*Journal of Thermal Analysis, Vol. 11 (1977) 241–247*

# APPLICATION OF DTA FOR CONTROLLING THE HEAT TREATMENT OF E AlMgSi ALLOYS*

M. FARKAS, M. KOVÁCS-TREER and E. ZÁVODI

*Hungarian Cable Works, Budapest, Hungary*

(Received October 19, 1976)

The phase changes in the solid state in E AlMgSi alloy are discussed. The dissolution and precipitation processes are investigated by DTA, and the results can be applied to control the technological parameters of dissolution heat treatments.

Besides the traditional copper and aluminium, the cable industry is nowadays using moderately alloyed aluminium in increasing quantities as an electric conductor material. The purpose of alloying is to improve the mechanical properties of wires at the same time reducing their electric conductivity only slightly compared to that of the aluminium. A well-proved alloy type for this purpose is temper-grade aluminium containing about 0.5% magnesium and silicon.

Magnesium and silicon form a brittle intermetallic compound $Mg_2Si$ in aluminium, the solubility of this compound in the parent metal depending on the temperature to a great extent. Depending on the rate of cooling, various amounts of $Mg_2Si$ precipitate from the melt during the process of cooling. Such material has to be treated with dissolution heat. If it is quenched to room temperature (in order to prevent precipitation of the alloying elements) a near-stable state of equilibrium is attained. This material is homogeneous, with a good processability.

However, the alloying atoms situated in the crystal lattice of the parent metal distort the lattice, thereby increasing the electric resistance. Material with good conductivity and good mechanical properties is obtained only if the distribution of the precipitated alloying elements is homogeneous. The material drawn to the desired size is therefore aged, to yield the optimum electric and mechanical properties.

No extra dissolution treatment is used for the preliminary product extruded with up-to-date technology. The high extrusion temperature ensures fusion of the $Mg_2Si$ phase, and "freezing" of this state is ensured by water cooling immediately following the process of extrusion.

The situation is different in the case of cast-rolled coarse wires. As a result of the production technology, the $Mg_2Si$ phase does not dissolve completely in

* Paper presented at the Scientific Session on Thermal Analysis held at Balatonfüred, Hungary, on 14–16 October 1976.

the aluminium, but appears in smaller or larger precipitates, and thus the material is unsuitable for further processing. A solution treatment technological process therefore has to be introduced before the drawing.

The dissolution treatment is performed with a heat-treatment apparatus developed by our company: wire taken from a reel is forwarded by rollers into the heat-treatment chamber, where it is heated to the desired temperature by conduction of an electric current of adequate intensity through the wire. The wire passing out of the heat-treatment chamber is cooled in water, in order that the alloying elements should remain in solid solution.

From the above description it is evident that the extents of precipitation and dissolution are very important as regards the qualitative characteristics of the wires, and the technological control of the heat-treatment processes is necessary for just this reason.

Phase changes (precipitation and dissolution) in the course of the heat treatment of AlMgSi alloys have been studied by many researchers [1–9]. The research has proved that the mechanical and electrical properties of AlMgSi alloys are influenced by the phase changes. It is known that identical resistance, tensile strength or microhardness values may be associated with the various physical states developed in course of the heat treatments [10–12].

Since neither the mechanical nor the electrical parameters unambiguously determine the heat-treated state of the materials, in our opinion differential thermal analysis together with other test measurements, is the suitable method.

The purpose of our test is to elaborate a measuring method to check the physical state of the heat-treated cast-rolled wires in the continuous heat-treatment apparatus.

## Experimental

The investigations were performed with a Paulik–Paulik–Erdey derivatograph (MOM, Budapest).

Samples: a 2.2–2.4 g sample was formed by cutting from the material to be tested a shape fitting well into the tapered ceramic jar.

Inert material: 99.99% pure aluminium.

Measuring range: from 200° to the melting point. Rate of heating 6°/minute. The chemical compositions of the materials tested are shown in Table 1.

Table 1

Compositions of tested materials

| | Iron % | Magnesium % | Silicon % | Copper % | Titanium % |
|---|---|---|---|---|---|
| Cast-rolled basic material | 0.13 | 0.45 | 0.42 | 0.004 | 0.020 |
| Extruded basic material | 0.15 | 0.48 | 0.44 | 0.006 | 0.010 |

## Results

As a first step the DTA curve of the 99.99% pure aluminium was compared with that of the extruded cast-rolled material heat treated under laboratory conditions (heated at 520° for 1 hour) and quenched (Fig. 1). The DTA curve of the dissolution-treated and quenched aluminium alloy shown in Fig. 1 indicates

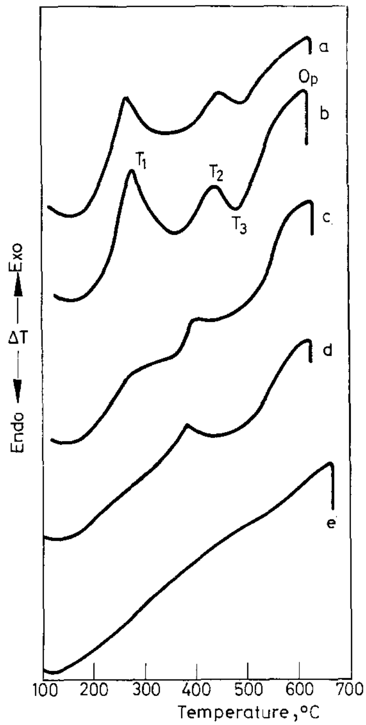


Fig. 1. a: Extruded basic material; b: material dissolution heat treated at 520° for 1 hour; c: cast-rolled basic material; d: cast-rolled basic material heat treated at 280° for 1 hour; e: DTA curve of 99.99% aluminium

a significant difference compared with the pure aluminium. Four heat effects are visible in the diagram. We shall not deal here with the processes taking place at low temperature (below 200°).

The ($T_1$) peak around 280° indicates the precipitation of $Mg_2Si$ from the solid solution. The dissolution treatment is proved by the appearence of this heat effect. The greater the amount of Mg and Si dissolved in the aluminium, the more pronounced the 280° peak. If no peak appears, this indicates that the precipitation took place during an earlier treatment. Thus, the peak or the area below the curves is characteristic of the extent of dissolution. In the course of our tests this curve section is the most significant.

The exothermic peak ($T_2$) around 440° represents a secondary phase change, smaller than the previous one and not yet clarified in the technical literature; it appears regularly before the dissolution.

The endothermic process of the 520° peak ($T_3$) is the repeat-dissolution of the alloying materials. Here the material is in a state of solid solution.

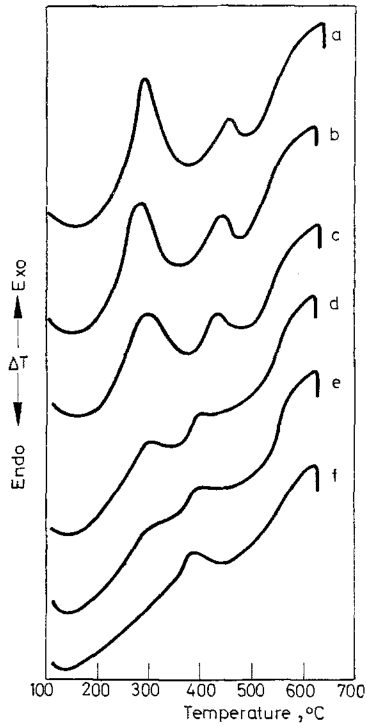


Fig. 2. DTA curves of extruded material heat treated in a laboratory furnace for 1 hour at a: 600°; b: 520°; c: 460°; d: 420°; e: 380°; f: 280°; and quenched

Finally, the melting point ($O_p$) of the material appears at around 625–630°, depending on the composition. The DTA curves of the cast-rolled wire (c), and samples extruded (a) and heat treated (b) in the laboratory differ considerably from each other. There is hardly any 280° peak in the DTA curve the cast-rolled wire (c), indicating that Mg and Si have more or less precipitated in the material in the form of $Mg_2Si$. In order to prove this artificial precipitation of $Mg_2Si$ was brought about with heat treatment of the extruded material at 280° (d). The DTA curve of this material is very similar to that of (c).

If the physical states of the wires processed by different methods are compared, it can be observed that curves of the materials extruded and heat-treated at 520°

in the laboratory are very similar, i.e. the Mg and Si atoms are present in solid solution in the aluminium.

Our next experiment was the DTA of sample heat treated at different temperatures in the laboratory. We thus obtained curves of the heat-treated states pertinent to the particular temperature values. Figure 2 shows the DTA curves.

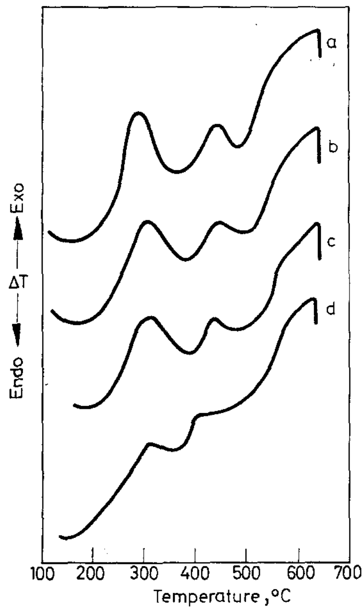


Fig. 3. DTA curves of materials treated. a: at 520° and quenched; b: at 460° and quenched; c: in continuous heat-treatment apparatus; d: at 420° and quenched

In order to decide whether the alloying elements have dissolved to the necessary extent in the wire passed through the continuous heat treatment, a comparative set of curves were prepared. Samples from the material of identical batch number were heat treated between 280–600°, and their thermal curves were then taken. The curves were drawn below each other in the manner to be seen in Fig. 2 in the sequence of decreasing temperature of heat treatment.

The DTA curve (c) of the material adequately processed by passage through the continuous heat-treatment apparatus is shown in Fig. 3. The temperature range in which the tested material can be fitted has been selected. From the curves it can be ascertained that the quality of the heat-treated state of the tested sample is lower than that of the sample treated at 520° (a), but higher than that of that treated at 420° (d). It resembles that heat treated at about 460° (b) in the laboratory. Technological practice shows that this temperature is sufficient for wire processing.

With the help of the set of curves a qualitative question arising in the course of the technological checking has been clarified.

The tensile strength of continuous heat-treated wire changed along the processed wire. We found this property to be suitable in certain sections, and too low in other sections. Fluctuation of the tensile strength values might be caused by significant inhomogeneity in the composition of the material, or by the heat treatment of the basic material not beeing adequate in all sections of the wire. However, on the basis of chemical analyses the material can be considered as homogeneous, and therefore inhomogeneity cannot cause the variation in the tensile strength values. The measured data are shown in Table 2.

It can be seen from the DTA curves that the dissolution has hardly started in the sections of low tensile strength, while in the material of adequate tensile strength it has taken place to the required extent (Fig. 4). The cause of the fault

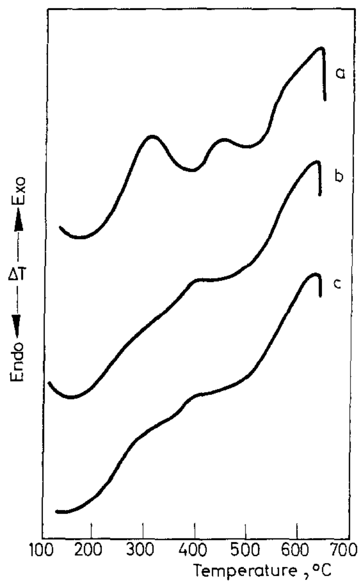


Fig. 4. DTA curve of the dissolution heat-treated basic material in the continuous heat-treatment apparatus: a: of adequate tensile strength; b: of low tensile strength; c: cast-rolled basic material

Table 2

| | Iron % | Magnesium % | Silicon % | Tensile strength kp/mm² |
|---|---|---|---|---|
| Basic material | 0.14 | 0.42 | 0.44 | 12.3 |
| Material of low tensile strength after continuous heat treatment | 0.12 | 0.40 | 0.43 | 11.8 |
| Material of adequate tensile strength after continuous heat treatment | 0.12 | 0.40 | 0.41 | 14.8 |

(as discovered during examination of the technological heat-treatment apparatus) was found to be the imperfect contact between the material and the receiving heads ensuring the current transmission.

## Discussion

Besides aluminium E AlMgSi alloy is also used as the basic material for overhead lines. Processing of this temper-grade alloy consists in the dissolution treatment of the base wire. Together with the usual tensile strength and resistivity measurements, DTA gives more accurate information about the physical state of the alloy. According to the results given here, the DTA method is suitable for following the process occurring in the course of the heat treatment of AlMgSi alloys; it is therefore suitable for checking the technological dissolution treatments as well. As an example, the degree of heat treatment attained with the continuous heat-treatment apparatus used by our company was examined.

The method is naturally suitable for checking not only the basic materials of AlMgSi used in the cable industry, but also the phase changes resulting from the heat effects of alloys with similar compositions, used for other purposes.

## References


1. A. Lutts, Acta Met., 7 (1961) 587.
2. G. Thomas, J. Inst. Phys., 90 (1962) 57.
3. C. Panseri and T. Federighi, J. Inst. Met., 94 (1966) 99.
4. D. W. Pasheley, J. W. Rhodes and A. Sendore, J. Inst. Met., 94 (1966) 41.
5. I. Kovács, J. Lendvai and E. Nagy, Acta Met., 20 (1972) 975.
6. Miyanchi Tadakazu, Fujikava Shinin Mirő and Hirano Kenichi, Light Metal, 21 (1971) 565.
7. P. Skalicki and H. Oppolzen, Z. Metallkunde, 63 (1972) 73.
8. S. Komatsu, T. Onishi and Y. Murakami, Jap. Inst. Met. Trans. 14 (1973) 347.
9. T. Hirata and S. Matsuo, Jap. Inst. Met. Trans., 12 (1971) 101.
10. J. Hajdu, L. Kertész, Cs. Lénárt and E. Nagy, Crystal Lattice Defects, 5 (1974) 177.
11. L. Kertész, Cs. Lénárt and M. Kovács-Treer, (under publication).
12. L. Kertész, Cs. Lénárt and M. Kovács-Treer, (under publication).


Résumé — Etude par ATD des changements de phases dans l'état solide de l'alliage E AlMgSi et des processus de dissolution et de précipitation. Les résultats peuvent être appliqués au contrôle des paramètres technologiques des traitments thermiques.

Zusammenfassung — Die Autoren erörtern die Phasenänderungen in festem Zustand in E AlMgSi-Legierungen. Die Lösungen- und Fällungsvorgänge werden mittels der DTA-Methode untersucht, wodurch die Versuchsegebnisse bei der Kontrolle der technologischen Parameter der Hitzebehandlung von Lösungen eingesetzt werden[5]können.

Резюме — Обсуждаются фазовые изменения сплава E AlMgSi, в твердом состоянии. С помощью метода ДТА исследованы процессы растворения и осаждения. Полученные результаты могут быть применены для контроля технологических параметров тепловой обработки.