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# Primary Structure and Mechanical Properties of AlSi2 Alloy Continuous Ingots

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## Abstract

The paper presents the research results of horizontal continuous casting of ingots of aluminium alloy containing 2% wt. silicon (AlSi2). Together with the casting velocity (velocity of ingot movement) we considered the influence of electromagnetic stirring in the area of the continuous casting mould on refinement of the ingot's primary structure and their selected mechanical properties, i.e. tensile strength, yield strength, hardness and elongation. The effect of primary structure refinement and mechanical properties obtained by electromagnetic stirring was compared with refinement obtained by using traditional inoculation, which consists in introducing additives, i.e. Ti, B and Sr, to the metal bath. On the basis of the obtained results we confirmed that inoculation done by electromagnetic stirring in the range of the continuous casting mould guarantees improved mechanical properties and also decreases the negative influence of casting velocity, thus increasing the structure of AlSi2 continuous ingots.

**Keywords:** Continuous casting, Aluminum, Silicon, Inoculation, Electromagnetic stirring

## 1. Introduction

Alloys from the Al-Si group are used in different industrial branches, e.g. in the automotive industry. These alloys are characterised by low density, a relatively low melting point, and good thermal and electrical conductivity. Moreover, they have good mechanical and foundry properties, i.e. high castability and small casting shrinkage, good machinability and relatively good corrosion resistance. However, a significant disadvantage of these alloys is their propensity to create a coarse-grain structure. Therefore, Al-Si alloys require inoculation of their structure by using additives of Na, Sr, Sb and Ti, B, C. The mechanism of this type of inoculation is presented in detail in papers [1÷7].

Another method of structure refinement is to use forced liquid metal movement during its solidification which results from the influence of electromagnetic stirring. The mechanism of this type of inoculation is based on mechanical and thermal erosion of the crystallisation front as presented in detail in papers [3, 8÷11].

Moreover, the continuous casting process can be used to produce Al-Si alloy ingots. This technology, usually used in the production of Fe [12÷14], Al [15÷18] or Cu [19 and 20] alloys, is characterised by high yield and quality ingots as a semi-product generally for plastic deformation or machining. The quality of continuous ingots in comparison to traditional gravity casting with the use of an ingot permanent mould concerns refinement and a uniform ingot structure, which results from solidification of metal in water cooled in a continuous casting mould.

Therefore, the aim of the studies was to determine the influence of casting velocity in a horizontal continuous casting process and inoculation with the use of an electromagnetic field on structure refinement and selected mechanical properties, i.e. tensile strength, yield strength, hardness and elongation of a continuous ϕ30 mm ingot of the AlSi2 alloy. The effect of structure refinement and mechanical properties obtained by the influence of electromagnetic stirring was compared with refinement obtained by using traditional inoculation which consisted in introducing additives, i.e. Ti, B and Sr, to the metal bath.

## 2. Range of studies

Table 1 presents the chemical composition of the studied AlSi2 alloy. The chemical composition of the studied alloy makes it possible to classify it to the group of Al-Si alloys for the plastic deformation EN AW-AlSi2Mn grade according to standard PN-EN 573-3. According to standard PN-EN 573-4 this alloy is intended for rolled products, e.g. strips, sheets and plates. Moreover, it is possible to classify this type of cast alloy EN AC-AlSi2MgTi grade according to standard PN-EN 1706. These ingots are intended for machining products, i.e. shafts or sleeves.

Table 1.
Chemical composition of the studied ingots of the AlSi2 alloy

| The content of components, % wt. | | | | |
|---|---|---|---|---|
| **Si** | **Mn** | **Fe** | **Mg** | **Ti** |
| 2,00 | 0,50 | 0,50 | 0,40 | 0,05 |
| **Cu** | **Zn** | **V** | **Ni** | **Al** |
| 0,20 | 0,10 | 0,03 | 0,01 | rest |

Figure 1 presents a view of the horizontal continuous casting process conducted at the Department of Foundry Engineering of the Silesian University of Technology. A description of this stand for horizontal continuous casting of Al and its alloys is presented in detail in paper [18].

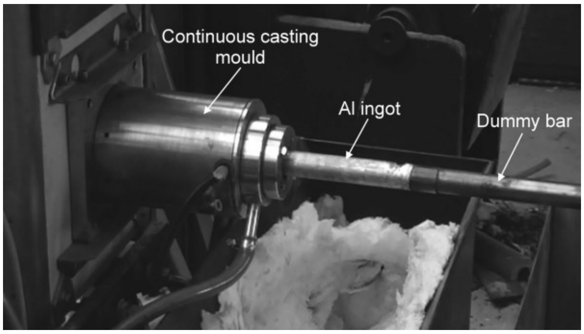



Fig. 1. View of the horizontal continuous casting process of the AlSi2 alloy

In the study presented here the applied method of ingot movement, defined as a combination of motion forward in time of 1 s at a velocity from 100 to 300 mm/min and stopping after 2 s. As a result of the presented method of ingot movement in the combination forwards/stop/forwards/stop/etc. we obtained an average casting velocity from 30 to 100 mm/min. Depending on the used velocities the temperature of the cooling water in the continuous casting mould was set to 45÷55 °C and the temperature of the ingot after leaving the continuous casting mould was equal to 150÷300 °C.

For inoculation using a electromagnetic field (IEF) we used an electromagnetic stirrer placed in a continuous casting mould. In the studies we applied a rotating electromagnetic field with induction 60 mT generated by a stirrer supplied with a current of 8A at a frequency of 100Hz.

Moreover, we used traditional inoculation which consisted in introducing additives, i.e. Ti in an amount of 0.1% wt. and B in an amount of 0.02 %wt. to the metal bath in the form of master alloy AlTi5B1 and Sr in an amount of 0.01% wt. in the form of master alloy AlSr10 (IA).

The degree of primary structure refinement of the AlSi2 alloy continuous ingots, also in initial state i.e. without inoculation (IS) was represented by the average area of equiaxed macro-grain (PKR). Macroscopic metallographic studies on the transverse section of the continuous ingots were carried out as refinement measurements in the AlSi2 alloy structure. The analysed surface for macroscopic analysis was etched with the use of a solution of 50g Cu, 400ml HCl, 300ml $HNO_3$ and 300 ml $H_2O$. The mechanical properties of the studied continuous ingots, i.e. tensile strength, yield strength and elongation, were determined on the basis of a tensile test of five-tuple samples 10 mm in diameter with the use of the VEB10T universal testing machine. Moreover, hardness of the ingots was determined using the Brinell method.

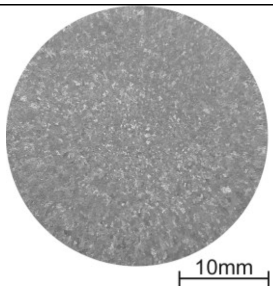
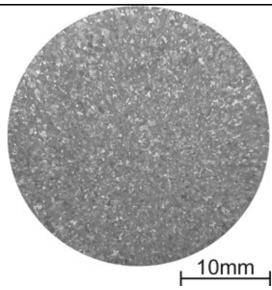
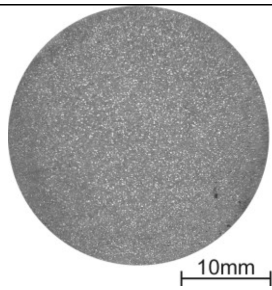
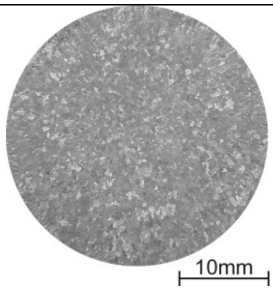
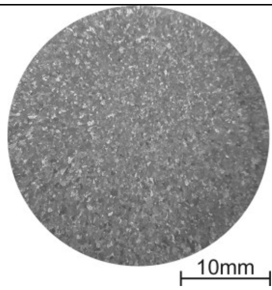
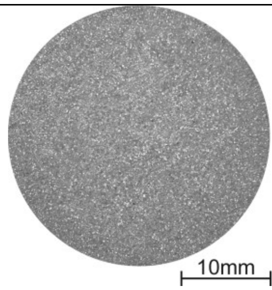
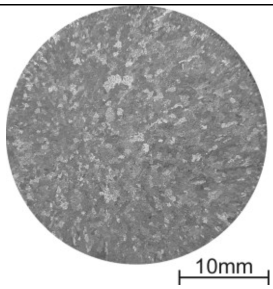
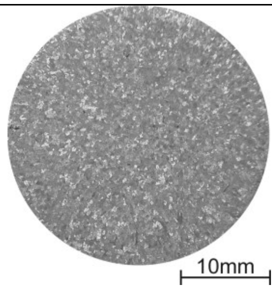
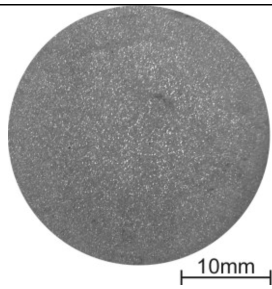
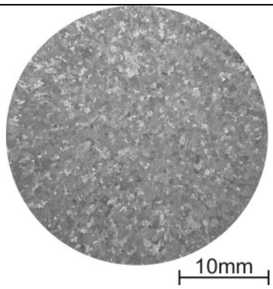
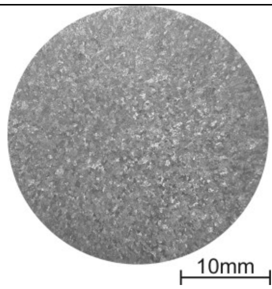
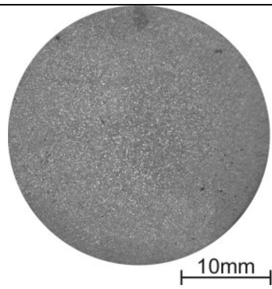
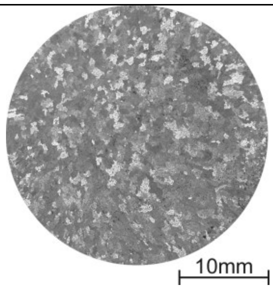
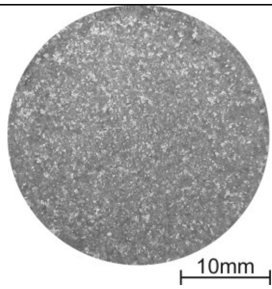
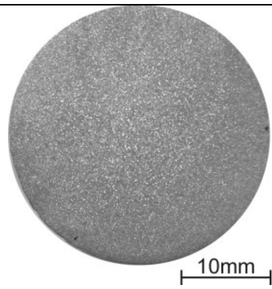
## 3. Results of studies

Table 2 presents the primary structures of the AlSi2 alloy's continuous ingots in initial state (IS), after inoculation with the use of electromagnetic stirring (IEF) and after traditional inoculation with the use of Ti, B and Sr additives (IA). Tab. 3 and Fig. 2 present the results of measurements of parameter PKR representing structure refinement.

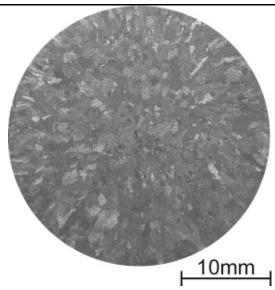
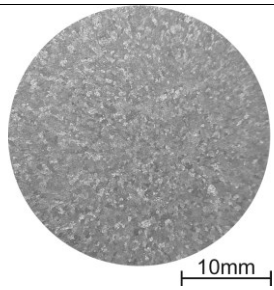
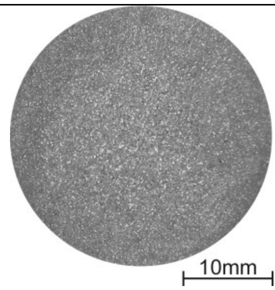
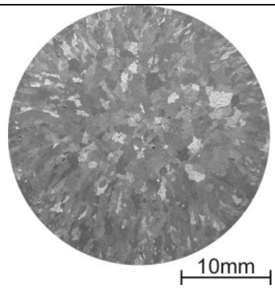
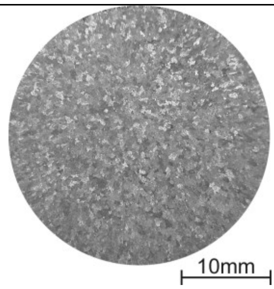
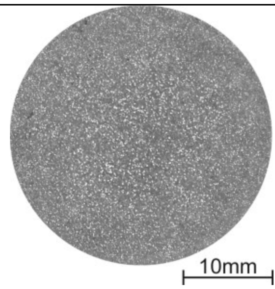
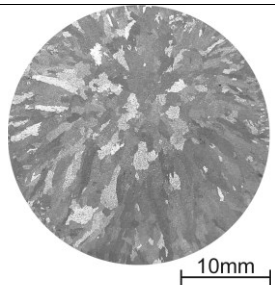
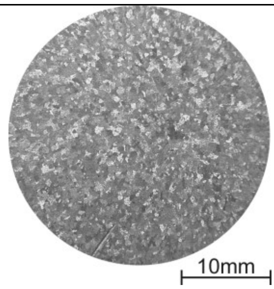
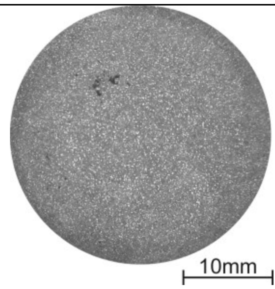
On the basis of the obtained results, it was confirmed that increasing the velocity of ingot movement in horizontal continuous casting of the AlSi2 alloy causes an unfavourable increase in the average area of macro-grain PKR due to a reduced temperature gradient at the crystallisation front. As a result, for ingots in initial state the primary structure transforms from relatively equiaxed fine-grained at small velocities through equiaxed coarse at medium velocities to coarse containing equiaxed and columnar macro-grains at high velocities. This unfavourable tendency decreases as a result of the use of electromagnetic stirring in the area of solidification of liquid AlSi2 alloy in a continuous casting mould. In this case at high velocities there are no coarse columnar macro-grains. Similarly, the use of traditional inoculation with the additives of Ti, B and Sr guarantees that a uniform and fine-grained primary structure of AlSi2 continues ingots will be obtained independently of the applied casting velocity.

Fig. 3 and Tab. 3 present the results of studies concerning the mechanical properties of AlSi2 alloy continuous ingots. On the basis of the obtained results, it was confirmed that in comparison to the initial state, inoculation with the use of electromagnetic stirring guarantees an increase in the strength of AlSi2 alloy continuous ingots, i.e. tensile strength increased by 17%, yield strength increased by 30% and hardness increased by 10%, at a very small decrease in toughness, i.e. elongation decreased by 5%. The application of inoculation with the use of Ti, B and Sr additives is more advantageous from the point of view of strength properties because in comparison to the initial state the tensile strength increased by 25%, yield strength increased by 50% and hardness increased by 40%. However, simultaneously a decrease is present in toughness, i.e. elongation decreased by 25%.

Table 2.
Primary structures of continuous ingots of the AlSi2 alloy

| Average casting velocity of ingot V, mm/min | In initial state without inoculation (IS) | After inoculation with use of electromagnetic stirring (IEF) | After inoculation with use of Ti, B and Sr additives (IA) |
|---|---|---|---|
| -1- | -2- | -3- | -4- |
| 30 |   |   |   |
| 40 |   |   |   |
| 50 |   |   |   |
| 60 |   |   |   |
| 70 |   |   |   |

continuation of Tab.2

| -1- | -2- | -3- | -4- |
|---|---|---|---|
| 80 |  |  |  |
| 90 |  |  |  |
| 100 |  |  |  |

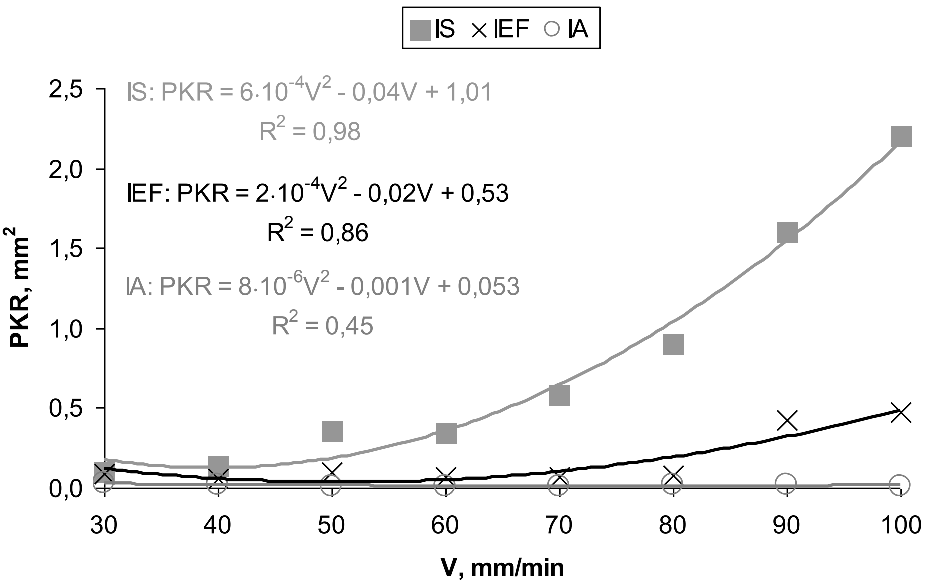



Fig. 2. Influence of the average casting velocity (V) on the average area of equiaxed macro-grain (PKR) of the AlSi2 alloy's continuous ingot in different states of inoculation

Table 3.
Results of the average area of equiaxed macro-grain (PKR) measurements in primary structure and mechanical properties of AlSi2 alloy continuous ingots in dependence of the average casting velocity (V) and type of inoculations (IS, IEF or IA)

| V, mm/min | IS | | | | | IEF | | | | | IA | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PKR, $mm^2$ | TS, MPa | YS, MPa | Elong., % | HB | PKR, $mm^2$ | TS, MPa | YS, MPa | Elong., % | HB | PKR, $mm^2$ | TS, MPa | YS, MPa | Elong., % | HB |
| 30 | 0.10 | 150 | 64 | 12 | 65 | 0.09 | 166 | 76 | 13 | 65 | 0.03 | 170 | 82 | 9 | 80 |
| 40 | 0.14 | 156 | 65 | 11 | 68 | 0.06 | 165 | 75 | 12 | 65 | 0.02 | 172 | 80 | 9 | 80 |
| 50 | 0.36 | 145 | 60 | 12 | 65 | 0.10 | 165 | 72 | 12 | 65 | 0.01 | 175 | 87 | 9 | 85 |
| 60 | 0.35 | 140 | 58 | 12 | 61 | 0.07 | 168 | 80 | 11 | 70 | 0.01 | 175 | 85 | 9 | 80 |
| 70 | 0.58 | 140 | 60 | 12 | 65 | 0.07 | 170 | 85 | 10 | 70 | 0.01 | 180 | 93 | 7 | 90 |
| 80 | 0.90 | 136 | 58 | 11 | 55 | 0.08 | 165 | 78 | 10 | 70 | 0.02 | 170 | 80 | 9 | 80 |
| 90 | 1.60 | 120 | 45 | 12 | 50 | 0.42 | 150 | 60 | 11 | 60 | 0.02 | 171 | 80 | 9 | 80 |
| 100 | 2.20 | 132 | 51 | 11 | 56 | 0.47 | 155 | 65 | 10 | 65 | 0.01 | 177 | 85 | 8 | 85 |

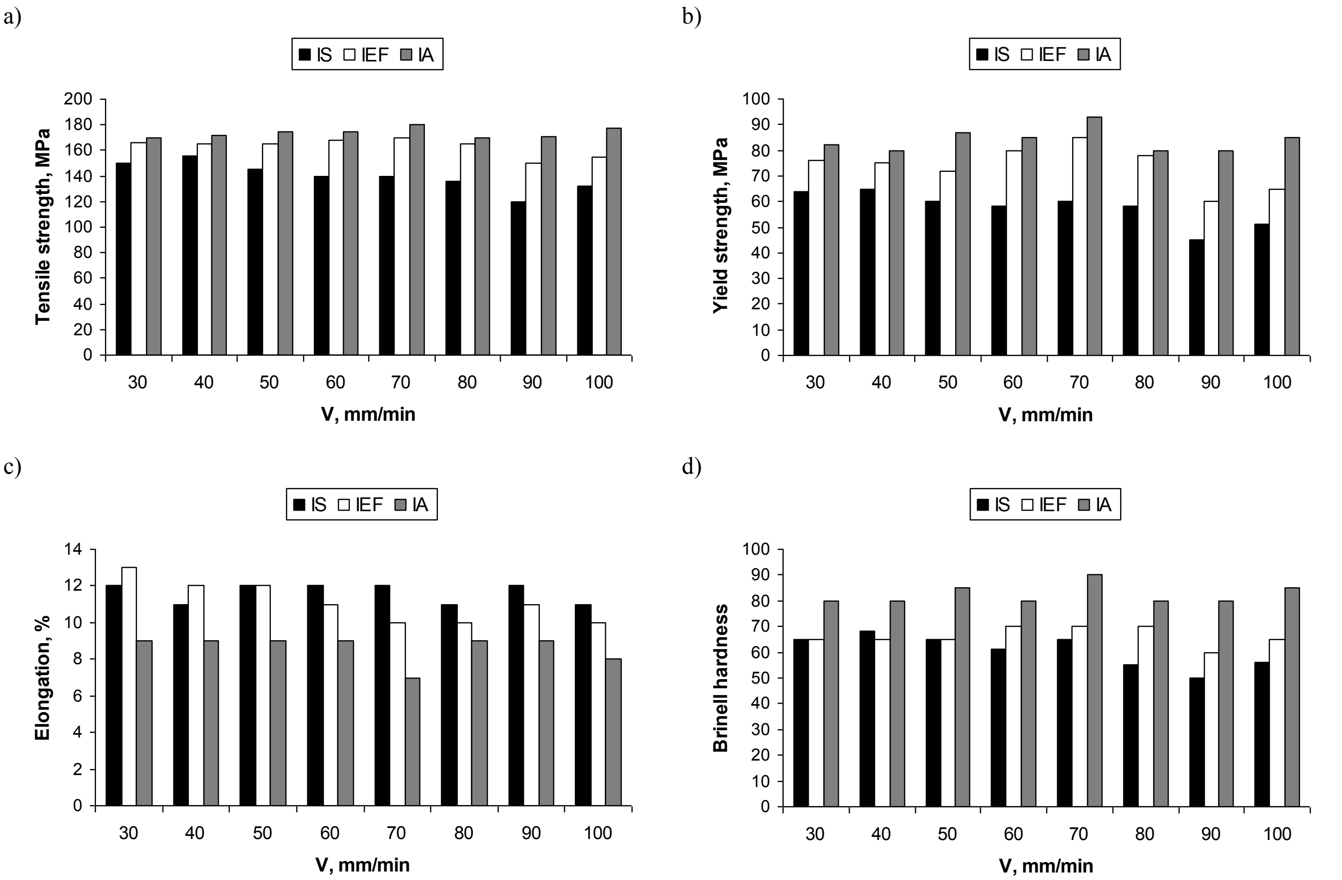



Fig. 3. Mechanical properties of AlSi2 alloy ingots in the dependence of inoculation type and casting velocity in the horizontal continuous casting process

Summing up, on the basis of the results analysis it was confirmed that the both methods of inoculation guarantee obtaining a primary structure and, in consequence, mechanical properties corresponding to values proper for non-heat-treated alloy EN AC-AlSi2MgTi grade cast in a permanent mould according to standard PN-EN 1706, which are respectively: tensile strength 170MPa, yield strength 70MPa, elongation 5% and hardness 50HB. Moreover, obtained mechanical properties of ingots are larger to values proper for non-heat-treated alloy EN AC-AlSi2MgTi grade cast in a sand moulds according to standard PN-EN 1706, which are respectively: tensile strength 140MPa, yield strength 60MPa, elongation 3% and hardness 50HB.

## 4. Conclusions

Based on the conducted studies the following conclusions have been formulated:

1. Increasing the average casting velocity has a negative influence on the primary structure of the AlSi2 alloy continuous ingot. However, sensitivity of structure on changes in the velocity of ingot movement in the horizontal continuous casting process can be reduced by using inoculation via electromagnetic stirring or mainly by the addition of Ti, B and Sr.
2. Inoculation done by electromagnetic stirring in the range of the continuous casting mould guarantees improvement in the primary structure refinement and mechanical properties of AlSi2 alloy continuous ingots.
3. Although traditional inoculation guarantees larger refinement of primary structure and values of the obtained strength properties of the AlSi2 alloy continuous ingot than the method of structure refinement based on thermal and mechanical erosion of the crystallisation front as caused by the influence of the electromagnetic field on the solidifying metal, there may be competition for inoculation with additives, e.g. Ti, B and Sr, especially from the point of view of the cost of the inoculation process.

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