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HDC PROCESS FOR SMALL DIAMETER INGOT

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Small diameter casting rods used VTR cylinder have become a big market in Japan. At the beginning, they were normally manufactured by VDC (Vertical Directchill Casting) process, but recently such merits by HDC (Horizontal Directchill Casting) process as higher recovery, lower equipment cost etc. have been recognized for manufacturing of the rods. Thus, the related studies were performed in our company. HDC process has some characteristic technical problems due to gravity difference between top surface and bottom surface at horizontal portion. Some factors which exert the influence on microstructure as well as surface condition such as casting condition, mould assembly etc. have been discussed in the paper.

INTRODUCTION

The casting of extrusion billets and rolling ingots of aluminum alloy has principally been done by DC (Directchill Casting) process. The DC process has been classified into VDC (Vertical Directchill Casting) process and HDC (Horizontal Directchill Casting) process, and presently VDC process has become the mainstay in casting process in this industry. However, in recent years, HDC process is attracting attention of the industry in Japan.

HDC process is a known casting process and has a long practical history, and has been used in casting conductor busbars in places like aluminum smelting plants.

The advantages of this casting process are:
(1) it requires less equipment costs.
(2) since the entire production equipment is spread on the plant floor, it is easy to operate. Thus, it requires less operating crew for total casting job.
(3) since this is a continuous casting process, its recovery ratio is favorable, doing away with necessity of cutting and throwing away the head and butt end of individual ingots. It also produces uniform ingot structure from end to end.
(4) this process is capable of casting small diameter ingots of less than 50mm in diameter.

On the contrary, the disadvantages of this process are:
(1) it is difficult to apply this process on small lot orders which comprise the most of present business.
(2) As this is a horizontal casting process, the upper and bottom portions of an ingot is influenced by the difference of gravity due to cooling water, lubricating oil, adherence of casting mould to molten metal.

HDC process has seldomly been used in casting extrusion billets nor rolling ingots in aluminum industry, due to many constraining factors, such as the necessary change of aluminum alloys, and of casting ingot sizes. However, in recent years, this HDC process is drawing attention because small diameter aluminum casting rods in sizes of 30-90mm are highlighted for casting of larger size ingots. This is due to the fact that these small diameter rods have larger share of the market. Due to the fact that small diameter rods, specially in sizes of 50mm or less, can not be successfully cast by the HDC process by the conventional VDC process, the study was initiated with our plant on the possiblility of utilizing this HDC process for this application.

Therefore, this paper deals with the study made on the horizontal casting equipment for casting small diameter aluminum rods, and more particularly with experimental results of casting small diameter rods and data obtained from these experiments.

EXCELLNCE OF HDC PROCESS OVER VDC PROCESS

In Japan, only a portion of small diameter casting rods at first were used for cold forging stock for making video tape recorder (VTR) cylinders. At precent, VTR cylinders were made from these small diameter casting rods for the most part. Quite recently this small diameter rod is taken up for study for potential application to the automotive parts or heat exchanger parts (for instance, car cooler and compressor components.) While the unique features of small diameter rods will be discussed later, the excellence of horizontal casting equipment is hereby taken up for deliberation.

In order to secure appoximately same number of strands and production capacity as VDC process with HDC process, there is a need of aligning many horizontal casting units vertically, thus requiring a larger casting plant building. On the other hand, it does not require deep underground casting pits nor tall plant building which is high enough to clear hoisting of cast ingots nor large cranes. As a result, it is no way superior to VDC process in terms of per plant area unit productivity. But, it certainly requires less equipment costs. moreover, auxiliary equipment, such as shears and heat treat furnaces can be built in line to assure continuous production.

In HDC process, complete continuous casting becomes possible by installing a shear in line. thus dispensing the need to cut off the head and end portions of an ingots. On the contrary, the VDC process is basically a semi-continuous process, therefore it requires to cut there head and end portions. What is more, this process is not capable of casting a small diameter rod (specially diameter of 50mm or less) while HDC process is technically capable of casting.

While the examples of recovery calculations for both VDC and HDC process are shown in Table 1, it can be learned from this table requires to cut off ends of ingots and also due to the need to allow residual molten metal per every drop.

TABLE 1 : Recovery Comparison

	HDC	VDC (Hottop)
residual molten metal	8.6%	8.6%
drain for every drop	2.1	7.1
head and butt crop	---	7.7
Recovery	89.3	76.6

Casting size : 65mm dia.
Product length : 5000mm

HDC EQUIPMENT

Fig.1 shows production of process of HDC equipment. As can be seen, chemical compositions and temperatures of various types of molten aluminum alloy are adjusted in a holding furnace. As casting operation is initiated, the molten metal, being purified as it undergoes through the countinuous in-line fluxing treatment, is supplied to the casting mould. A small diameter cast ingot, solidified in the casting mould, and cooled as it is pulled out horizontally by a casting conveyor. Such rod is cut to the required length by a flying saw which is timed to synchronize the casting conveyer. These small diameter cast rods are shipped out after they are heat treated, machined and inspected by an ultrasonic testing equipment. Table 2 carries specifications of main body of HDC equipment.

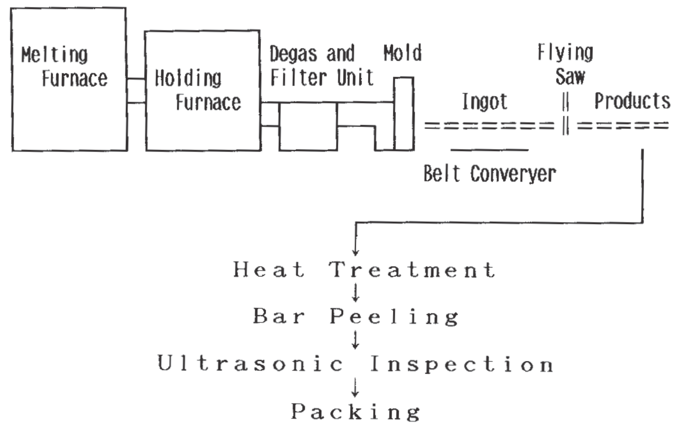


FIG. 1:HDC Process flow chart

TABLE 2 : Specification of HDC equipment

Casting Alloy	1000-7000	alloys
Casting Size	(25)- 90	mm dia.
Strand	11	
Cutting Length	2500-5000	mm
Casting Speed	100-1500	mm/min
Cooling Water	100- 600	l/min
Fiying Saw	Chipsaw 425	mm dia.

Photo 1 carries a description of the vicinity of casting mould. Major key point of HDC process lies in
(1) how best to minimize the gravity difference of top and bottom portions of an ingot, and
(2) how to successfully maintain the stabilized casting conditions throughout the entire casting operations.
Thus, the know-how lies in the structure of a mould assembly.

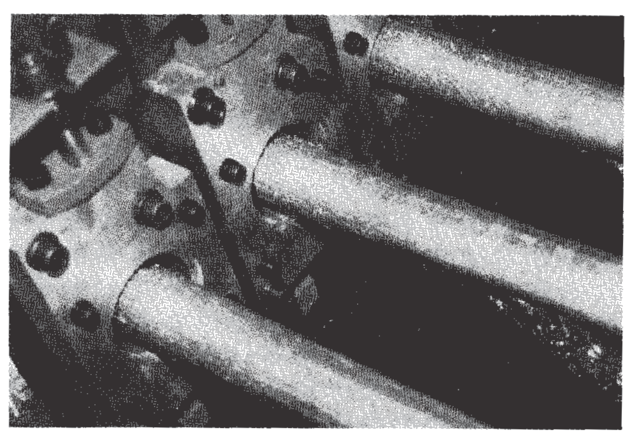


PHOTO 1 : HDC process for small diameter casting rod.

Similar to VDC's hottop process, molten metal in the HDC process is surrounded by refractry and the edge of casting mould at the initiating point of solidification (this is comparable meniscas portion which contacts mould in DC process.) Moveover, quite difference from VDC's hottop process, as the metal is cooled as it is pulled out in the horizontal direction, ununiform tensionis liable to occur on a shell being solidified. Besides, in the vicinity of a mould, the extraction of heat tends to vary between upper and bottom portions due to the unbalanced cooling, ununiform application of lubricant and gravity difference. If these adversary conditions occur simultaneously, the surface of ingot tends to deteriorate and create unstable casting conditions, and in the worst case, this may end up in the "break-out."

SURFACE CONDITIONS AND INNER STRUCTURE

The important task in casting small diameter rods by HDC process is to how best to maintain the cast surface as smooth as possible. Same as VDC's hottop process tends to cause "ripple" on the cast surface. But, large rippled cast surface not only causes to increase machining part of surface but it alse tends to cause ununiform grain structure and segregation larger just below the cast surface.

As compared with VDC process, HDC process has a problem in that the progress of solidification advances ununiformly in the top and bottom portions of casting ingot. This is principally caused by the differnce of gravity and by below mentioned phenomena, causing heat extraction volume to be larger at the bottom of an ingot being cast, thereby casting tends to advance in a condition that the heat is concentrated on the upper portion of an ingot:

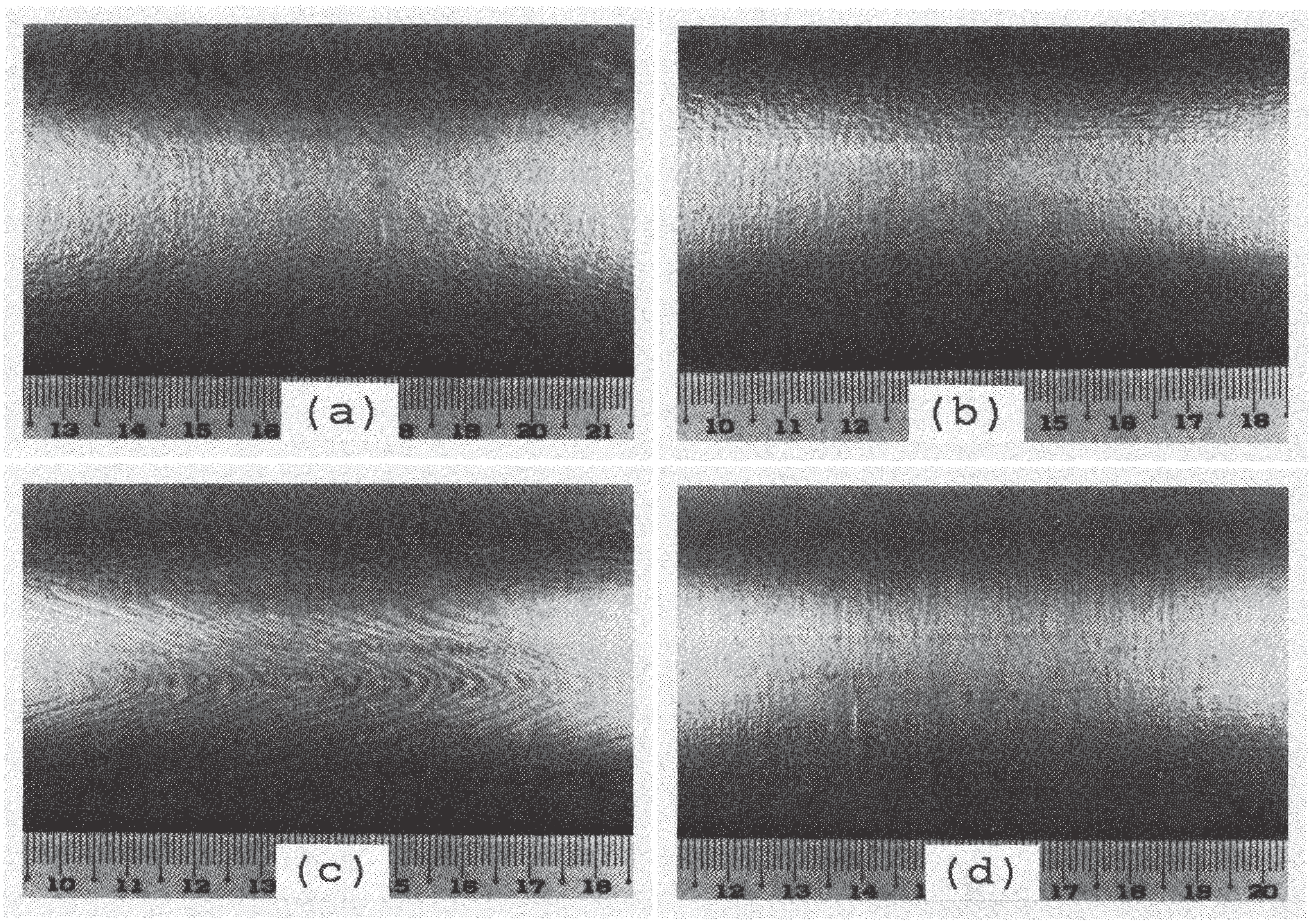


PHOTO 2 : Cast surface finish of AA2218 alloy.

(a) smooth surface on the top side of an ingot
(b) and on the bottom side of the same ingot.
(c) delayed solidification pattern on the top side of an ingot,
(d) and on the bottom side of the same ingot.

(1) The difference of cohesion between the molten metal or the cast ingot.
(2) Excessive lubricant drips downward.
(3) Cooling water positioned atop seeps downward.

Photo 2 carries the typical cast surface. This shows that the top surface of an ingot itself is very smooth. On the other hand, it tends to develop a pattern which is peculiar to the delay in solidification. In contract to this, the rippled pattern which is common to VDC's hottop casting, is recognized on the bottom side of an ingot. This difference can be considered to caused by the difference in the metal head. But this is greatly influenced by the chemical composition. Therefore, it is important to ease the difference between the top and bottom by the adequate mould assembly by controlling the casting conditions in a narrow range.

In the past, it was mentioned that in HDC process, the final solidification portion tended to become eccentric from the core portion of cast ingot to the upward portion caused by the delay in solidification occurred in the upper portion of an ingot. Various proposals were made to prevent these phenomena. However, in small diameter rods as taken up in this report, eccentricity rarely occurs due to the faster casting speed employed than the casting speed of regular extrusion ingots by HDC process. Photo 3 carries a longitudinal cross section of macrostructure of an ingot cast without the addition of grain refiner. It is observed that the columnar structure, which grew along the heat extraction direction from the direction of top and bottom surface, crosses in the central portion. Therefore, it is concluded that the final solidification portion does not have any eccentric portion.

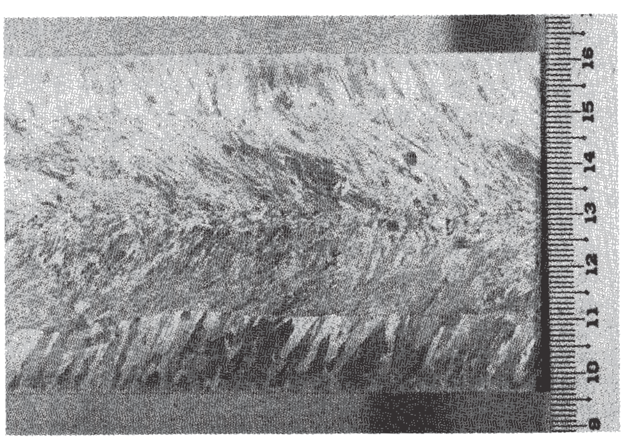


PHOTO 3 : Macrostructure of a longitudinal section without the addition of grain refiner.

Changing the conductivity ratio by adequate choice of mould material can be considered as another means of controlling the heat extraction volume. As one example, coarse cell boundary thicknesses of ingots cast by different mould, namely, copper, aluminum and copper moulds inserted by graphite sleeves are shown in Fig.2. It was discovered that coarse cell boundary thicknesses did not change as the difference of thermal conductivity of the mould material, but it was found that these thicknesses decreased as the casting speed gets larger. This was assumed that this is not directly as a large difference in the thermal conductivity as the molten metal contacts the mould via lubricant oil.

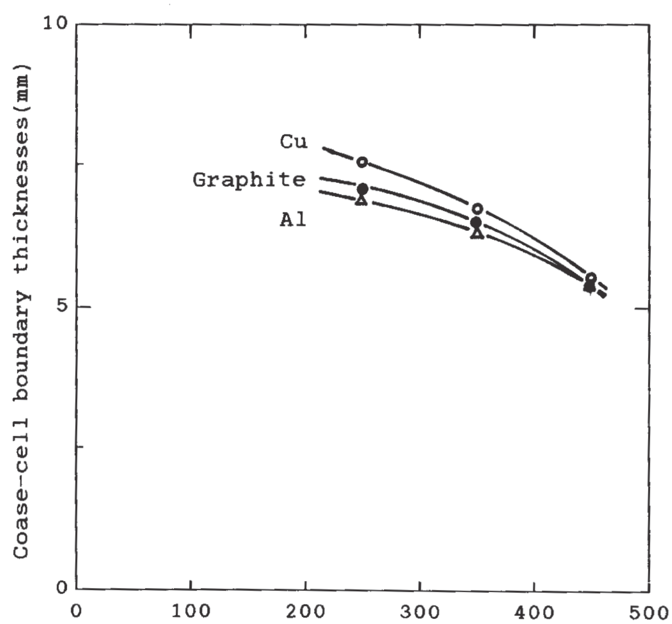


FIG.2 :Coarse cell boundary thicknesses of ingots cast by different mould

Fig.3 carries the variety of thicknesses of coarse cell boundary when the casting temperatures are changed. Some difference was recognized in the thicknesses when the casting speed is low, but difference grows thin when the casting speed gets larger. Our study revealed that it was the length of a mould that greatly influences the coarse cell boundary thicknesses.

Fig.4 shows its results of our study. It shows that coarse cell boundary varies greatly within the range of 25-63mm in mould length. However, the measurement becomes difficult as the variation of DAS gets less as the mould length gets longer. Thus it was not possible to measure coarse cell boundary when the mould length was 75mm in the experiments.

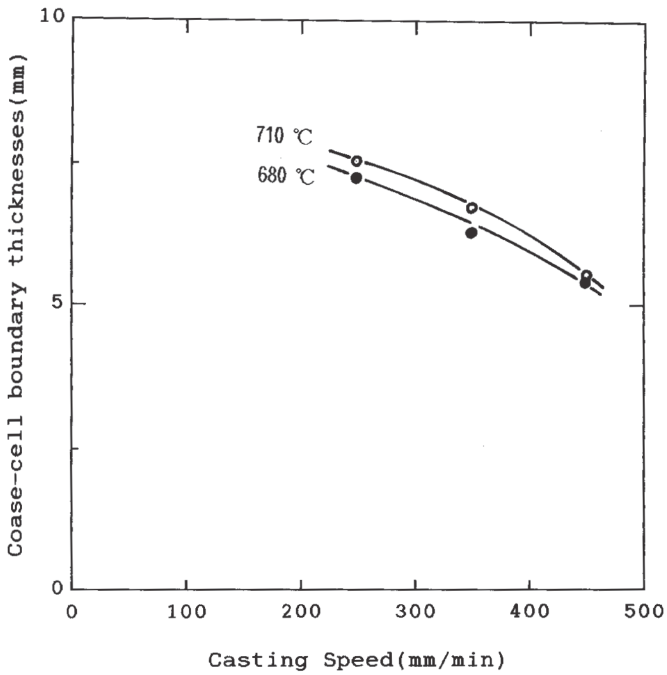


FIG.3:Coarse cell boundary thicknesses of ingots cast by different temperature

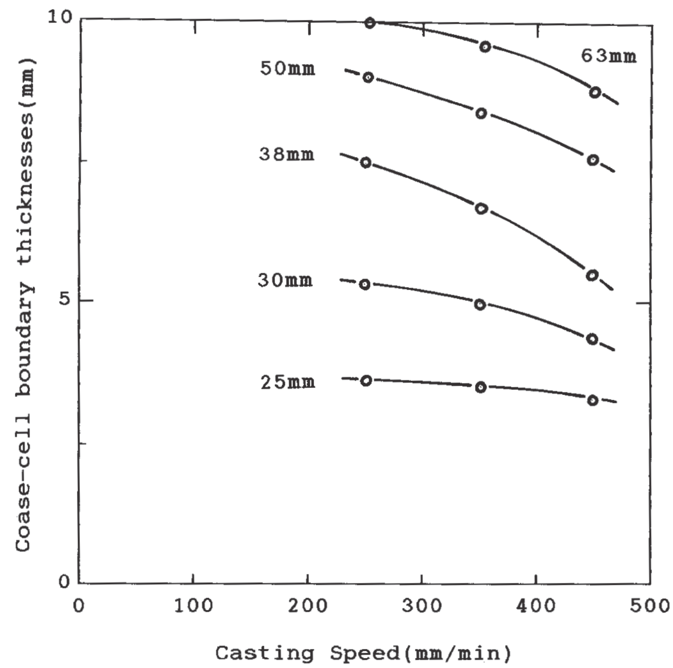


FIG.4:Coarse cell boundary thicknesses of ingots cast by different mould length

On basis of data accumulated in above manner, the most optimum mould assembly and casting conditions are determined. It can be said that the surface of small diameter cast rod cast by the most optimum casting conditions is free from the distortion in microstructure caused by subsurface structure and ripples, and the variation in chemical composition is limited only to surface. Photo 4 shows the structure in the vicinity of surface. It shows that the cast surface is smooth and has uniform structure and thin segregation layer.

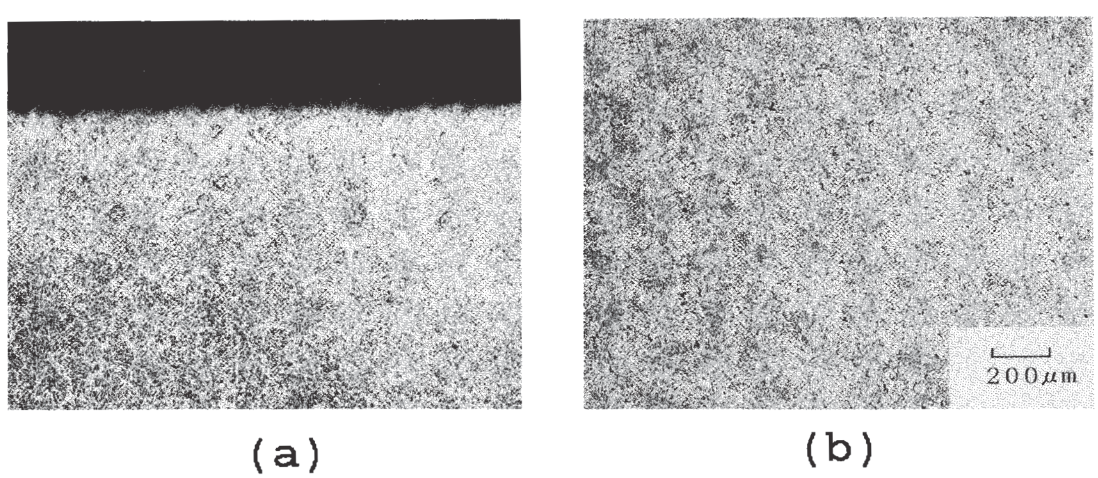


PHOTO 4 : Microstructure in the vicinity of surface(a), and in the center section(b)

QUALITY FEATURES OF RODS CAST BY HDC PROCESS

Cast rods features quite different from those of extruded bars which has conventionally been used. Here, quality characteristics of small diameter rods cast by HDC process are shown.

Photo 5 is a comparison photo of microstructure between cast rods and extruded bars. It shows that cast structure of AA2218 extruded bar(A) which is indirectly extruded from 350mm dia. cast billet and hot worked, is completely destroyed and turned into fiber structure. In comparison to this, HDC cast small diameter rods(B) have three dimensionally isotropic structure which has very minute dendrite arm spacing. In extruded bars, rather coarse second phase particles, which grow at the casting of large size billets, are dispersed along the extruding flow. While in HDC cast rods, minute particles, caused by rapid cooling, are dispersed continuously along dendrite arms and grain boundary. The grain refining of particles by rapid cooling is particularly effective to high density alloys such as Al-Si alloys, and in Photo 5 shows stabilized refining of eutectic particles in extruded bar(C) and cast rod(D) Al-12%Si alloy.

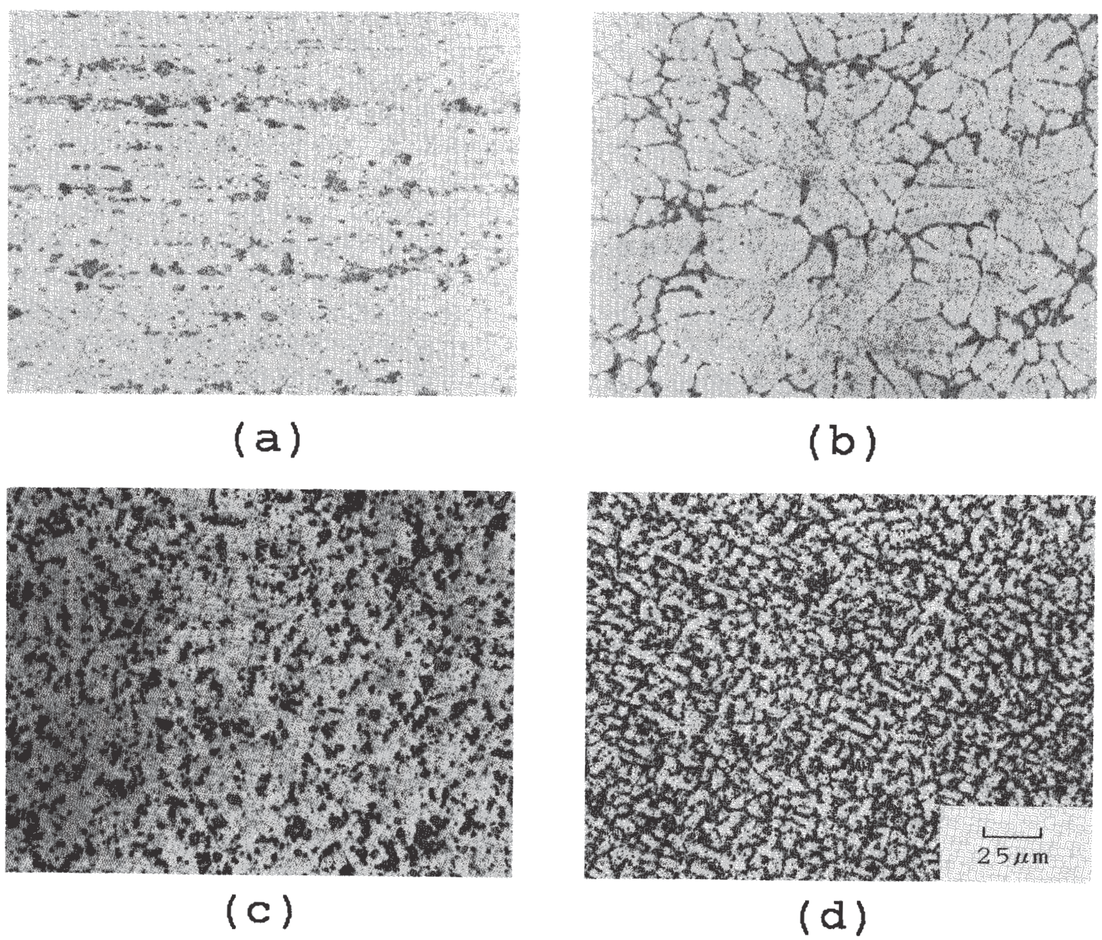
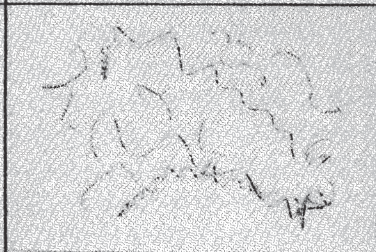
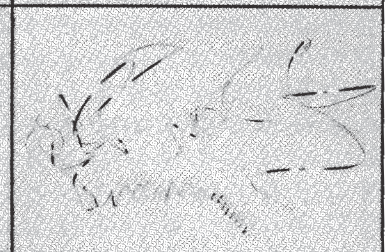
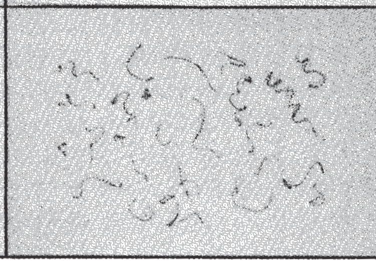
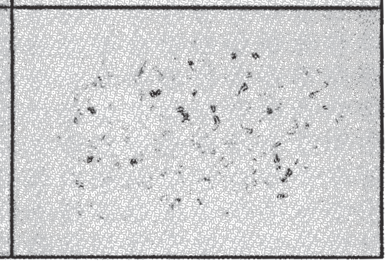


PHOTO 5 : Microstructure comparison between cast rods and extruded bars. AA2218 extruded bar(a), and cast rod(b). Al-12%Si alloy extruded bar(c), and cast rod(d).

PHOTO 6 : Machinability comparison between different materials

material	Depth of cutting (mm)	Cutting feed(mm/rev)		
		0.025	0.1	0.2
Extruded bar	1.0			
Casting rod	1.0			

These difference of microstructure as shown above greatly influence the properties of rods. As an example, machinability of VTR cylinders made by these two different materials are compared in the form of cutting chips. In case cast rods are used, chips tend to be curled into small sections and broken thus showing that these chips are easily handled. Specially, in case they are continuously works by an automatic cutting machine, if chips continues to be unbroken, this tends to bother cutting tools and become cause for failures.

When the cold forgeability is taken into consideration, cast rods which do not have unisotropicity such as extruding flow are deformed without prejudice, are advantageous material for cold forging application.

SUMMARY

Here, this paper has taken up how the study was made on the continuous casting by means of HDC process for the casting of small diameter cast rods and their properties. The features of our HDC process lies in the relatively simple mould. This has already been in use for the floor production of rods for VTR cylindor application. While the demand is expected to expands due to the properties which are different from extruded rods, the study is anticipated to pursue the possibility of using this process as a means to produce smaller diameter rods which are difficult to produce by conventional extruding process.