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New version of experimental setup for investigation of linear contraction and shrinkage stresses of metals and alloys

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Abstract

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. By new method the examinations of the shrinkage phenomena are conducted in a vertical rod-casting with circular cross-section. The test rod casting can have a constant cross-section (constrained contraction, parted mould) or can be tapered (unconstrained contraction, no parted mould). The examinations can be conducted in sand and metal mould. A microprocessor recorder has been used for registering of measured signals. In the contraction experiment the dimensions changes of solidified test bar and the test mould are registered. By the investigation of contraction stresses, a contraction force effecting on the solidified test bar is registered instead of its dimension changes. The temperature changes of the shrinkage rod casting (in 6 points) and the mould (in one point) can be measured. Exemplary investigation results of linear contraction development in aluminium have been presented.

Keywords: Linear contraction, Shrinkage stresses, Experimental set-up

1. Introduction

The knowledge about shrinkage behaviour in solidification period and after solidification (thermal contraction) is very important by projecting of foundry technological processes. Pioneer works on the field of metals and alloys shrinkage behaviour are linked with the name of Novikov [1], who has an experimental set-up proposed including a graphite mould with rectangular cavity. The cavity was T-shaped at one end and open at the other end, which was closed with movable graphite block. This block was connected to the solidifying sample by a steel screw and his another side was with displacement sensor connected. Similar solution of experimental set-up have been used by Korolkov [2] and by Eskine with co-workers [3, 4]. Some interesting experimental technique to measure of linear shrinkage was also developed in Poland [5,6,7]. The experimental set-up elaborated by author this paper [7] has allowed to investigate both of phenomena: i) the evaluation of casting linear dimension changes, ii) the evaluation of shrinkage stresses in solidifying test bar. The shrinkage test bar (236 mm gauge length) was horizontal and had a square cross-section (20 mm side). The developed experimental set-up has allowed to measure the linear dimension changes of the shrinkage test bar (test sample) as well as of his mould. This has given an opportunity to investigate a pre-shrinkage expansion phenomenon of solidifying metals and alloys. It has been shown that this might be connected with the phenomenon of thermal expansion of testing mould [8,9,10]. The phenomenon of casting tension by thermal lengthened mould wall is depended on mechanical properties of solidifying metal and on friction forces on a mould-casting boundary. Square cross-section of the shrinkage test bar causes that the friction force is strongly depended on fulfilment degree by metal the corner regions of mould. Taking this into account, it should be assumed that circular cross-section of the test sample would be a better and would be apply in a new version of experimental set-up. Moreover, in order to have a possibility to investigate an influence of friction forces on the contraction behaviour it should be additional assumed that a new version of experimental setup should ensure a possibility of leading the investigation by test sample with constant cross-section (constrained contraction, parted mould) and by tapered test sample (unconstrained contraction, no parted mould).

By investigations of shrinkage behaviour it is very important to determine a temperature dependence of the linear contraction and the shrinkage stresses. According to the opinion of Ignaszak [11] for this aim the time depended thermal field of test sample should be know. In order to this, it was assumed that in new version of experimental setup a possibility of temperature measuring in some points of test sample should be ensured.

2. Description of experimental setup design

Some details of the new design of experimental setup are shown in Fig. 1. The new version ensure, how the previous, the ability to investigate (in the same mould) the shrinkage- as well as the shrinkage stresses behaviour. The new design is vertical oriented. All of design elements are on a shaped frame (1) installed. Fig 1a. shows the setup arrangement for the shrinkage stresses investigation (force sensor installed).

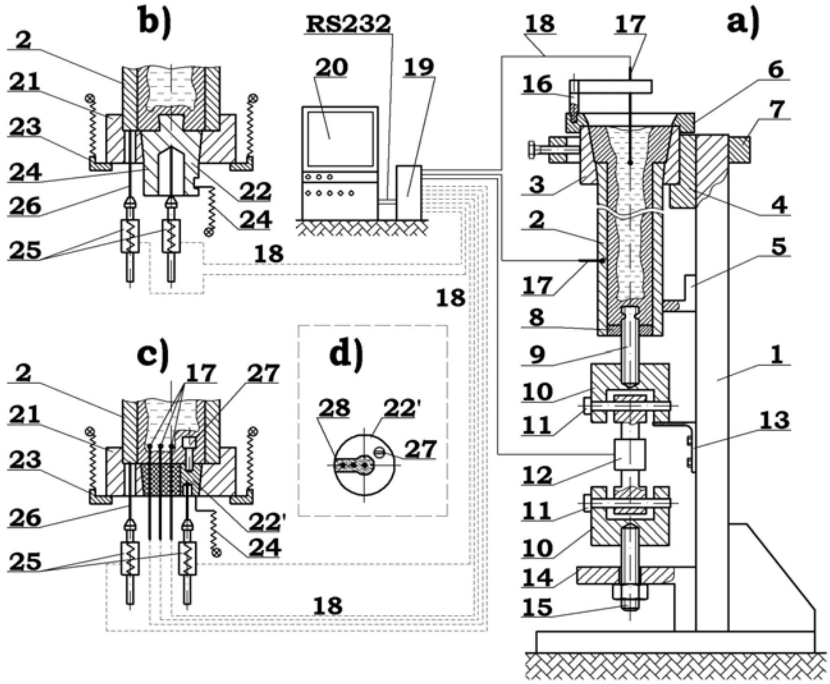


Fig. 1. Scheme of experimental set-up for investigation of linear contraction and shrinkage stresses behaviour of solidifying and cooling metals and alloys: a) general scheme (configuration for shrinkage stresses investigations), b) configuration for contraction investigations (version without thermocouples), c) configuration for contraction investigations (version with thermocouples), d) upper view on closing conical insert with catch screw and embedded thermocouples: 1-shape frame, 2- shrinkage bar mould segment (test channel), 3- pouring cup mould segment, 4- pouring cup bracket, 5-plumb bracket, 6-level raiser, 7- arch with clamping screw, 8- round closing plate, 9- shaped catch screw, 10- couplings of sensor arms with the strain screw 15 and the catch screw 9, 11-blocking pins, 12- force sensor, 13- drag bracket, 14- strain screw drag plate, 15- strain screw, 16- thermocouple clamper,17- thermocouple, 18- wire, 19- microprocessor recorder PDOC-16, 20- computer, 21- closing base, 22- closing conical insert with catch tip, 22'- closing conical insert with catch screw and embedded thermocouples, 23-spring-loaded catch, 24- screw spring, 25- distance sensor with return spring, 26- injection needle, 27- catch screw, 28- resin-bonded sand

Fig. 2. Closing conical insert (No. 22’ in Fig. 1.) with embedded thermocouples

How assumed, the replaceable mould segment of test sample (2) can be in two version: (i) conical shaped and no parted (d1=20 mm, d2=21 mm, gauge length=200mm) and (ii) parted with constant diameter of 20 mm (gauge length=200mm).

By arrangement for shrinkage stresses examination an outlet of test channel (2) is closed by using round closing plate (8) connected with a shaped catch screw (9), which by coupling (10) is also connected with the force sensor (12). Free-play in force sensor assembly can be by screw (15) reduced (initial strain).

By arrangement for shrinkage examination (pre-shrinkage expansion, solidification shrinkage, thermal contraction) the outlet of test channel (2) is closed by using of the closing base (21) equipped in the closing conical insert (22 or 22’). The closing conical insert (22, Fig 1b.) is used by measurements, in which the temperatures in an outlet region are not registered. In another case the solution from Fig. 1c. should be used (closing conical insert (22’)). Fig. 1c. shows that proposed design ensures a recommended way of temperatures measurement (thermocouples placed in isotherm). A standard distance between adjacent thermocouples amount 4 mm, but the last one can be bended to the mould surface. A place in which the sample temperatures should be measured one can establish by choosing of thermocouples length (distance of thermocouples measuring join from surface of the closing conical insert, see Fig. 1c. and Fig. 2.). The temperatures can be measured also in upper region of test sample (in inlet area of test channel (2), see Fig. 1a.). In Fig. 1a. one can see single thermocouple, but the thermocouple clamper (17) ensures a possibility of placing of additional thermocouples. The clamper design also ensures a recommended way of temperatures measurement (thermocouples placed in isotherm).

Independently from design version, in both cases the linear displacement of the sample and the mould wall are measured (Fig. 1b, c). Using of the displacement sensors with the return spring makes possible an easy measurement both the expansion and the contraction of analysed dimensions. Analysis of possible pre-shrinkage expansion of solidifying test rod ensures a springy clamping of the closing base (21, Fig. 1b, c).

The microprocessor recorder PDOC-16 (19) ensures an acquiring of the measurement data.

3. Exemplary measurement

For a usefulness check of elaborated experimental setup for investigations of shrinkage phenomena in solidifying and cooling metals and alloys a series of experiments on aluminium and aluminium-silicon alloys have been carried out. Two exemplary results of experiments carried out for aluminium have been presented on Fig. 3-6. and shortly described below. Results for some Al-Si alloys have been presented in parallel paper [12].

The two mentioned experiments for aluminium differed with the used shrinkage bar mould segment (2): (i) parted mould segment with constant cross-section (constrained contraction) and (ii) no parted mould segment with tapered test channel (unconstrained contraction).

In the first version of experiment the temperature was measured in six points of test bar (tree thermocouples: T1- in channel axis, T2 – 4mm from axis, T3- 8mm from axis in inlet region of the test mould, tree thermocouples:T5- in channel axis, T6– 4mm from axis, T7– 8mm from axis in outlet region of test mould - arrangement like in Fig. 1c.). The standard distance between of all adjacent thermocouples (amounting 4 mm) was adapted. By bottom thermocouples the measure joints were about 10 mm above closing base (21) placed. By upper thermocouples the measure joints were about 5 mm below of shrinkage channel inlet (2) placed.

In the second version of experiment the temperature was measured only in one point (T1)- like in Fig. 1a.

In both cases the test mould was pre-heated to about 130 °C and the mould temperature (T2- notation used for first version of experiment or T4 - notation used for second version of experiment) was measured and registered in a point shown in Fig. 1a.

For analysis of the registered data a computer program elaborated by author of this paper was used. As analysis results the Fig. 3-6 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,….) it have been marked characteristic points on derivatives. At the left side of all the pictures some values for marked points have been written in successive lines. In all of the line the first information is about number of measuring channel of register (for example: (1-7)-for temperatures: T1-T7; 13, 14-for displacement sensors: 13-shrinkage sample, 14- mould wall). For example, according to this, 1L means the T1 temperature in point L, 13P- means a displacement of shrinkage sample in point P. There are also more complex notations, for example: 1-T’-LK –means the average value of time derivative of T1 in time interval between points marked as L and K. The fulltime lines of all registered signals by no tapered shrinkage bar (6 temperatures) shows Fig. 3a. Fig. 3b. shows all temperatures lines for first 30 seconds. Fig. 4a. shows for data from Fig. 3 the time dependence (first 240 second) of T1, T4, T1’, S (sample shrinkage), Sm (mould shrinkage). Fig.4b. shows for data from Fig. 3. relative contraction S(T) and length of sample temperature derivative L’(T) as functions of T1 temperature.

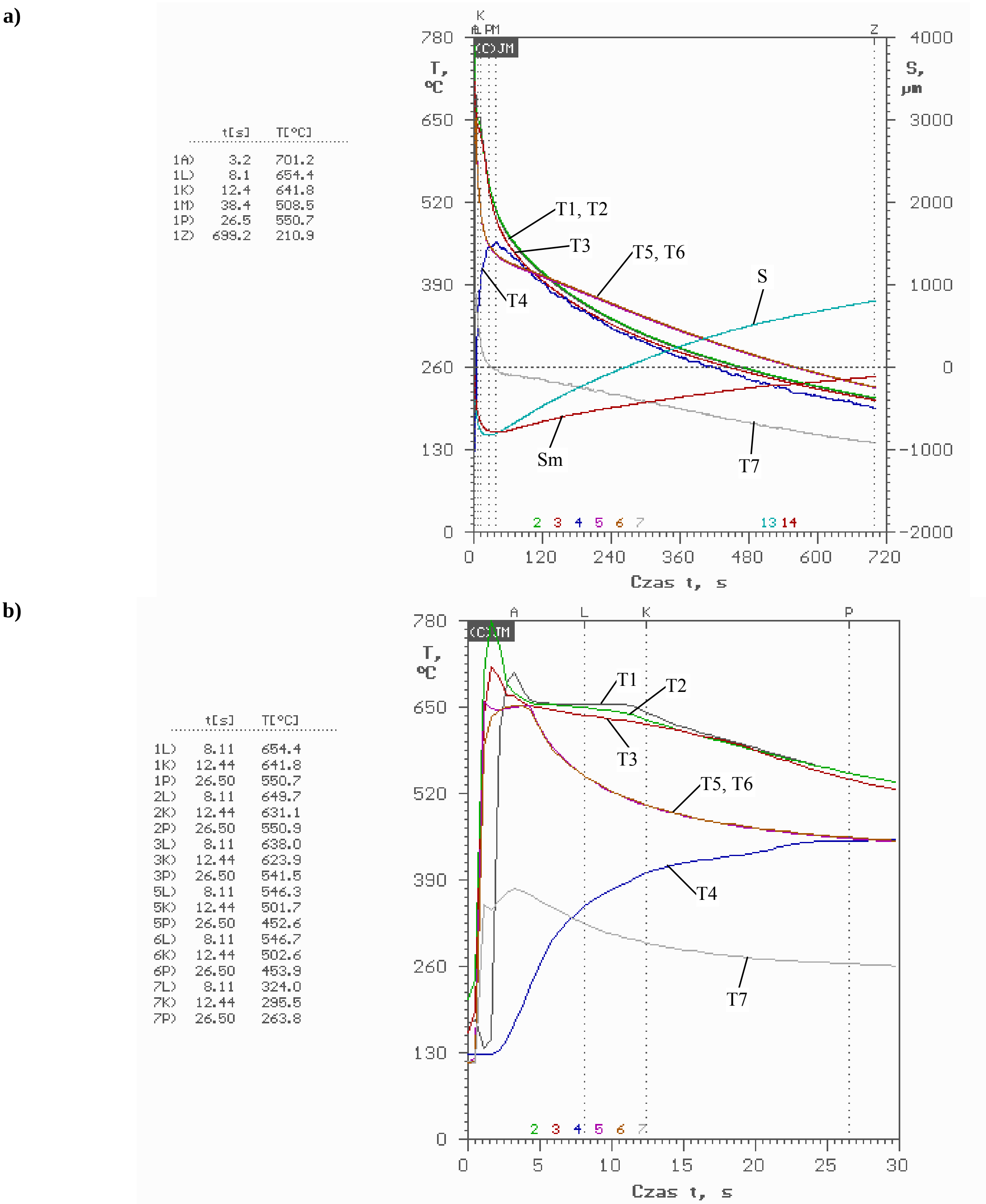
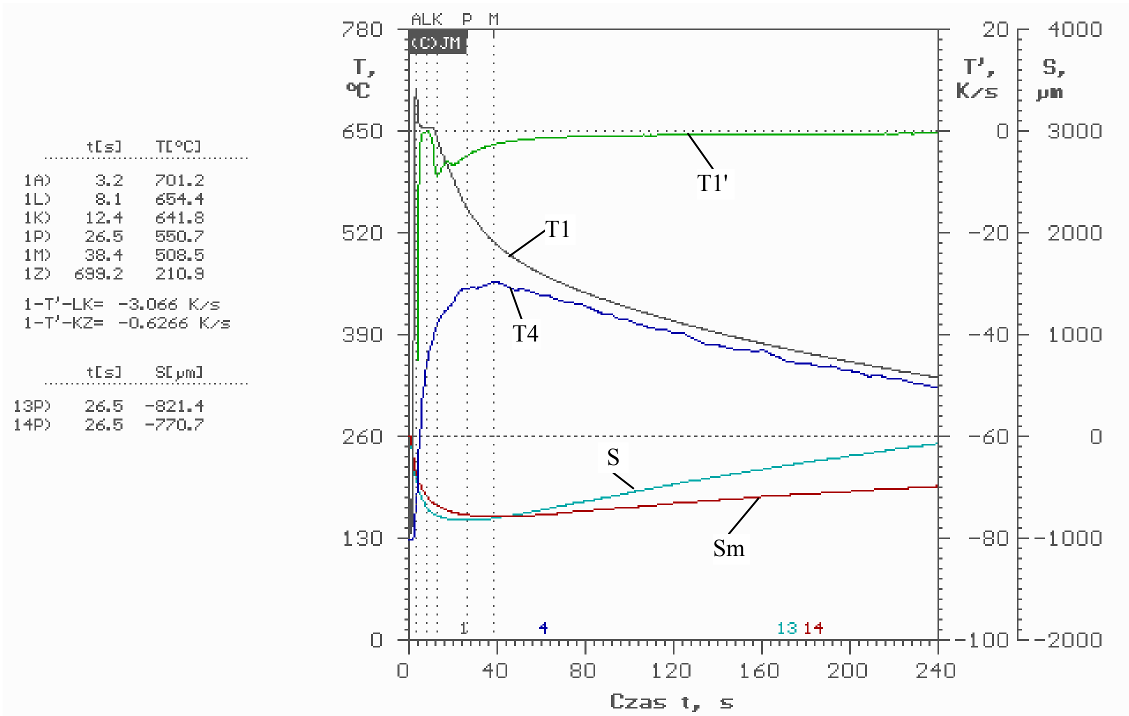


Fig. 3. Linear contraction of aluminum in no tapered test channel: a) full time dependence of all registered data: metal (T1,T2,T3,T5,T6,T7) and mould (T4) temperatures, test sample (S) and mould (Sm) length changes, b) time dependence of metal (T1,T2,T3,T5,T6,T7) and mould (T4) temperatures (first 30 s)

a)



b)

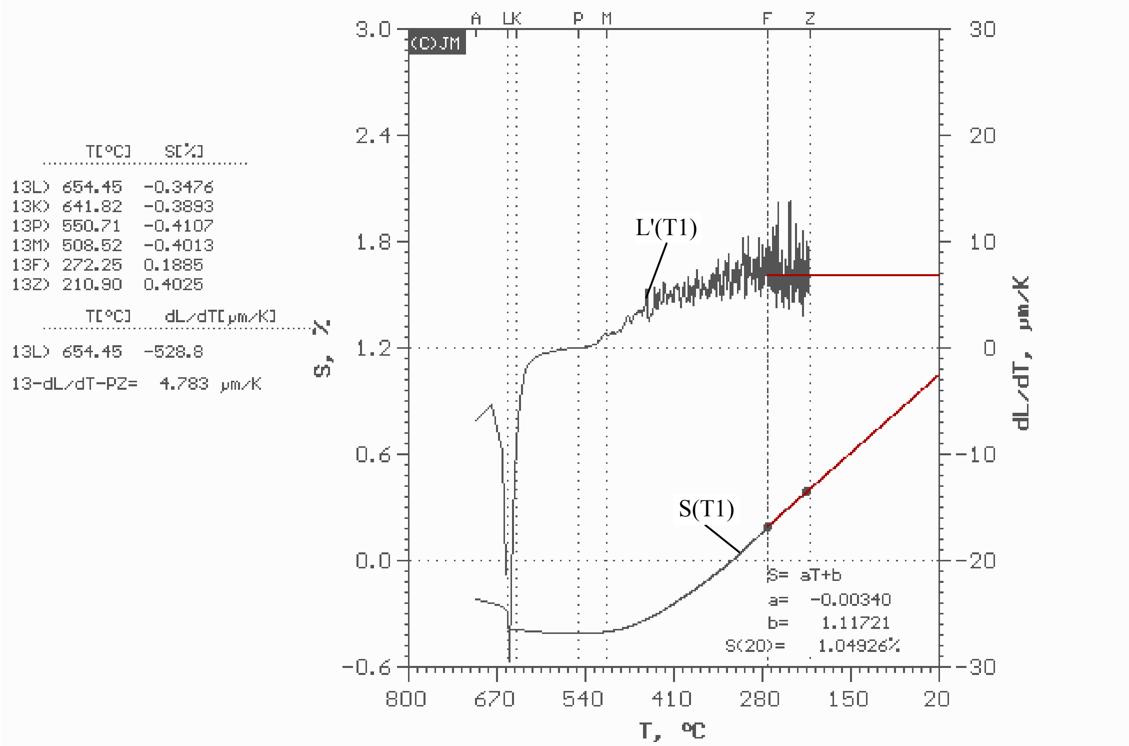


Fig. 4. Data from Fig. 3.: a) time dependence of: metal (T1) and mould (T4) temperatures, temperature time derivative (T1'), test sample (S) and mould (Sm) length changes (first 240 s), b) relative contraction S(T) and length of sample temperature derivative L'(T) as functions of T1 temperature

a)

b)

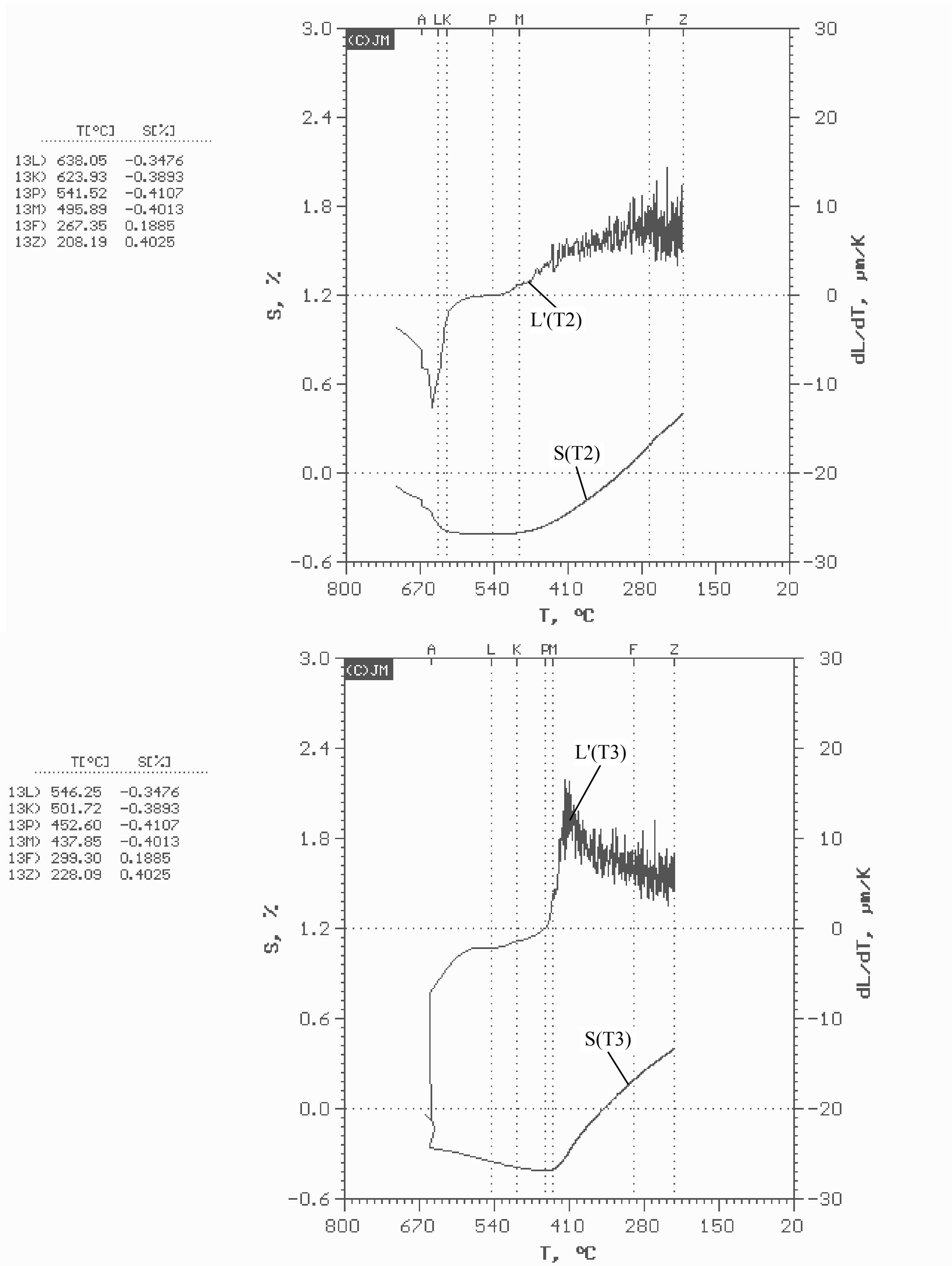
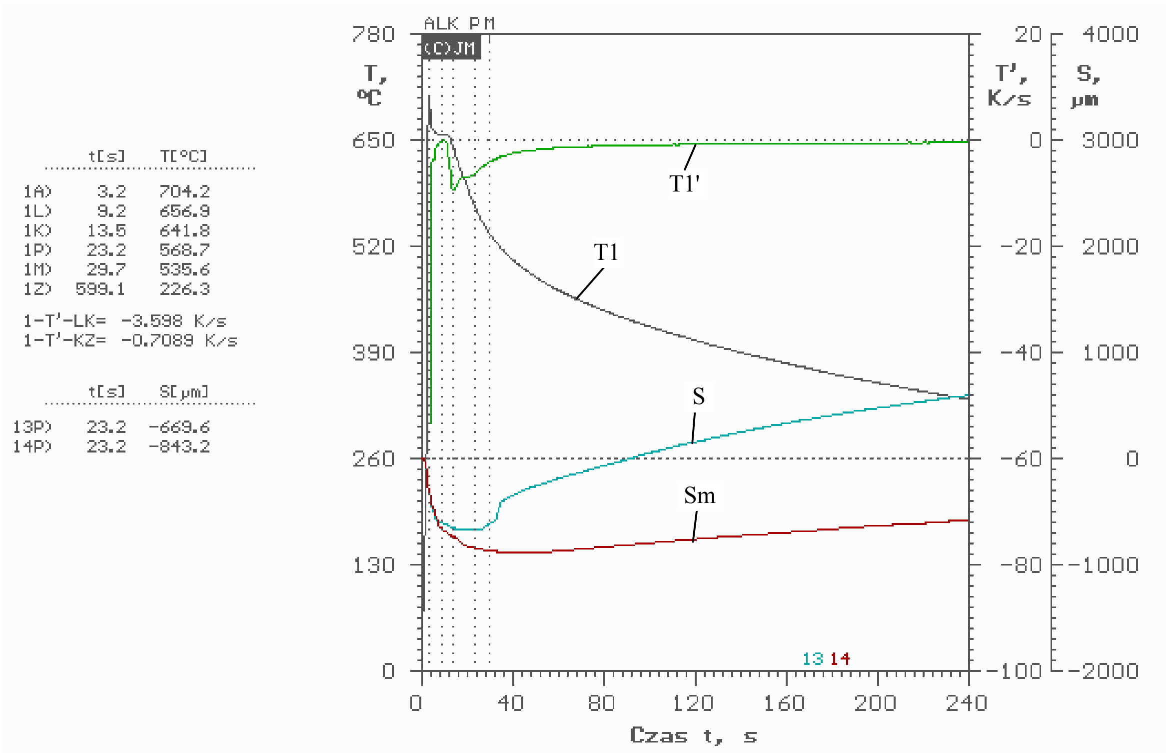


Fig. 5. Data from Fig. 3.-Relative contraction (S) and length of sample temperature derivative (L') as a function of: a) T2 temperature, b) T3 temperature

a)



b)

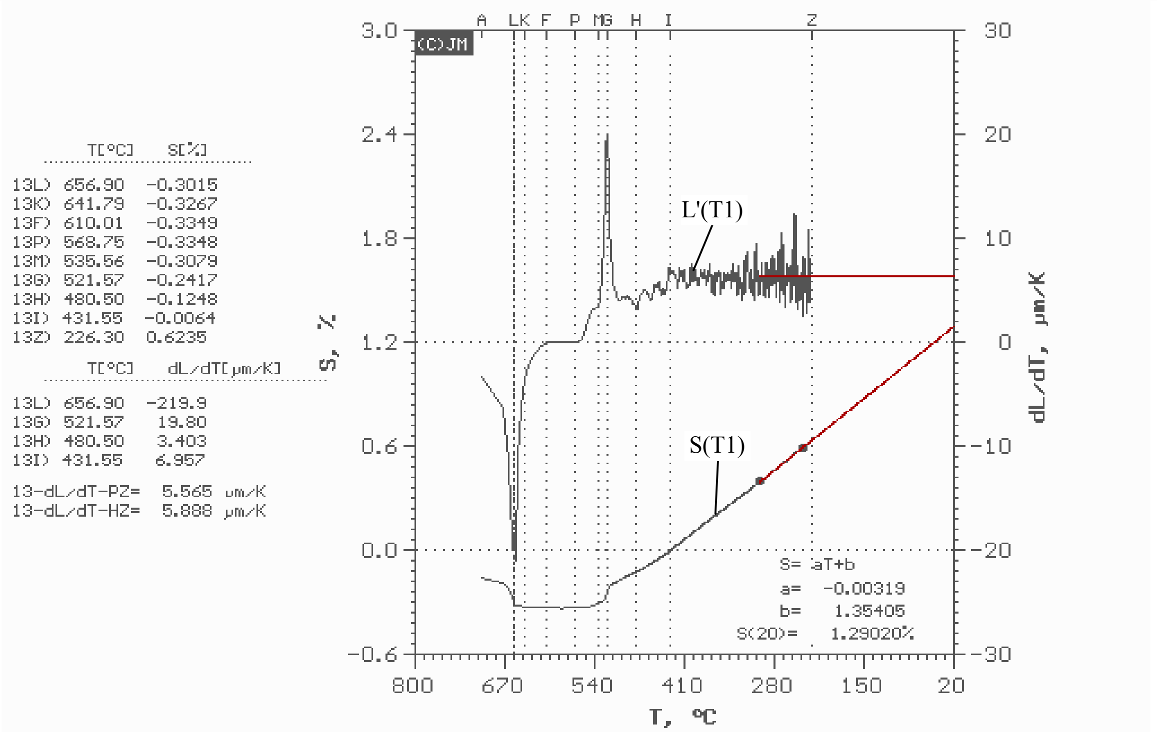


Fig. 6. Linear contraction of aluminum in tapered test channel: a) time dependence of: metal temperature (T1), temperature time derivative (T1'), test sample (S) and mould (Sm) length changes, b) relative contraction S(T) and length of sample temperature derivative L'(T) as functions of T1 temperature

For the data from Fig. 3. in Fig. 5 the relative contraction (S) and the length of sample temperature derivative (L') are presented as functions of: a) T2 temperature, b) T3 temperature. A curves composition like in Fig. 4, but for the case of tapered test channel presents Fig. 6. In Fig. 4b. and Fig. 6b. 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.

4. Conclusion

The new version of experimental setup for examination of shrinkage phenomena in solidifying and cooling metals and alloys allows to:

- investigate the evolution of shrinkage (pre-shrinkage extension, solidification shrinkage, thermal contraction after the solidification),
- investigate the evolution of shrinkage stresses in shrinkage test bar,
- conduct investigation in sand (resin-bonded sand) and metal mould,
- conduct investigation in tapered and no tapered test channel (constrained contraction-parted mould, unconstrained contraction - no parted mould),
- measure of the shrinkage bar temperature in 6. points.

The computer program elaborated for the new version of experimental setup allows to:

- present the time dependence of the registered measuring signals,
- present the temperature dependence of alloy shrinkage and shrinkage stresses (for each registered temperature of shrinkage rod, see Fig. 4b, 5, 6b),
- point out on the signal curves some characteristic points and assign them a letter notation,
- write out on picture area the signals value (temperature, contraction, their derivative etc.),
- write out in picture area some calculated value (e.g. average value of selected signal in chosen time or temperature interval; average value of selected derivative in chosen time or temperature interval (see Fig. 4, 6) etc.).

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