Mn, Ti, Fe EFFECT ON HOT SHORTNESS OF Al-Cu-Mg SYSTEM ALLOY LOCATED IN PHASE REGION α-S

E.F.Chirkov

VIAM, 17 Radio Street, 107005, Moscow, Russian Federation

ABSTRACT: Using the example of model alloy from phase region α-S of aluminium angle of system Al-Cu-Mg, the effect of additions Mn (0 ... 1%), Ti (0 ... 0.5%), and Fe (0.15 ... 0.6%) on hot shortness is shown. Use of mathematic planning and of experimantal results processing made it possible to plot diagrams of distribution of hot shortness level lines of model alloy investigated compositions in relation to transition metal addition content in them.

Keywords: *hot shortness; Al-Cu-Mg system; α-S region; Mn, Ti, Fe effect.*

INTRODUCTION

One of the main research problems in the field of aluminium alloys is the problem of their hot cracking susceptibility. The success in solution of some tasks of this problem greatly influences the following: quality and competitiveness of the developed alloys, profitability of metallurgical production of semiproducts and parts of aluminium alloys, reliability and serviceability of complicated expensive welded structures of aerospace and the other branches of engineering industry.

Recently, a great number of articles and monographs were published on hot shortness investigations. The analysis of them enables to devide them into several main considerable directions (mentioning some publications which are of interest for the present article):

- laboratory investigations of hot shortness of concentration regions in aluminium angles of two-, three-, four-component systems of alloying [1, 2, 3, 4, 5, 6];
- laboratory investigations of certain model or industrial alloys [1, 4, 7, 8];
- laboratory and production investigations of hot crack formation during industrial alloy ingot casting at alloying change within the established chemical compositions [4, 9, 10, 11, 13];
- laboratory and industrial investigations of tendency to hot crack formation during the welding of certain industrial alloys [4, 7, 11, 12].

In monographs [4, 7, 11] the investigation results on several of above mentioned directions are often represented.

As the conditions of crystallization process are of great difference during large industrial ingot and welded joint casting, some time, many investigations and discussions were necessary before metal scientists, foundry men and welding operators made a conclusion concerning unity of objective laws of hot shortness for the both processes [11]. Comparative investigations carried out by the author of this article with the help of experimental alloys of Al-Cu-Mg system using casting and welding samples [12] demonstrated correlation of values for these two kinds of a sample. These results enabled the author to extrapolate to the welding processes the objective laws obtained on the casting sample; subsequently it was confirmed by practice.

This work concerns the second direction in the proposed classification of work on investigation of aluminium alloy hot shortness problems.

EXPERIMANTAL

The proposed work is a part of a large complex investigation of hot shortness and fluidity of aluminium angle concentration region of Al-Cu-Mg system containing practically all existing commercial alloys of this system. Partially, the results of this systematized investigation have been published already [6, 12, 14]. In the previous publications, aluminium alloys were used which in addition to Cu and Mg contain Mn, Fe, Ti and Si additions in strictly fixed constant percentage. It made it possible to obtain results maximum close to commercial alloys. The task of the proposed work was as follows: to investigate, using one model alloy (Al, Cu, Mg), the effect of alloying additions Mn and Ti mostly used in industrial alloys, and the effect of inevitable impurity Fe on aluminium alloy hot shortness for the investigated region of Al-Cu-Mg system.

The investigations were carried out using model alloy (Al, Cu, Mg) located in phase region α-S and having low level ($\approx$ 5 mm) of hot shortness determined with the help of standard circular casting sample. Alloy phase composition was of solid solution (α) and phase S (Al_2CuMg).

The used additions content was strictly regulated: for Mn - 0; 0.5; 1.0%, for Ti - 0; 0.125; 0.25; 0.375 and 0.5%, for Fe - 0; 0.15; 0.3; 0.45; 0.6%. For alloy preparation, increased purity aluminium was used. Alloy hot shortness was determined using standard circular casting sample which had been cast in sand mould where hot shortness value corresponds to the thickness (in mm) of the first ring on which hot crack appeared during crystallization. On the whole, 81 alloys were investigated, and about 400 samples were cast. Prepared alloy volume was always the same. Technology of preparation, pouring, alloying component content were controlled thoroughly, 4-5 samples were cast in each experimental point. Alloys were manufactured in electric furnaces with air atmosphere, in graphite crucibles.

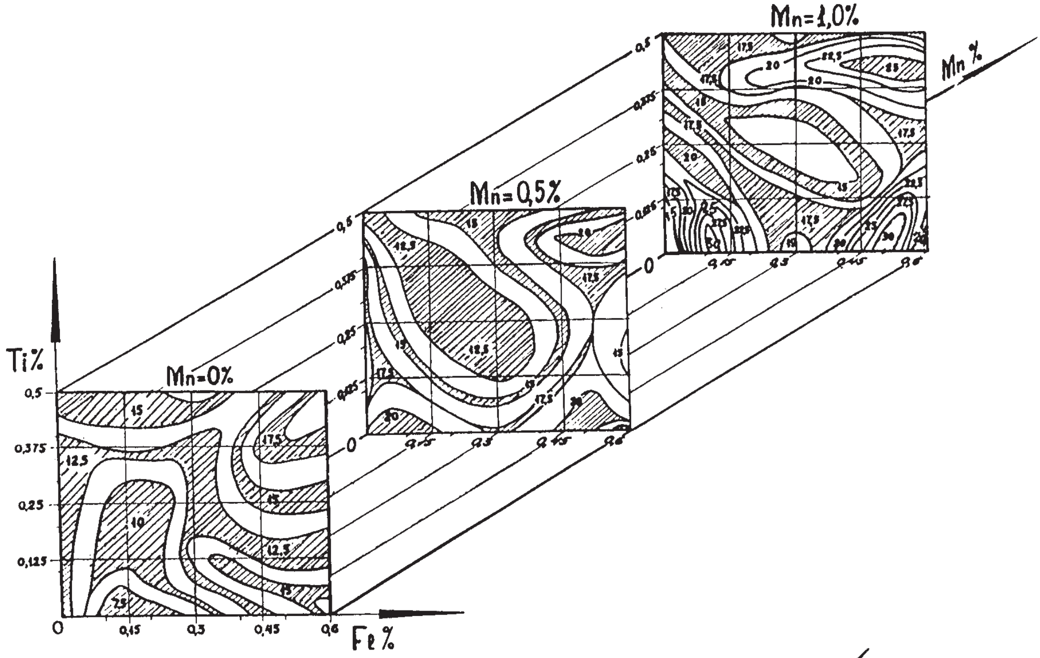
The work was carried out using experiment planning (Scheffe simplex-plans). The method of simplex lattices is widely used for investigation of "content-properties", however, in case of polynominal model use, thorough working out of experiment methodology is of great importance, and it was fulfilled completely.

RESULTS AND DISCUSSION

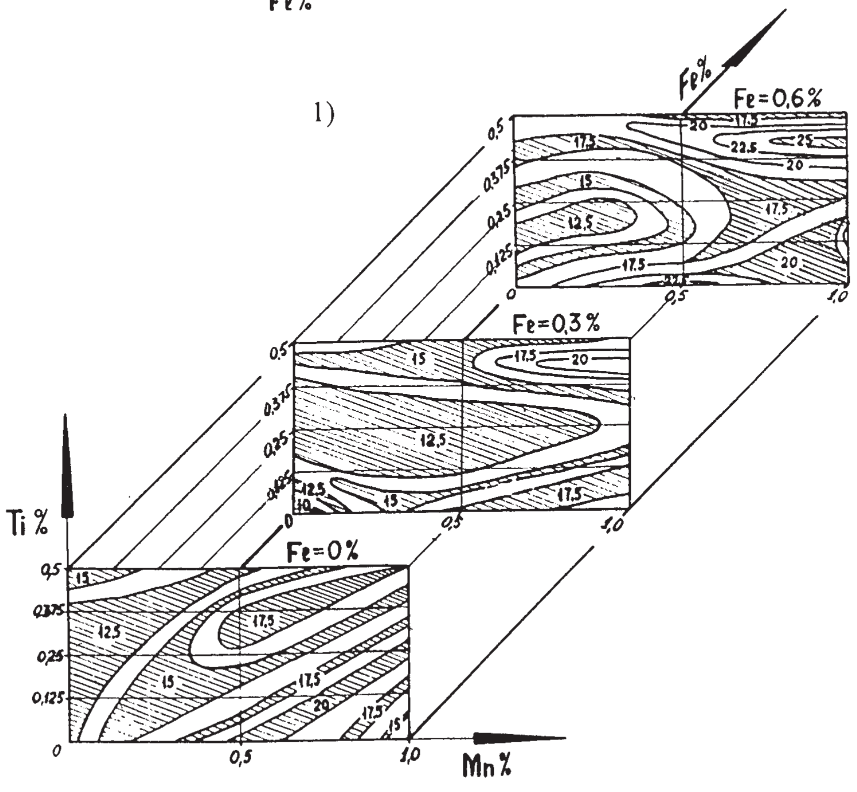
In Fig. 1, model alloy hot shortness change character in relation to Mn, Ti, and Fe additions content is shown graphically. In the first main part of Fig. 1, 3 planes are located, and each of the planes corresponds to Mn constant content (0; 0.5; 1.0%) in model alloy and is restricted by Ti and Fe concentration axes. On the surface of each of the planes, hot shortness level regions are shown; here, hot shortness is a function of alloying of Ti and Fe model alloy. Hot shortness level regions are formed by projections of response surface intersection lines (hot shortness value surface) with hot shortness level horizontal planes (e.g.: 10 mm; 12.5 mm; 15 mm, etc, with spacing of 2.5 mm). In the second and in the third parts of Fig.1, auxilliary concentration planes are represented with hot shortness levels for better understanding of this characteristic change during joint effect of Mn, Ti, and Fe. In the course of auxilliary graphic representations plotting, data of the first main part of Fig. 1 were used.

Analysis of test results shows that model alloy hot shortness value (K) changes within wide range of values (7.5 - 30 mm) at the selected range of Mn, Ti, and Fe additions. In case **of Mn lack** and at minimum values of Ti (0 ...0.5%) and Fe (0.7 ... 0.22%), hot-shortness value is the lowest: 7.5 mm. Region of relatively low values of hot-shortness (10 ... 12.5 mm) is found at Ti content up to 0.35% and Fe up to 0.45%.

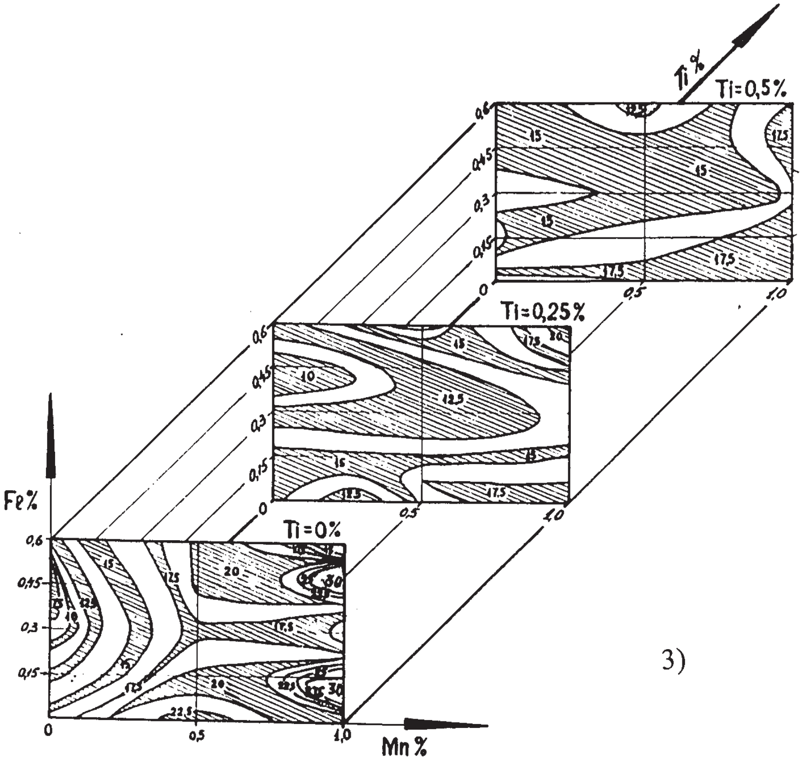
In case of Ti content increase from 0.35% to 0.5%, and Fe content increase from 0.45% to 0.6%, **(at Mn = 0)**, hot shortness values reach 15 ... 17.5 mm. After 0.5%, and especially 1% of Mn introduction into alloy, its hot cracking susceptability increases.


Mn=1,0%
Mn=0,5%
Mn=0%
Mn %
Ti%
Fe %
0,5
0,375
0,25
0,125
0
0,15
0,3
0,45
0,6

1)


Fe%
Fe=0,6%
Fe=0,3 %
Fe=0%
Ti %
Mn %
0,5
0,375
0,25
0,125
0
0,5
1,0

2)



3)

Fig. 1 (1, 2, 3). Distribution of hot shortness value levels of the model alloy depending on relation of Mn (0. ..1%), Fe (0. ..0,6%), Ti (0...0,5%) additional alloying.

Thus, in case of **0.5% of Mn content**, low values of hot-shortness (7.5 ... 10 mm) disappear, and the values of mean quantity (12.5 mm) appear, but in narrow concentration range - in Ti alloy they are ≈ 0.125 ... 0.38%, and in Fe alloy they are ≈ 0.1 ... 0.4%. Here, two concentration regions appear with increased (15 ... 20 mm) values of hot shortness: the first one at Ti ≈ 0 ... 0.25% and Fe ≈ 0 ... 0.15%, and the second one at Ti ≈ 0 ... 0.5% and Fe ≈ 0.45% ... 0.6%.

In case of **Mn content increase to 1%**, model alloy hot cracking susceptability increases at all investigated contents of Ti (0 ... 0.5%) and Fe (0 ... 0.6%). In this case, the lowest value of hot shortness equals 15 ... 17.5 mm, and it is observed in narrow concentration region of Ti (≈ 0.125 ... 0.3%) and of Fe (≈ 0.15 ... 0.45%). Considerable increase of hot shortness value (from initial ≈ 5.0 mm) to 25 ... 30 mm is observed at low content of Ti (0 ... 0.125%) and low (0 ... 0.2%) and high (0.4 ... 0.6%) content of Fe.

In case of high content of **Mn (1%)** and Ti (≈ 0.38 ... 0.5%), model alloy increased tendency to hot shortness is observed practically for all investigated Fe contents (0 ... 0.6%); here, Fe highest hot shortness values correspond to ≈ 0.35 ... 0.6%.

For more concrete conclusions concerning Mn, Ti, and Fe effect on model alloy hot shortness, comparison of results was carried out for effect of collating content of these elements in alloy (Fig. 1, 1, 2, 3): e.g. Mn - 0.5%; Ti - 0.5%; Fe - 0.6%, and Ti - 0.25% and Fe - 0.3%. This comparison showed that the character of effect on the change of tendency to alloy hot-shortness remains; to decrease this effect, the elements could be arranged as follows: Mn, Fe, Ti.

The results of the fulfilled investigation enabled to establish certain law depending on tendency to hot shortness of alloy of Al-Cu-Mg system, (phase region α-S) and on Mn, Ti, and Fe content in the alloy. Additional investigations carried out on this system alloys, but with the other (in comparison with the investigated alloy) content of Cu and Mg, confirmed the character of alloys hot shortness dependence on the degree of alloying them with Mn, Ti, and Fe.

The results of the proposed work represent certain interest for metallurgists and welding operators, because they can contribute to correct establishment of optimum content of such transition metals as Mn, Ti, and Fe in system Al-Cu-Mg alloys in order to decrease reject during casting and welding, and to increase reliability and serviceability of engineering industry structures.

CONCLUSIONS

1. Hot shortness level line distribution diagrams were plotted for model alloy (Al, Cu, Mg) at the contents of Mn - 0; 0.5 and 1%, Ti - 0 ... 0.5%, Fe - 0 ... 0.6%.

2. The laws of model alloy tendency change depending on Mn, Ti, and Fe content in it were established:

- in case of Mn increase from 0 to 1%, hot shortness value decreases by ≈ 5-6 times and reaches 25-30 mm;
- the less effect on hot shortness increase (increase by ≈ 3-4 times) is exercised by Fe content (0... 0.6%) - hot shortness value reaches 15-25 mm;
- the lowest effect is exercised by Ti content - from 0 to 0.5%. It results in increase of hot shortness values only by 2.5-3 times (up to 12.5-15 mm);
- the character of the above mentioned transition metals effect on experimental alloy remains at comparison of their collated concentrations: Mn - 0.5%, Ti - 0.5%, Fe - 0.6%, and Ti - 0.25%, Fe - 0.3%.

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