Cooling-Water Circulation Core for Casting Hollow Ingots

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ABSTRACT Today it is required to make multilateral efforts to streamline the production costs for current aluminum extrusion processes. We designed and developed an innovative core, which is superior in quality and tactful with attaching smoother inner surfaces to hollow ingots for extruded mandrel pipes, in the process of hot-top casting.

This core serves to bring about mass improvement in the surface smoothness inside a hollow ingot and the inner- surface microstructure. It turns out that lesser aluminum chips result from boring a hollow, preparatory to extrusion work, thereby creating a raise in the yield or the boring rate, and a drop in the production cost. Concurrently, the merits of hot-top casting remain equipped. Accordingly, its superiority to float casting (conventional technique) will be unaffected, namely, the inward quality of a hollow ingot to be produced.

This paper points out features and drawbacks of the hollow-ingot casting techniques, which have been put into practice or under study. It's another content covers structural standouts of the developed core and results of what was cast, using the same core. It is also discussed how to form smooth inner-surface texture with certainty and efficiency: the making of a core, setup of a core, and casting conditions.

1. INTRODUCTION

Use of a hollow billet is a rational approach to provision against variation in thickness over an extruded mandrel pipe. Hollow billets are made out of hollow ingots, which should have been cast, followed by having their hollows bored.

What ought to be improved in streamlining the production cost, is the hollow boring rate or the production yield. In brief, it will create the most efficiency to raise the boring rate or lessen the thickness to be bored. In particular, a certain measure of thickness must be provided, because the inner-surface smoothness or the surface microstructure of a hollow ingot cannot be made ultimately perfect.

Our task was to attempt an authentic design change in the conventional core, which had been used to form a hollow through an ingot, in order to solve the above point at issue. In general, a core (inner mold) to form a hollow inside an ingot is of a metal cylinder, into which cooling water is fed, with the result that the cooling water is injected directly onto the inside of the formed hollow. The same applies to hot-top casting. Looking back on the past, graphite cores with no cooling water and water-cooled hot-top cores were tried out, in this context. However, the former turned out to be unstable in internal cooling, and the latter ended up with rough inner-surface smoothness, due to overcooling. Taking those bitter experiences into consideration, we contrived a method of circulating cooling water in a core, till being drained out, allowing no cooling water to be in direct contact with the inner surface of the hollow ingot being formed.

This method has turned out to be practical. To be brief, appreciable improvement has taken shape in the inner-surface smoothness or the surface microstructure in a hollow ingot, leading up to a lesser measure of thickness to be bored.

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2. HOLLOW INGOT CASTING TECHNIQUE

Hollow-ingot casting methods are outlined in Figures 1, 2, 3 and 4. This topic covers each mechanics and points of question. Float casting as sketched in Figure 1 is incapable of driving out oxides assignable to spout or float, and is not free from a threat to fluent feed melting [1].

Figure. 2 picturizes "Hot-Top Casting" for hollow casting, in which melting is fed as leveling out, and is free from the same faults as in float casting, corresponding to solid-ingot casting. But the water-cooled aluminum core carries through in the midmost of the mold. Consequently, the sump in the hollow gets rather deep or long, where liquation results from remelting of a solidified shell --the most serious drawback, as shown in Figure 5. The remelting of a solidified shell is a key factor in roughening the inner-surface smoothness [2].

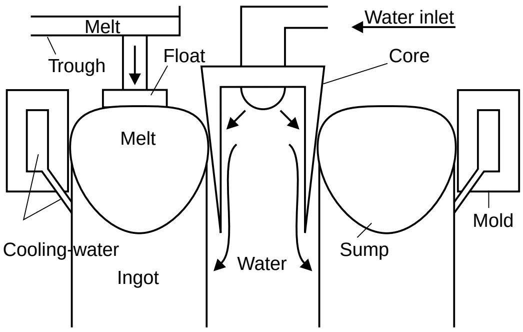


Figure 1 Float casting (conventional model)

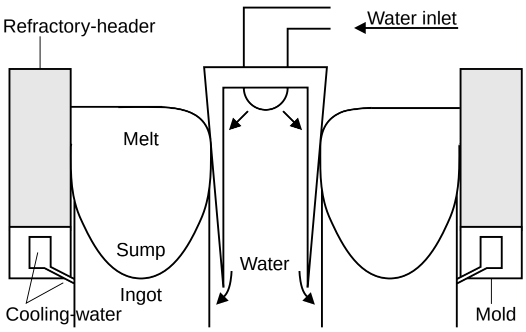


Figure 2 Hot-top casting with aluminum alloy core

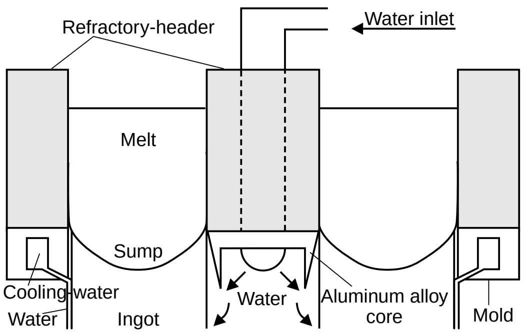


Figure 3 Hot-top casting with aluminum alloy core and refractory header

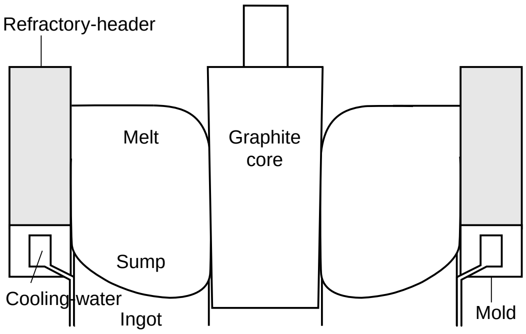


Figure 4 Hot-top casting with graphite core

Figure 3 picturizes hot-top casting with a core in a hot-top scheme, where the water-cooled aluminum-alloy core is shrouded with a refractory header. The water-cooled segment, being fairly short, is least likely to induce liquation. Moreover, the upward refractory header acts to

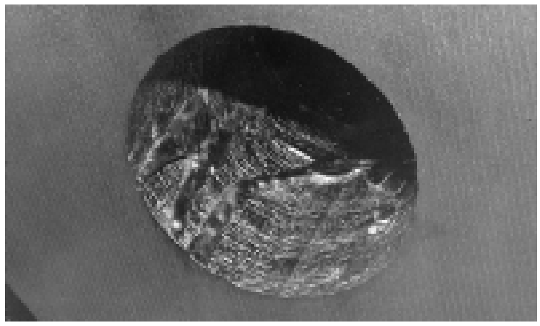


Figure 5 Liquation from remelting

advantage: being free from variation in the level of molten metal. Yet on the contrary, a lead-off point of solidification reaching the not-lubricated refractory header will tear the solidified shell --a threat to safety (causing a breakout of melting): this fashion has not been commercialized.

Figure 4 picturizes hot-top casting with a graphite core, in which the solidification proceeds invariably from outer to inner reaches and is blocked out by the graphite surface, thus forming a hollow. It is characterized in that the intrinsic lubricity of graphite is utilized not to necessitate any other lubrication; the inner-surface smoothness is fine and smooth [2]. Nevertheless, graphite has one factor in roughening cast surfaces, due to its being eroded in melting and another factor in varying a boundary of solidification due to its being sizable in thermal conductivity: graphite cores have not been commercialized yet.

3. COOLING-WATER CIRCURATION CORE

Guidelines to design a faultless core that were extracted from the referenced four cores:

- -to apply hot-top casting
- -to set and fix a lead-off point of solidification at a lowest possible level
- -to furnish adequate cooling to a hollow being formed

In line with the above, a scheme to circulate cooling water in a core was contrived in combination with hot-top casting.

Figure 6 draws a brief scheme of the forgoing core, which can be characterized as follows:

1) The upper part is a refractory header and the lower is of an aluminum alloy; Two-fold structure to moderate the measure of remelting.
2) The aluminum-alloy part is positioned lower than the outer mold. Besides, the core is cooled down, only with the water circulating in itself; therefore, the inner surface of a hollow ingot later as designed. The intent here is to slacken the measure of remelting, and to retard the chilling effect from the core for evasion of lead-off solidification on the refractory header.
3) Hot-top casting is least likely to involve oxides due to turbulent melting or result in giant compounds.
4) The in-hollow area is structured to make the outer mold fed continuously with a lubricant.

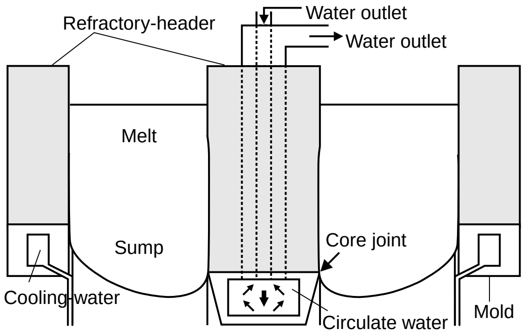


Figure 6　Brief scheme of water circulation core

5) The inflow and outflow ducts of cooling water are coaxially laid out to make the water flow as impartial as possible.
6) Because no cooling water is injected directly onto the in-hollow area, if a breakout of melting should occur there, no threat of vaporizing burst will emerge: superiority in safety over others.

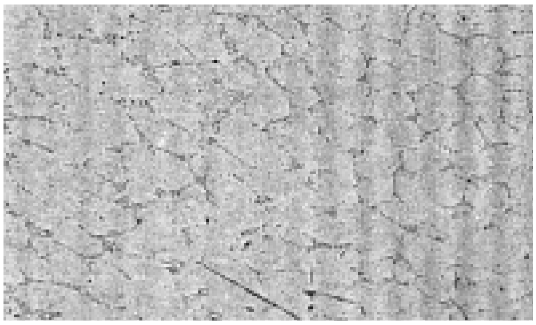
The objective of our task was to enlarge the inner diameter of a hollow ingot using this core, to reduce the measure of thickness to be bored and to raise the boring rate. The diametrical enlargement was designed by thinning the coarse cell-boundary inside the hollow, in order to reach the following target:

Target inner diameter: 190 mm (inner diameter as bored: 200 mm)
50% improvement in boring rate
Present level: 175 mm (inner diameter as bored: 200 mm)

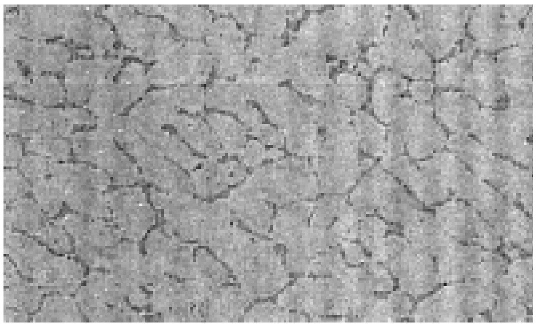
4. CASTING WITH A COOLING-WATER CIRCURATION CORE AND THE INGOT MICROSTRUCTURE

Based on the casting results from the past trial cores, the core border level was set to be 60 mm lower than the upper end of the outer mold. The taper angle of the core was θ degrees (intentionally veiled) and the casting speed was 45 mm/min. The other conditions (water feeding rate, temperature of molten metal, etc.) remained the same as ever. As a result, no breakout of melting at the outset of casting took place. Nor did any hanging due to shrinkage in solidification. This setup turned out to bear practical casting. Notably, preferable, fine ripples inside the hollow ingot were caught by sight --a great deal of improvement as contrasted with others (see Figure 7). The ingot measured 190 mm in diameter.

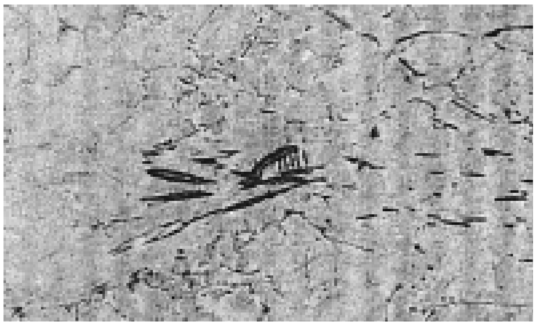
Figure 7　Inner surface smoothness, water-circulation core



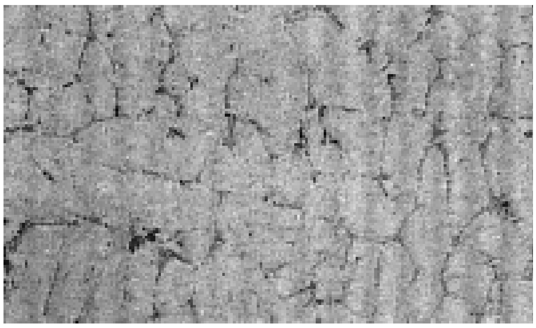
1) 2 mm from inner surface



2) 4 mm from inner surface



3) 12 mm from inner surface



4) 15 mm from inner surface

Figure 8　Inner-surface microstructure
1), 2) water-circulation core; 3), 4) hot-top casting with Al-alloy core

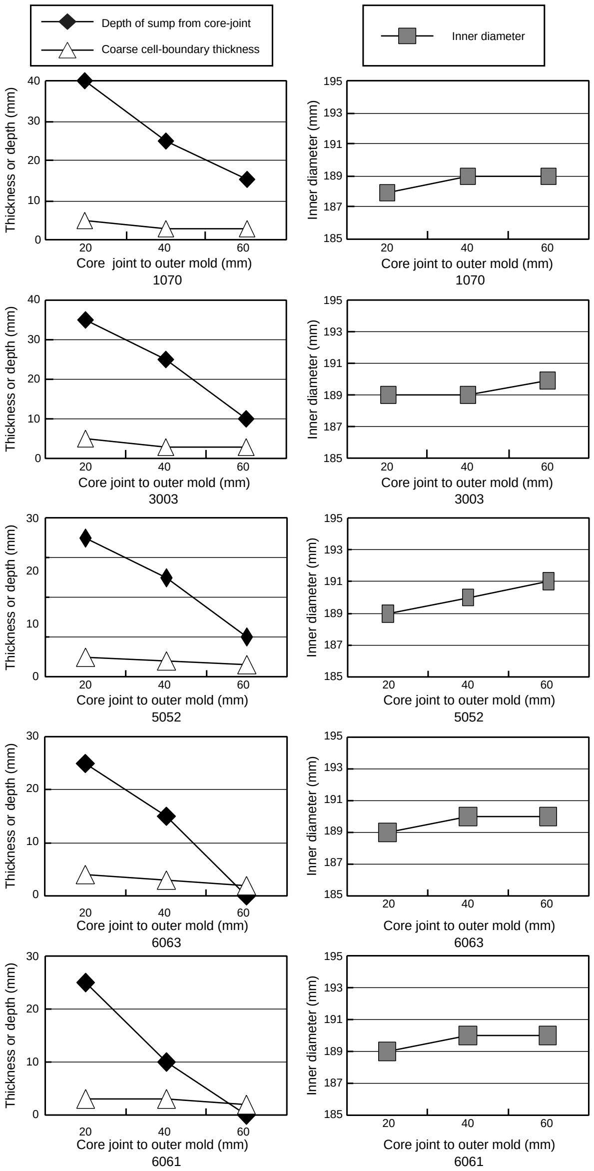


Figure 9 **Coarse cell-boundary thickness, sump depth or inner diameter vs. core-joint level**

As for microstructure, the coarse-cell boundary was found uniform to the depth of 3 mm, circumferentially. The other parts were also found fairly sound with no inclusion of giant compounds. These findings ensured a lesser measure of boring thickness (see Figure 8).

4.1 Upgraded Boring Rate

We succeeded in reducing the measure of boring thickness, as planned: from 175 mm to 190 mm in diameter for 3003 (7.5 mm in thickness). This result represents 53% of improvement in the boring rate.

4.2 Practicability in Combination with 1070, 3003, 5052, 6061 or 6063

Aluminum alloys 1070, 5052, 6063 and 6061 were cast, using the same method and hardware, where all combinations of casting turned out to be practicable under the conventional conditions, with no initial faults emerging.

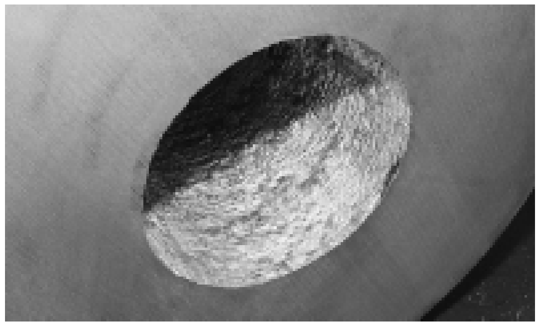


Figure 10 **Inner-surface smoothness of a 3003 ingot, with water-circulation core, core joint to outer mold: 20 mm, core taper angle: θ, and casting rate: 45 mm/min.**

4.3 Core-joint level, taper angle, casting rate vs. inner-surface smoothness

4.3.1 Core-Joint Level

Distances from the top of the outer mold to the joint of the core, were on trial adjusted to 20, 40 and 60 mm for 1070, 3003, 5052, 5056, 6061 or 6063, respectively. Parameters were determined to judge the levels of smoothness: (depth of an inner-surface cell boundary), inner diameter of a hollow, depth of a sump. The taper angle was given as θ; the casting rate was adjusted to 45 mm/min for all the casting trials. Figure 9 plots determined values for the parameters. Each of the alloys shows a decline of remelting as the core joint lowers, thinning the cell-boundary thickness, improving the inner-surface smoothness. By contrast, the inner diameters remained almost constant. Figure 10 presents the smoothness inside a hollow ingot of aluminum alloy 3003, with the core joint being 20 mm lower. As compared with Figure 7, given a core joint: 60 mm lower, taper angle: θ, a casting rate: 45 mm/min., the inner surface shows larger ripples, and traces of facial turbulence due to slight remelting.

4.3.2 Core taper angle

If the core taper angle is more increased, a more air gap arises, interposing between the core and ingot: a thicker thermal insulation forms to make remelting easier to occur. The intent of this particular is to judge the influence of core taper angles on the inner-surface smoothness.

Cores attached with a core taper angle of θ or 2θ were fabricated to cast hollow ingots of 1070, 3003, 5052, 6061 and 6063. Those ingots were measured in the depth of an inner-surface coarse cell boundary, the length of a sump, and inner diameter. Notably, the core-joint level was adjusted to be 60 mm lower than the top of the outer mold; the casting rate was fixed at 45 mm/min.

Figure 11 plots the magnitudes of influence of core taper angles with reference to the respective checkpoints. Each alloy shows a coarse cell-boundary thinner and more even at θ than at 2θ, and the inner surface smoothness being fine and fair. The depth of a sump is less at θ than at 2θ. There are scarcely any differences between both inner diameters. Figure 12 presents the inner-surface smoothness of a 3003 hollow ingot cast at 2θ, which

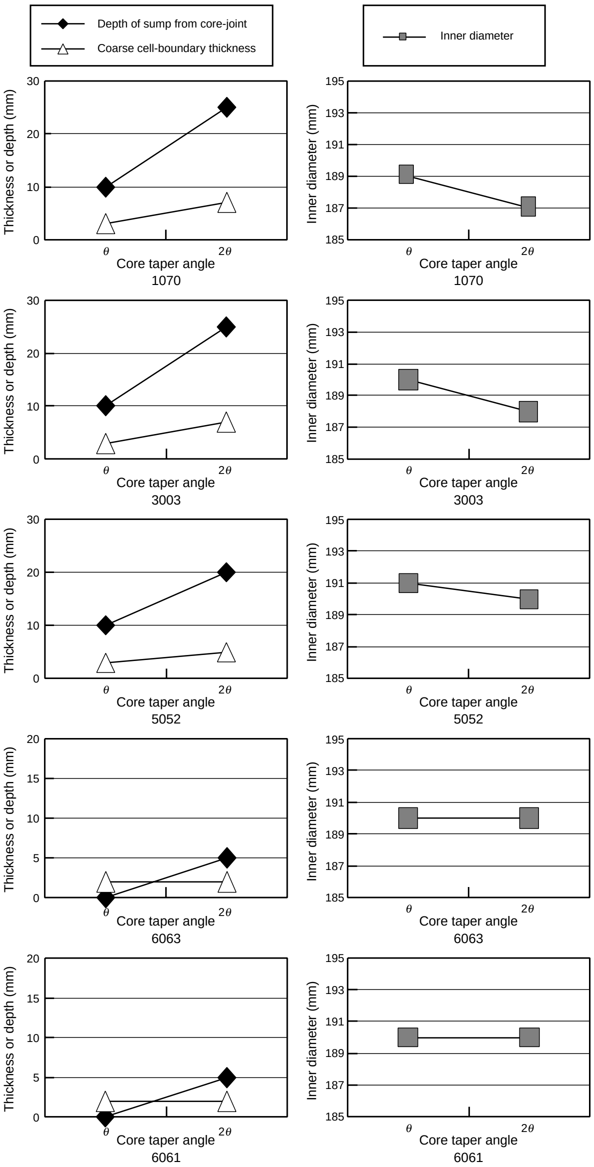


Figure 11 Inner-surface coarse cell-boundary thickness, sump depth or inner diameter at core taper angles of θ and 2θ

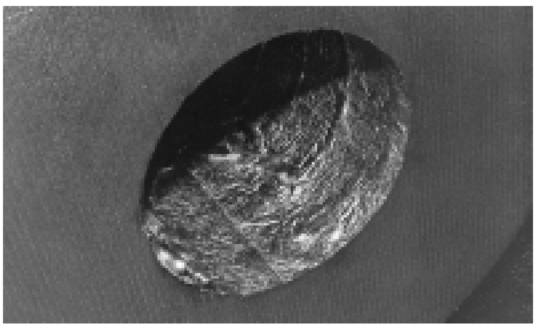


Figure 12 Inner-surface smoothness of a 3003 ingot, with water-circulation core, core joint to outer mold: 60 mm, core taper angle: 2θ and casting rate: 45 mm/min.

underwent remelting, and no doubt appears worse than in Figure 7. On analysis, the core taper angle should produce significant influence.

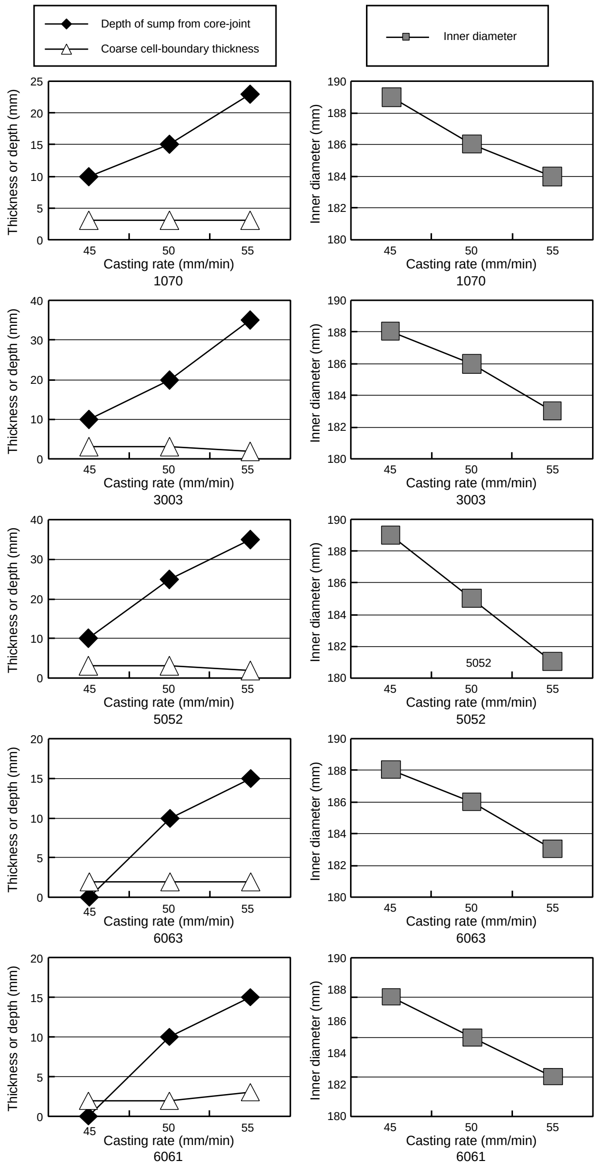


Figure 13 Coarse cell-boundary thickness, sump depth or inner diameter vs. casting-rate

4.3.3 Casting rate

The most significant factor in affecting ingot microstructure or proceedings of solidification is a casting rate. Aluminum alloys 1070, 3003, 5052, 6061 and 6063 were cast at casting rates of 45, 50 and 55 mm/min. Each hollow ingot was measured in the depth of an inner-surface coarse cell-boundary, the depth of a sump, and inner diameter.

Figure 13 plots the magnitudes of influence of casting rates with reference to the respective checkpoints. Each alloy shows a coarse cell-boundary thinner and more even at a greater sinking rate than at a less casting rate. But the inner diameters became smaller. Talking about the inner-surface smoothness, greater casting rates resulted in least remelting. On the contrary, 1070, 3003, 5052, 6061 and 6063 showed slight roughness; each sump more deepened in step with greater casting rates.

Figure 14 presents the inner-surface smoothness of a 3003 hollow ingot cast at 55 mm/min.

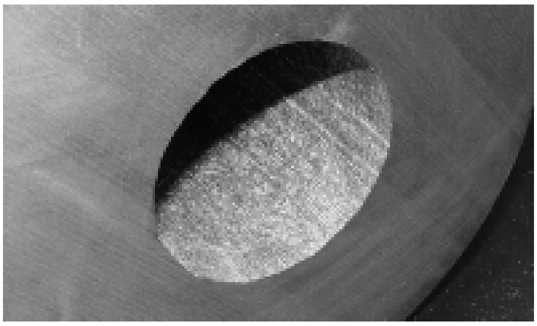


Figure 14 Inner-surface smoothness of a 3003 ingot, with water-circulation core, core joint to outer mold: 60 mm, core taper angle: θ and casting rate: 55 mm/min.

5. DISCUSSION

Factors in affecting the inner-surface smoothness of a hollow ingot were studied out, based on the findings from the trial casting with a water circulation core, as follows:

1) Correlation between core-joint level and outer mold
The joint of the upward refractory header of a core and its lower aluminum-alloy part should be at a lowest possible level, or as distant as possible from the top outer mold. This setup moderates remelting, which makes the inner-surface smoothness of a hollow ingot, fine and smooth. It is because the core approaching the bottom of a sump refers to going farther away from the high-temperature region of melting: it gets less likely to remelt a solidified shell.
2) Casting conditions
The most significant factor in affecting ingot microstructure or proceedings of solidification is a casting rate. In reality, the finding points out that a greater casting rate results in rougher inner-surface smoothness or ingot microstructure; concurrently, the inner diameter gets smaller.

Shrinkage in solidification takes place in casting a hollow ingot as in a solid one: compressive strength acts toward the center. Along this line, a rise in the casting rate led to some rise in the cooling rate, where the shrinkage in inner diameter was even greater than expected. The inner diameter shrinkage just as described should have served to largely lessen the air gap between the aluminum alloy of the core and the inner surface of the hollow ingot: remelting should have been moderated, and a better inner-surface smoothness should have come into existence. Yet in fact, the inner surface showed lengthwise wrinkles, which did not seem to have resulted from remelting. It is inferred that the inner-surface roughness is assignable to a solidified shell distorted by the compressive stress from the shrinkage in solidification more grown at the greater casting rate.

6. CONCLUSION

Hot-top casting combined with a water circulation core was designed and made, bringing out the items as given below:

1) Being successful in carrying out mass-production of hollow ingots with certainty and efficiency. The inner-surface smoothness has far improved.
2) Forming a uniform coarse cell boundary with a depth of 3 mm in the inner surface of a hollow ingot, and making the outer surface preferable and free from giant compounds. It is proven that the measure of boring thickness can be 3 mm to each side in diameter, much less than 12.5 mm of usually required thickness.
3) Being capable of boring a hollow of an ingot 53% faster than conventional methods.
4) Preferable casting conditions:
   - longer distance between the joint of an aluminum alloy part of a water-circulation core and its outer molding
   - inner surface texture vs. core taper angle and casting rate (each influence on surface roughness)

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