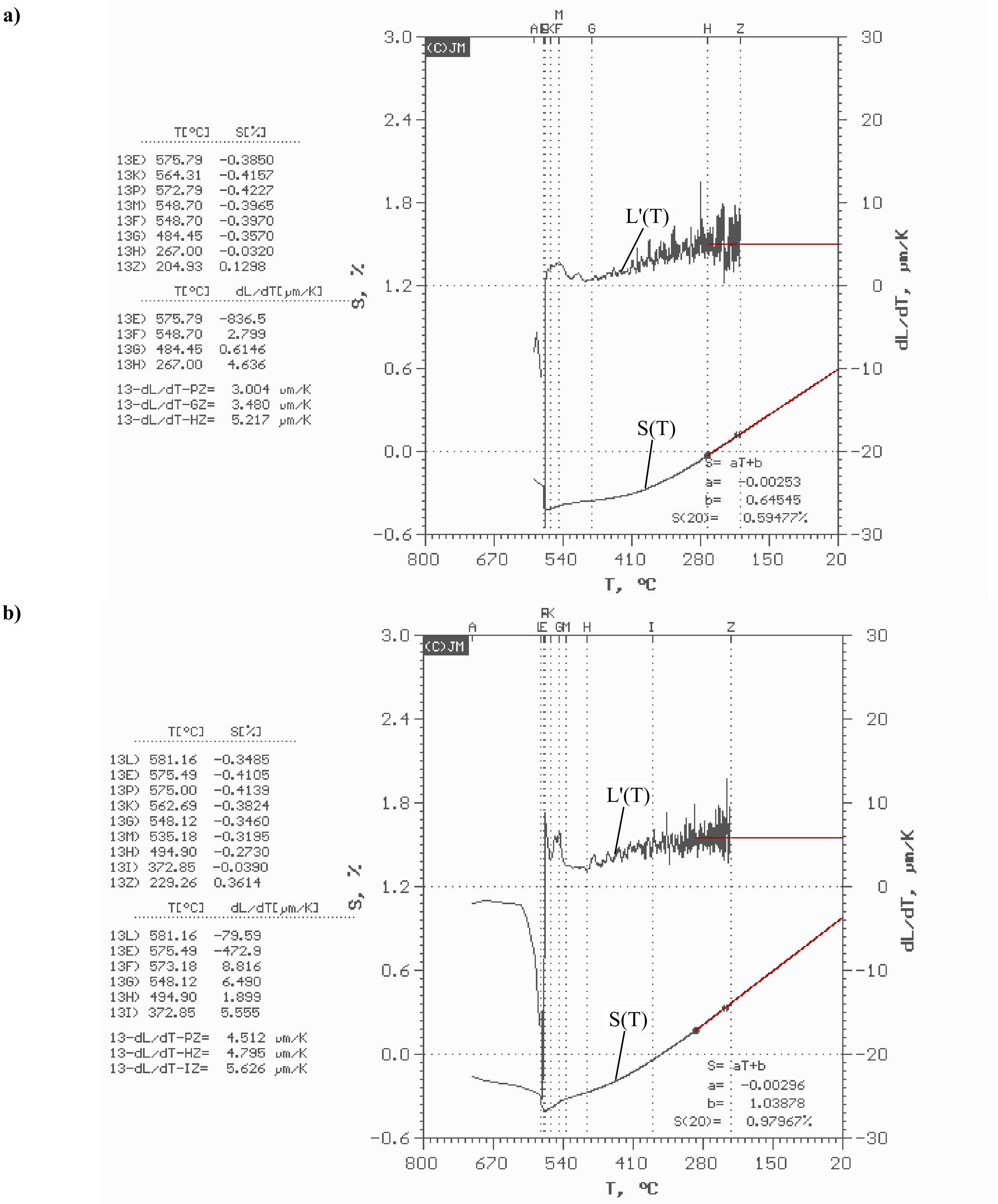
S= aT+b
a=   -0.00258
b=    0.64086
S(20)=   0.58920%
```

Fig. 4. Linear contraction of the AlSi21 alloy in pre-heated to 130 °C no tapered mould: a) first 240 second time dependence of: metal (T1) and mould (T2) temperatures, temperature time derivative (T1'), test sample (S) and mould (Sm) length changes, b) temperature dependence of relative contraction S(T) and length of sample temperature derivative L'(T)



a)

T[°C]		S[%]
13E)	575.79	-0.3850
13K)	564.31	-0.4157
13P)	572.79	-0.4227
13M)	548.70	-0.3965
13F)	548.70	-0.3970
13G)	484.45	-0.3570
13H)	267.00	-0.0320
13Z)	204.93	0.1298

T[°C]		dL/dT[μm/K]
13E)	575.79	-836.5
13F)	548.70	2.799
13G)	484.45	0.6146
13H)	267.00	4.636

13-dL/dT-PZ= 3.004 um/K
13-dL/dT-GZ= 3.480 um/K
13-dL/dT-HZ= 5.217 μm/K

S= aT+b
a= -0.00253
b= 0.64545
S(20)= 0.59477%

b)

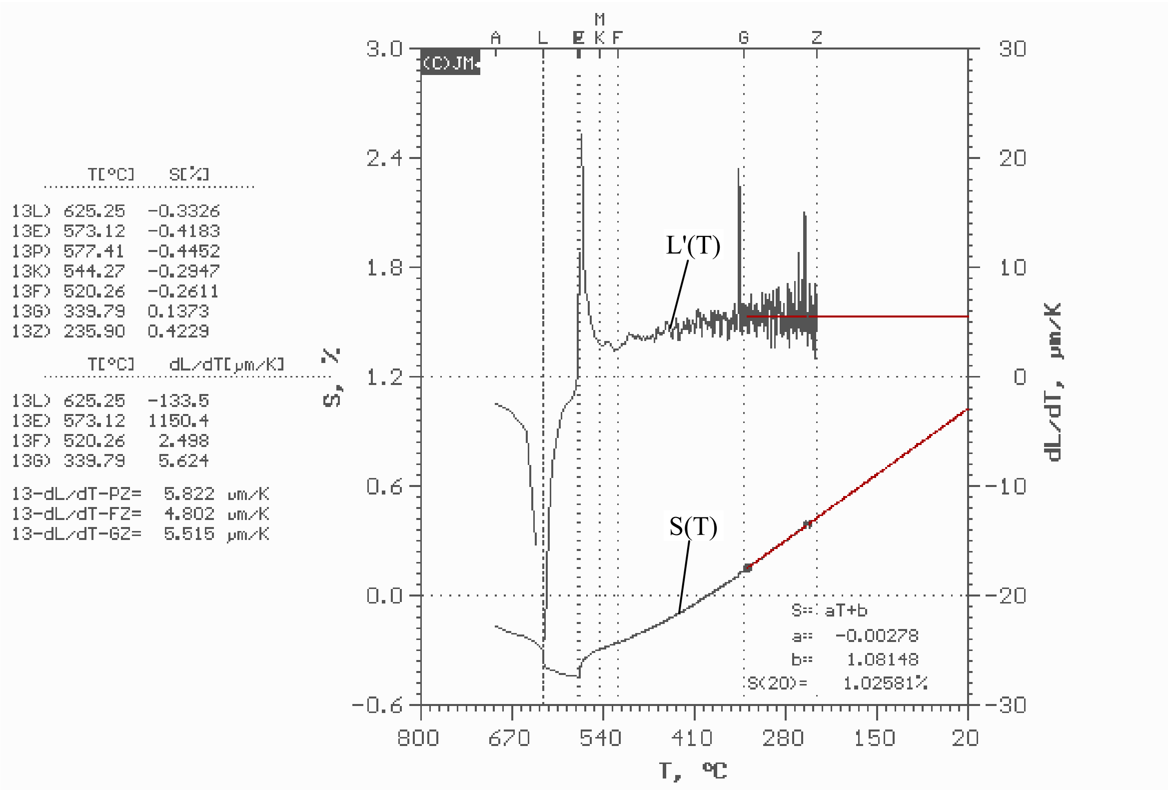
T[°C]		S[%]
13L)	581.16	-0.3485
13E)	575.49	-0.4105
13P)	575.00	-0.4139
13K)	562.69	-0.3824
13G)	548.12	-0.3460
13M)	535.18	-0.3195
13H)	494.90	-0.2730
13I)	372.85	-0.0390
13Z)	229.26	0.3614

T[°C]		dL/dT[μm/K]
13L)	581.16	-79.59
13E)	575.49	-472.9
13F)	573.18	8.816
13G)	548.12	6.490
13H)	494.90	1.899
13I)	372.85	5.555

13-dL/dT-PZ= 4.512 um/K
13-dL/dT-HZ= 4.795 um/K
13-dL/dT-IZ= 5.626 μm/K

S= aT+b
a= -0.00296
b= 1.03878
S(20)= 0.97967%

Fig. 5. Temperature dependence of relative contraction S(T) and length of sample temperature derivative L’(T), pre-heated to 130 °C tapered mould: a) AlSi12.5 alloy, b) AlSi11 alloy



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        T[°C]    S[%]
   .................................
13L) 625.25  -0.3326
13E) 573.12  -0.4183
13P) 577.41  -0.4452
13K) 544.27  -0.2947
13F) 520.26  -0.2611
13G) 339.79  0.1373
13Z) 235.90  0.4229
        T[°C]    dL/dT[µm/K]
   ..............................................
13L) 625.25  -133.5
13E) 573.12  1150.4
13F) 520.26   2.498
13G) 339.79   5.624

13-dL/dT-PZ=  5.822 µm/K
13-dL/dT-FZ=  4.802 µm/K
13-dL/dT-GZ=  5.515 µm/K
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Fig. 6. AlSi5 alloy: temperature dependence of relative contraction S(T) and length of sample temperature derivative L'(T); tapered mould pre-heated to 130 °C

Table 1.
Average value and standard deviation (in brackets) of relative contraction (extrapolated to 20°C)

	A0	AlSi5	AlSi7	AlSi9	AlSi11	AlSi12.5	AlSi18	AlSi21
Tapered channel	1.22 (0.06)	1.01 (0.03)	0.85 (0.12)	0.93 (0.08)	0.95 (0.11)	0.57 (0.09)	0.56 (0.02)	0.65 (0.07)
No tapered channel	1.21 (0.22)	0.94 (0.04)	1.00 (0.16)	0.91 (0.15)	0.81 (0.08)	0.63 (0.11)	0.48 (0.05)	0.58 (0.02)
Together	1.22 (0.15)	0.97 (0.05)	0.94 (0.15)	0.92 (0.12)	0.88 (0.12)	0.59 (0.09)	0.52 (0.06)	0.62 (0.06)

In all of the experiments the temperature (T1) of shrinking sample at inlet of the test mold channel and the temperature (T2) of the test channel mould wall were registered (see Fig. 1 in [1]). In one case the sample temperature has been measured in six points [1]. For analysis of the registered data a computer program elaborated by author of this paper was used. As analysis results the Figs. 1-6 were obtained. In all of the pictures same specific time-oriented points have been marked by letter: A- for pouring temperature (maximum of temperature T1), L- for a liquidus temperature on T1, K- for the end of solidification on T1, P- for begin of real contraction, M- for maximum of the mould wall temperature, Z- for total measuring time. With another letter (F,G, H, I, J,….) some characteristic points on derivatives have been marked. At the left side of all the pictures some values for marked points have been written in successive lines (for more information see [1]). Figs. 1a, 2a, 3a, 4a show the time dependence (first 240 second) of the temperatures T1, T2 as well as of the sample (S) and the mould (Sm) shrinkage.

Figures 1b, 2b, 3b, 4b, 5, 6 show a relative contraction S(T) and a length of sample temperature derivative L'(T) as functions of T1 temperature. In all cases the curves of relative contraction have been extrapolated to the room temperature (20°C) using the line function (S=aT+b). Function value in 20°C (s(20)) as well as the values of function parameters (a, b) have been written in Figures area.

Analysis of the time dependence of shrinkage sample temperatures (measured in 6. points) [1] lets to see, that even by aluminium a temperature gradient on cross-section of test channel is not great and rapidly decreases after solidification. Taking this into account and the temperature dependences of linear contraction ([1], Figs. 4b, 5) it seems, that this relation is very well expressed by T1-temperature. Therefore, the shrinkage temperature dependences for remaining alloys have been also as functions of T1-temperature presented. In all cases it is clearly to see that abrupt shrinkage changes have place always by solidification range temperatures (liquidus, solidus). By another temperatures the shrinkage rate (by length of sample temperature derivative L'(T) expressed) is considerably smaller (see values on the left side of pictures).

Analysis of the shrinkage time dependence for hypoeutectic (AlSi7) as well as for hypereutectic (AlSi21) alloy (Figs. 1-4) shows that in both cases (independently on test channel version) the test sample elongation in first time period are nearly equal to this one for test channel wall. This means that described in literature so-called pre-shrinkage extension is mainly caused by mould thermal expansion.

3. Conclusion

The main conclusions of this work are:

- pre-shrinkage extension of solidifying aluminium and aluminium-silicon alloys is first of all by mould thermal extension caused,
- pre-shrinkage extension of solidifying aluminium and aluminium-silicon alloys is in small degree on silicon concentration depended and on the average amounts about 0.3-0.5%,
- results of relative contraction are not identical depended in meaning on the test mould version (tapered/no tapered test channel: constrained/unconstrained contraction) (Table 1),
- average value of relative linear contraction decrease slowly with the growth of silicon concentration to eutectic value,
- by eutectic concentration the average value of relative linear contraction decrease abruptly (Table 1),
- in hypereutectic range the influence of the silicon concentration on average value of relative linear contraction is small (Table 1),
- shrinkage process (shrinkage behaviour) of eutectic- and hypereutectic alloys is similar and differ from this for hypoeutectic one.

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