DIRECTIONAL SOLIDIFICATION OF Al-CU IN-SITU COMPOSITE

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ABSTRACT

Directional solidification was used to produce in-situ composite of an eutectic of Al-33% Cu alloy. The solidification process was achieved by isolating an ingot from all sides and cooling it from bottom only. Three cooling conditions were applied to obtain different temperature gradient, and various rates of growth.,namely, direct water spray cooling, indirect water cooled Cu-chill, and conventional cooling (i.e. casting in rammed magnezite mould).

The cast ingots were subjected to extensive metallographic studies, and to hardness and porosity measurements.

Results showed that morphology, porosity content as well as hardness are greatly influenced by temperature gradient and growth rates.

INTRODUCTION

Directional solidification of eutectics were first studied by Wineguard et al.[1]. The mode of solidification are influenced by temperature gradient of the liquid, as well as rate of growth of the solid at the solid / liquid interface. The regularity of an eutectic has a marked effect on its mechanical properties, and this become very important when it is required to control the orientation of the solidified phases in order to obtain in-situ composite [2,3]. Using a controlled heat flux technique, the eutectic phases can be caused to grow in a well aligned manner. This technique realizes coherency between the fibre and the matrix with a strong relative bonding which is a necessary condition for smooth stress transition from the matrix to the fibre. There are appreciable interest in the Al-Cu eutectic system as a composite material because a more or less perfect lamellar structure was expected to be obtained during its solidification, and for its wide industrial application as a structural material [4].

The purpose of the present study is to investigate the effect of temperature gradient as well as growth rate on the interlamellar spacing of directionally solidified Al-33% Cu eutectic alloy and their influence on porosity and hardness measurements.

EXPERIMENTAL PROCEDURE

Al-33% Cu eutectic alloy was prepared by adding pure Al to a master alloy of Al-50% Cu. The eutectic alloy was melted to a super heating temperature of 200°C over the alloy melting temperature (548°C). The melted alloy was directionally solidified using an enhanced cooling apparatus similar to that used by Versnyder and Guard [5].

Cylindrical mould opened from both bottom an top, made of rammed magnezite was used with 180 mm in height, and an inner diameters of 60 mm at the bottom and 90 mm at the top, to provide temperature gradient along the length (height) of the cast ingot. The ingot mould was highly isolated from all sides with asbestos sheets, then cooled from the bottom to provide directional solidification. Heat extraction was achieved either by direct water spray, or indirect water cooled Cu-chill [6]. For comparison, the melt was cast into a mould closed at the bottom made of rammed magnezite, to represent the conventional casting ingot, i.e. heat extraction was achieved from the three directions. During each casting process, continuous temperature data were recorded at sex points distributed along the ingot length from bottom to top using multifunction computerized instruments. The obtained data were used to determine the temperature gradient and the growth rate.

The cast ingots were sectioned into two halves. One half was used for macrostructural examination, and the other one was further cut horizontally from bottom to top at 2 cm intervals along the ingot length for microstructural studies, and porosity and hardness measurements. The porosity was measured by using the well known Archimede's rule, more details can be found elsewhere [6].

RESULTS AND DISCUSSION

On macroscopic scale, columnar grains are shown throughout the longitudinal section of ingots of Al-33% Cu alloy directionally solidified with either direct water spray or indirect water cooled Cu-chill, as those indicated in Fig.1. a and b, respectively. One can notice that finer columnar grains manifest themselves in the case of cast ingot of direct water spray cooling than those attained from indirect Cu-chill one. This can be attributed to the faster of the heat extraction of the direct water spray cooling than the water cooled Cu-chill. The macrostructure of conventional ingot showed equiaxed grains.

On microscopic scale, Fig.2 a to d shows the microstructures of longitudinal sections of Al-Cu eutectic of: direct water spray, indirect Cu-chill cooling, and conventional casting. The direct water spray cooling micrograph, Fig.2a, indicates finer and much more directionality of lamellae than those of indirect Cu-chill cooling, see Fig.2b, in which the lamellae are not ideal in directionality, but bend and terminate, particularly, at the top of the ingot of indirect cooling, as indicated in Fig.2c. Fig.2d illustrates the microstructure of conventional casting ingot, in which one can observe that lamellae have different orientation and directions. It could be seen that temperature gradient and rate of growth have great effects on the microstructure morphology.

To investigate these effects, the temperature gradient was measured with respect to time, and the growth rate was plotted against the distance from the chill, as those indicated in Fig.3 and 4, respectively. It is noted that the temperature gradient as well as the growth rate of conventional casting are almost time independent. However, both direct and indirect cooling conditions are time dependent. The temperature gradient decreases with respect to time and the growth rate reduces as solidification moves up far from the bottom. These reduction of temperature gradient and growth rate could be attributed to the liberation of latent heat during solidification.

Our findings indicated that the interlamellar spacing of Al-Cu eutectic was increased from bottom to top, as shown in Fig.5, due to the decrease of both temperature gradient and the growth rate. It was also found that the interlameller spacing is proportional to the inverse root of growth rate, as those illustrated in Fig.6. One can notice that the interlamellar spacings of conventional casting are much larger than those of direct or indirect casting ingots, and they vary appreciably from bottom to top.

Hardness measurements (VHN) and porosity percentage made on Al-33%Cu eutectic alloy directionally solidified at various growth rates with respect to distance from the chill are shown in Fig.7.

The results indicate that the amount of porosity increases from bottom to top. Generally, the ingots cast with direct water spray cooling exhibit the lowest porosity and the higher hardness values, compared to those of Cu-chill and conventional castings. This attributed to the higher rate of cooling associated with the direct water spray cooling. The formation of pores depend on two pressures operated together during directional solidification, namely, negative and positive pressures. The negative pressure is caused by a volume change due to contraction of solidifying metal and acts as the driving force for feeding castings. The positive pressure is due to the atmospheric pressure and metallostatic head over the melt in the mould, and this positive pressure is only activated when the negative pressure is operative within the casting. The rate of increase or decrease in negative pressure depends on the rate of growth of solid and its solidification contraction factor. At the beginning of solidification, positive pressure is greater than negative pressure and the feed metal channels are opened. Under such circumstances, no pore will be formed. As solidification proceeded, the feed metal channel is progressively become narrow and irregular. The positive pressure might, therefore, drop to a stage where it equals to the negative pressure. At this stage two phenomena could take place. Any increase in negative pressure would increase the ability to suck-in feed metal and enhance continued feeding. On the other hand, the feeding would be opposed to an extent when stagnation point would be set and all contact with the residual feed metal would be lost and a pore will be nucleate [7,8]. Once a pore is nucleated, the shrinkage is accommodated by the growth of the pore.

Hardness measurements along the length of the cast ingot showed that the hardness values decreased from bottom to top. Also, the hardness values of ingots of direct cooling are higher than their respective values in the other two casting conditions, i.e. indirect cooling and conventional castings. The high hardness of directionally solidified of direct water spray cooling material is attributed to the finer structure and higher mismatching.

CONCLUSIONS

1. Generally, the higher growth rate of directionally solidified Al-33% Cu alloy, the finer columnar structure.
2. The interlamellar spacing of Al-33% Cu eutectic is proportional to the square root of growth rate.
3. The higher the growth rate, the lower the porosity in the cast ingot. Generally, the directionally solidified casting exhibits lower porosity than the conventionally solidified ones.

4. The increase in growth rate increases the hardness of the directionally solidified ingots.

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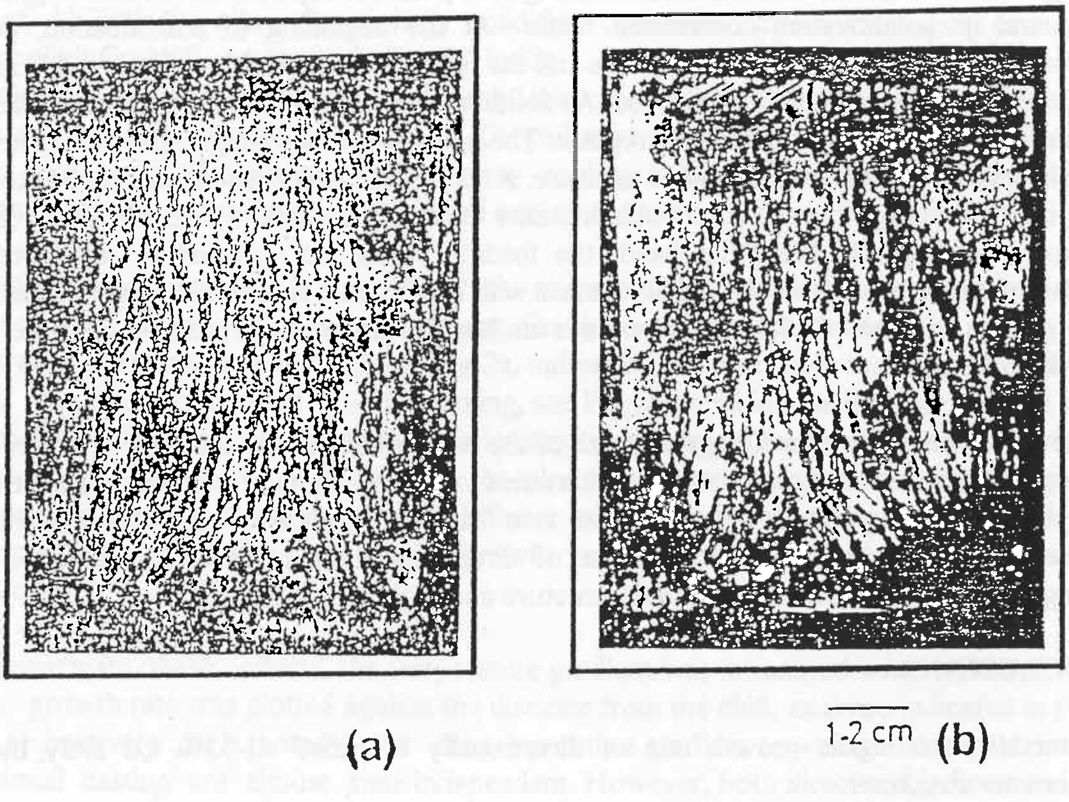

Fig.1: Macrostructures of Al-33%Cu alloy directionally solidified with:
a) direct water spray cooling, and b) indirect water cooled Cu-chill.

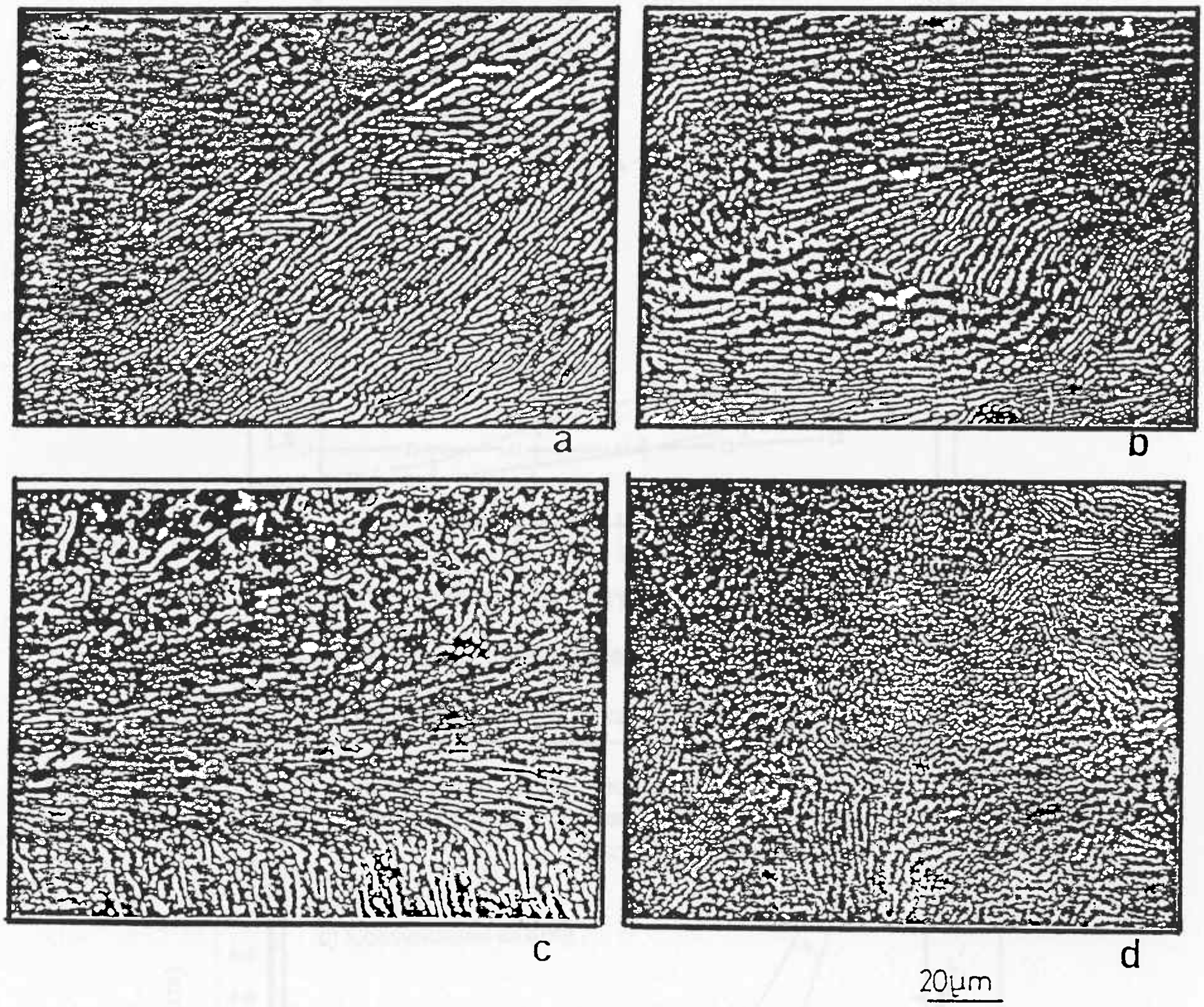

Fig.2: Microstructures of longitudinal direction of Al-33%Cu alloy directionally solidified with:
a) direct water spray cooling, b) indirect water cooled Cu-chill near bottom,
c) indirect water cooled Cu-chill at the top, and d) conventional casting.

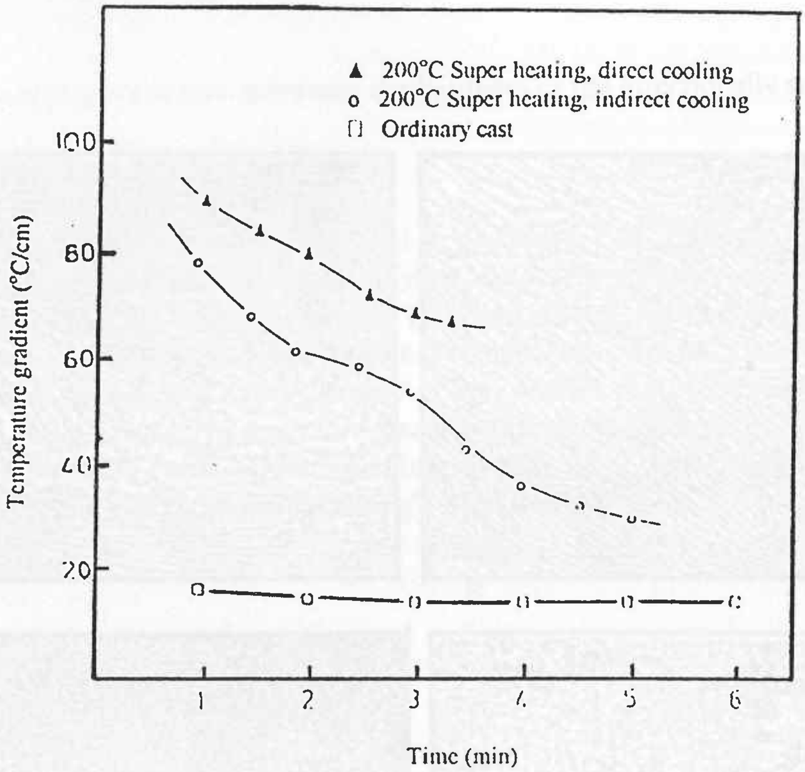

Fig.3: Variation of temperature gradient as a function of time.

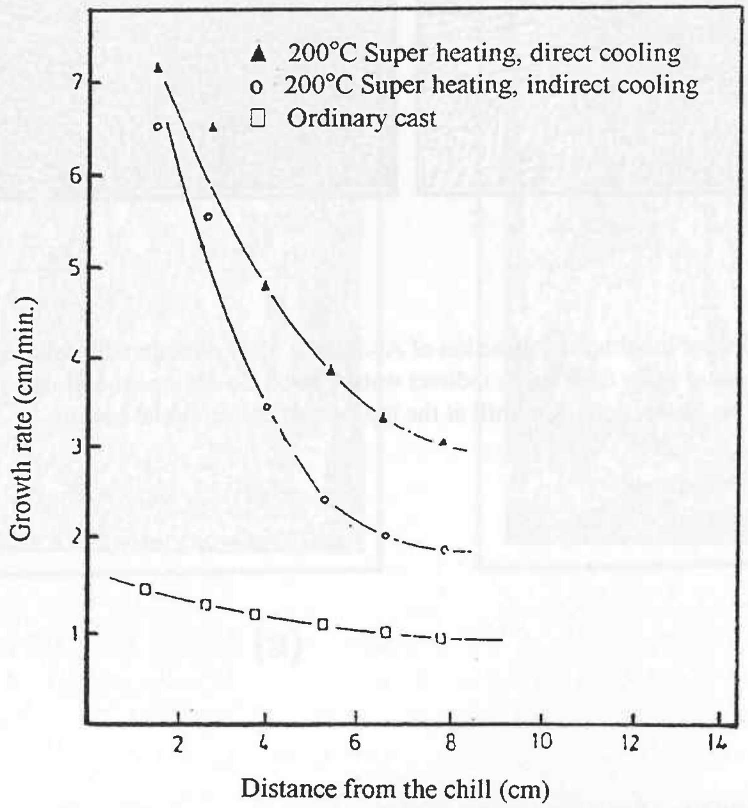

Fig.4: Variation of growth rate as a function of distance from the chill.

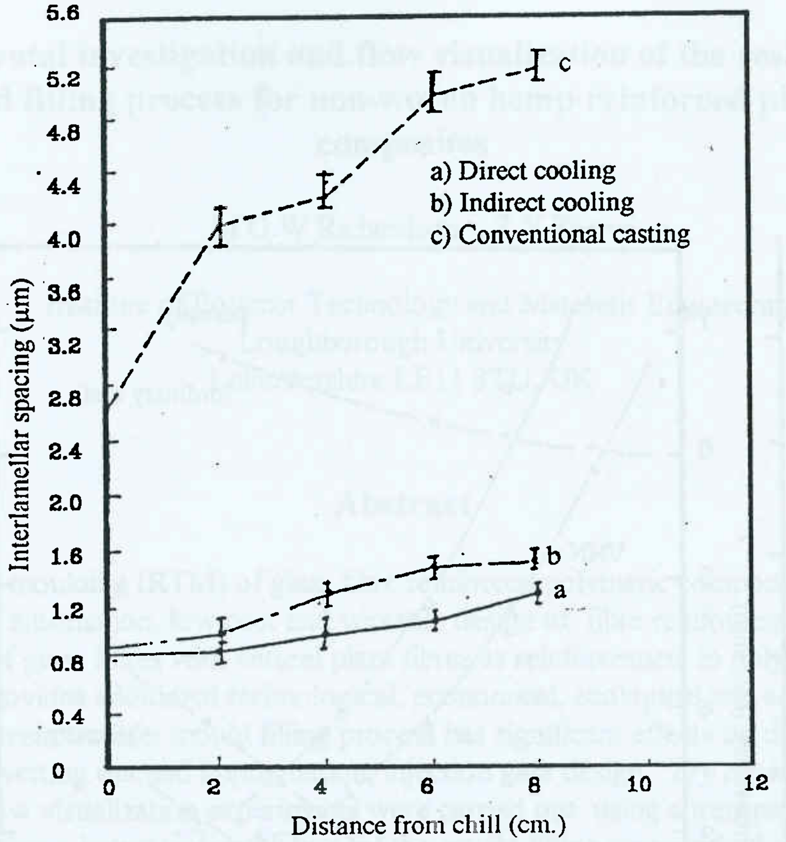

Fig.5: Interlamellar spacing vs. distance from the chill of Al-33%Cu.

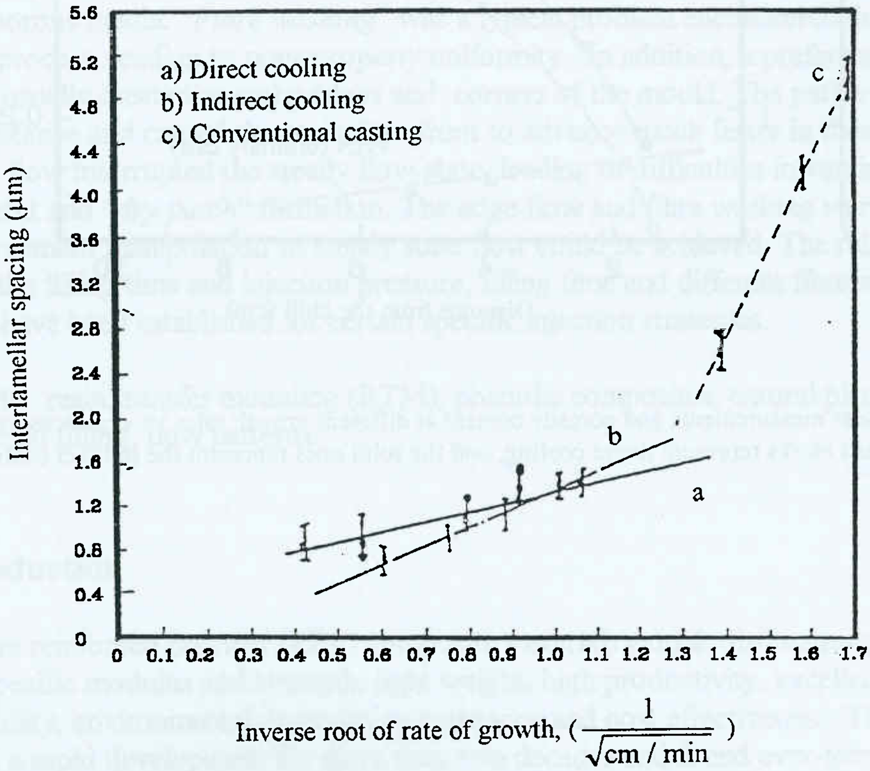

Fig.6: Interlamellar spacing vs. inverse root of growth rate of Al-33%Cu eutectic alloy.

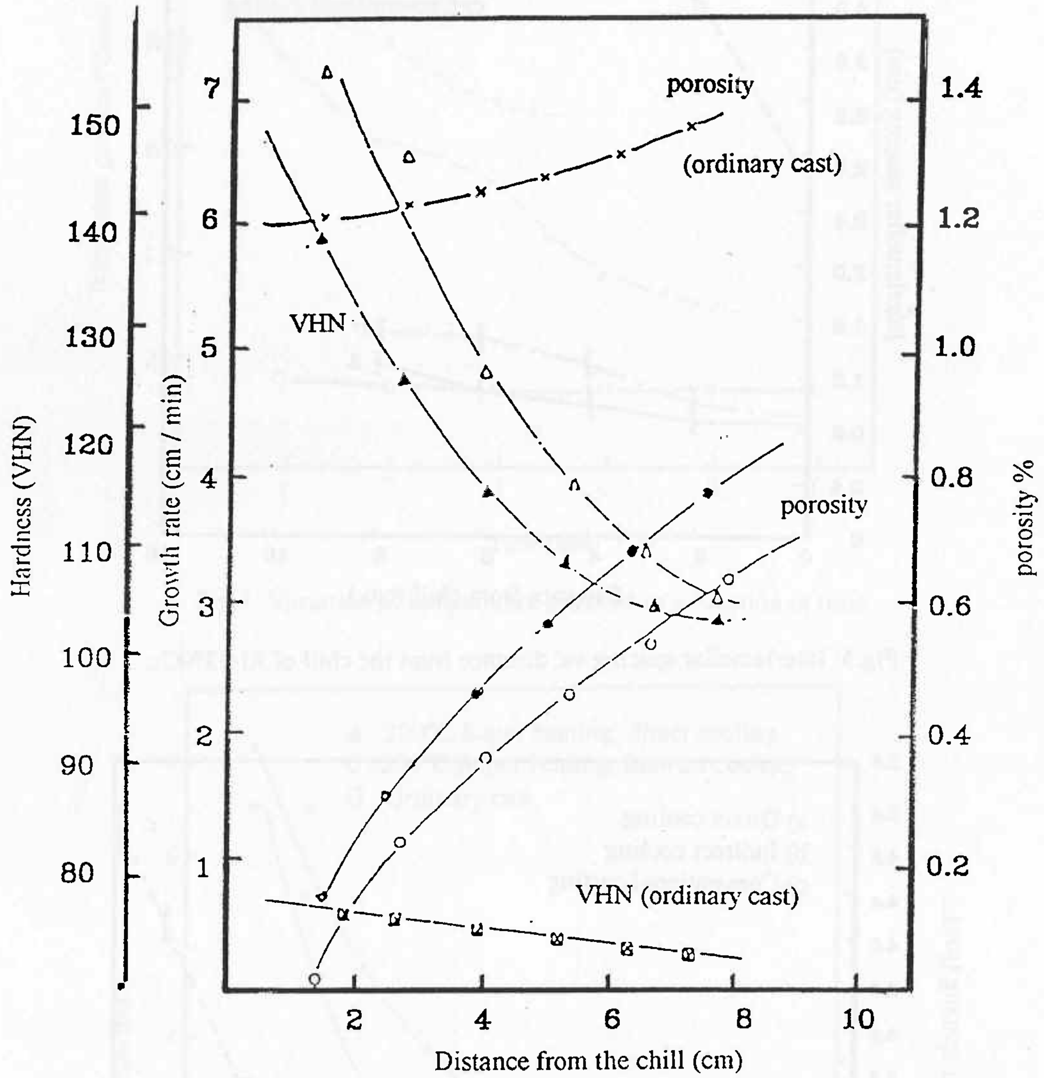

Fig.7: Hardness measurements and porosity content at different growth rates vs. distances from the chill (opened marks represent direct cooling, and the solid ones represent the indirect cooling).