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Physical Modelling for Solidification Processes of Bi and its Alloys Using Peltier Effect

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Abstract

The solidification process were investigated for Bi and BiPb eutectic alloy in cases when direct electric current are applied normally to solidifying surface. Modelling processes include measuring of temperature and solidification speed for various electric current density. It is shown that due too high Peltier coefficient of Bi is possible to increase solidification speed. There where discussed other Peltier effect influences in MHD processes.

Introduction

It is well known that thermoelectric properties of metals are used in various measuring devices. One of such devices are thermocouple that can be used for temperature measuring in wide interval of temperature. If temperature of two different metals contact region are increased than the electric potential difference between contact appeared. It allowed to transfer heat energy straight to electric power. Thermo electrical effects appear not only between various metals, bat also in the same metal if phase transition take place.

In [1] the theoretical calculation were done that shown possibly to control solidification process using Peltier effect. Because the calculation where done for pure metals and in real cases the thermo physical properties of metal in solid and liquid phases is not very exactly known [2] we experimentally investigate solidification process using simple models. If two metals one contact is at temperature T_2 and other one at T_1 , the thermo electromotive force appears

$$E = \alpha(T_2 - T_1),$$

where α – thermo electromotive coefficient between both metals. It induces thermoelectric current if the two metals made closed loop. The current direction is defined by thermo properties of contacting metals. If in the same direction the external current is applied it causes the heat energy Q in contact region

$$Q = \Pi I,$$

where Π is the Peltier coefficient and I- the external current.
The $\Pi = \alpha T$, where T is the absolute temperature of contact between two metals or one metal in solid and liquid state. The energy or heat Q could be positive or negative. It means that contacting region are cooled or heated.

Experimental results

For experimental investigations the metal Bi were choose. It is because thermo electromotive coefficient of Bi is sufficiently high. In solid phase α_S ~ -55 μV/grad and in liquid phase α_L~ -5 μV/grad. The solidification temperature T_s is 544 °K and Peltier coefficient

$$.\Pi = (\alpha_S - \alpha_L)T_s = -0{,}027V \quad .$$

Near the solidification front the electric field direction are from solid phase to liquid. So, if the external current goes on that direction the solidification front were cooled due to Peltier effect. Such energy is proportional to current linearly. To measure such effect experimentally is not so easy because there are Joule heating effect that is proportional to I^2. Another problem are that thermo physical parameters is known only for clean metals. There where made a few experimental systems and found the acceptable method to investigable Peltier effect.

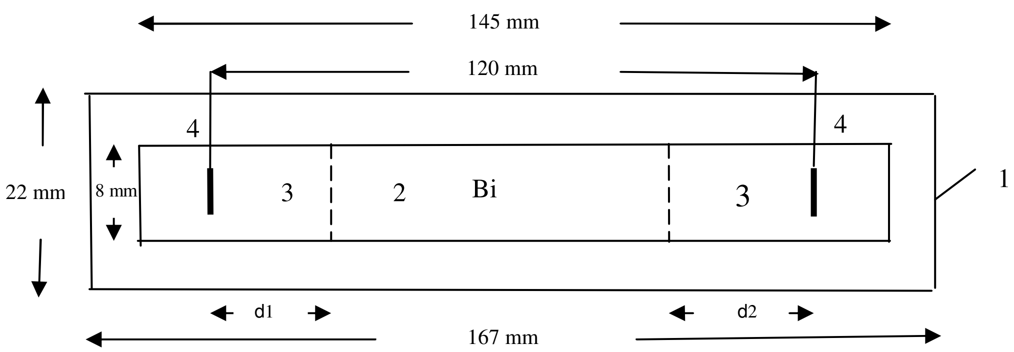

Fig. 1. Experimental system I. 1 – Al_2O_3 bath ; 2 – liquid Bi; 3 – solid Bi; 4 - electrodes.

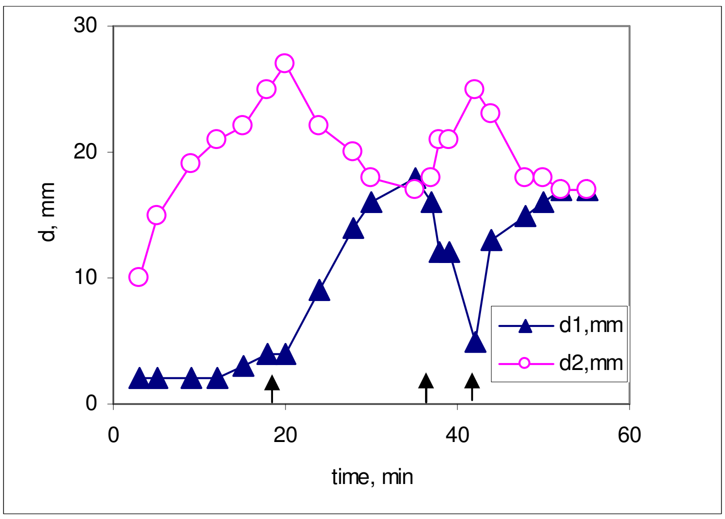

Fig. 2. Thickness of solid state Bi near anode and cathode in time when current 1 A/mm² is applied ↑- time when the current direction is changed.

One of the experimental system are shown on Fig.1. There where small Al_2O_3 bath with Bi heated from below. Heating regime were choose such, that there and back of the bath metal are in solid state but liquid in middle region. When such stationary state were achieved through two copper electrodes at both sides the direct current were applied. There were measured the solid state front changes in time.

Fig.2. shown how the solid state distances changed near both electrodes in time. At time axle the moment when the current direction is changed are marked. We can see that near the anode the solidification front increase but near cathode decrease. When the current direction are changed the situation is opposite. It looks like current absorbs heat energy near anode and transfers it to cathode.

Because some results changes that is due to systems geometry and heating process, the another system with optimal geometry where done Fig.3. In this cases the Bi cross section are reduced and the current density constant along the bath.

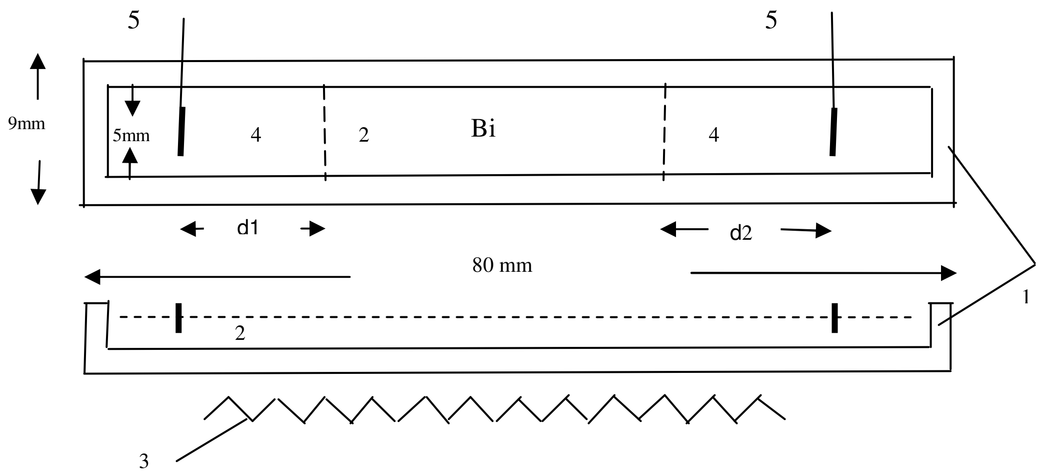

Fig. 3. Experimental system II. 1 – Al_2O_3 bath; 2 – liquid Bi; 3 – electric heater; 4 – solid Bi layer; 5- electrodes.

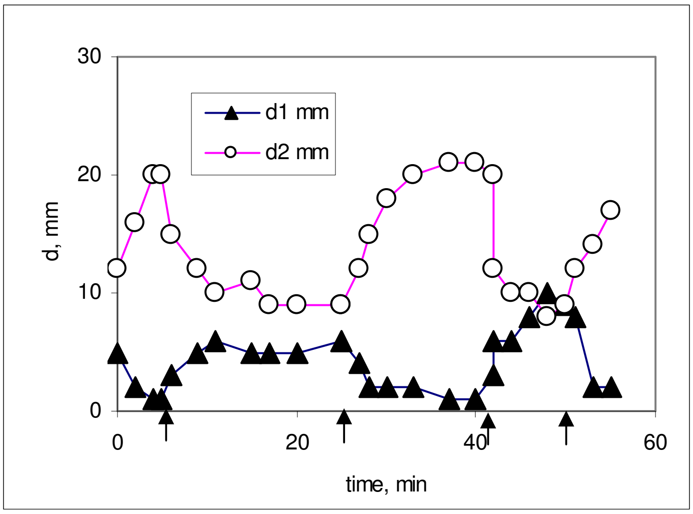

Fig. 4. Thickness of solid state Bi near the anode and cathode in time when current 1 A/mm^2 is applied. ↑ – time when the current direction is changed.

On Fig.4 are shown the results that have better repeatability. Experimentally results confirmed the theoretically predicted situation [1]. For current 1 A/mm^2 in [1] the increase of solidification front due to Peltier effect could be 0,026 mm/sec. In our cases Fig. 4. it is 0,013-0,02 mm/sec.

Such method with DC current can be used also in continuous casting processes when thermoelectric properties of the mould, liquid and solidified metal are different. One of the problem is when solidifying metal goes out of mould the solid layer sometimes is not enough thick hold the hydrostatic pressure. It could be sometimes accident breakthrough when ingot goes out of mould. The situation could be improved by DC current where anode are at mould and cathode in upper or lower part of ingot. In that cases we will have the stabilized solid layer in lower part of mould and it will avoid breakthrough and allow to increase the casting speed.

Another process where such effect need to be taken into account is MHD DC pumps. If we use such pump for liquid Bi and the temperature is not far from T_s than near the anode additional cooling can stimulate solidification or admixture deposition.

Because in nuclear physics the PbBi eutectic alloy is used there where idea to investigate Peltier effect to improve such eutectic producing. The idea were based on the Bi thermoelectric properties. We made a lot of experiments with PbBi eutectic alloy at different currents, but the results were to small to be detected compare with one using pure Bi. It is because the solidification temperature in that cases is lower and the Peltier coefficient ~ T_s smaller. Another reason is that in eutectic alloy the Bi are to bound chemical and its Peltier effects suppressed. Practically near anode and cathode the solidification front changed in the same way. There where statistically some small increase near the cathode.That shown that in PbBi eutectic alloy situation the Peltier effect is small and the main effect is Joule heating.

Conclusions

It is experimentally shown that Peltier effect can be used to control solidification process for Bi metal.

For PbBi eutectic alloys the influence on Peltier effect in solidification processes are too small to be practically used.

The results in principle can be used in continuous casting processes in cases when mould, solidified and liquid metal thermoelectric properties are different – in order to stabilize solid layer in lower part of mould and increase the speed. It can be achieved by DC current when anode are at mould and cathode in upper or lower part of ingot. It is when Peltier effect are significant.

References

[1] Иофе А. Ф. : Полупроводниковые термоэлементы. Ленинград. 1956, стр. 42-84.
[2] Вилсон Д.Р. : Структура жидких металлов и сплавов. Москва «Металлург», 1972 , 267 стр.

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