NEW CASTING METHOD FOR IMPROVING BILLET QUALITY

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Extrusion billet cast by the direct chill (DC) casting process frequently has inconsistent quality. This can adversely affect extrudability of the billet, for example, by causing a poor as-extruded surface. A recent development, the Wagstaff AIR-SLIP™ casting mold, incorporating several proprietary features, overcomes the problem of inconsistent quality and produces billet to exceptional metallurgical standards. Samples of 6xxx alloy aluminum billet cast by the AIR-SLIP™ process have had ≤ 0.005" peripheral segregation and an extremely smooth as-cast surface.

Data obtained from over 10 x 10^6 lb. of production of various alloys of extrusion billet are used to demonstrate how the AIR-SLIP™ casting process has significantly improved both billet quality and overall cast shop productivity.

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Introduction

All aluminum alloy extrusion billet is cast by some variant of the basic direct chill (DC) casting process, a process for billet casting which has been described at length in the literature (1,2,3). Numerous authors, for example Bergmann (4) and Collins (5), have described the problems in using the D.C. process to cast billet which has both: 1) a uniform as-cast surface free of defects such as tears and cold folds; and 2) little or no segregation near the periphery of the billet -- often referred to as liquation.

Defects remaining from the casting process are known to affect the characteristics of subsequent extrusion (6,7). Thus, research has been directed at ways to eliminate these defects and produce billet which will improve extrudability, for example, by permitting higher extrusion rates and/or better mechanical properties in the finished extrusions.

To overcome one or more of the problems associated with the basic D.C. casting process, many different casting systems and methods have been developed. These include, but are not limited to, electromagnetic casting (8,9), the variable chill depth mold system (10), level feed casting (11), and others.

A recent development, the Wagstaff AIR-SLIP™ casting mold, incorporating several proprietary features, overcomes the problems of inconsistent quality and produces exceptional billet. Additionally, the process can significantly improve overall cast shop productivity.

This paper discusses the equipment and procedures used to cast extrusion billet with the Wagstaff AIR-SLIP™ casting mold. It also presents quality, recovery, and productivity data based on casting of over 10 x 10^6 lbs. of extrusion billet using the AIR-SLIP™ technology.

Background

The cast shop at Martin Marietta Aluminum's plant at The Dalles, OR, casts 5 1/8" - 12" diameter extrusion billet. Production is predominantly 6xxx alloys (e.g., 6060, 6063, 6061, etc.), although other alloys such as 1435 and 3102 are also cast. Typical production rates are 12,000,000 lb./mo. Since the majority of this metal comes from adjacent potrooms, or reduction cells, cast shop processes and practices are designed to minimize any delays that would adversely affect the potrooms' tapping schedule. Furthermore, the quantity of scrap billet must also be minimal since the cast shop furnaces are designed to be charged with molten metal rather than solid mill scrap.

Prior to 1983, The Dalles used two types of tooling to cast extrusion billet. The majority of the billet (i.e., 5 1/8" diameter up to and including 8" diameter) was cast using a type of hot top mold. The remaining sizes (over 8" diameter through 12" diameter) were cast with a conventional type mold employing a downspout and float to control the molten metal head in the mold. Although this arrangement produced acceptable billet, there were several operational and quality problems that included:

- As-cast surface quality, particularly on the smaller diameter billet, namely 5 1/8" - 8" diameters, tended to be inconsistent both within a given drop and from drop to drop.

- Production rate (i.e., numbers of ingots/drop) was restricted due to mold design.
- Billet recovery was adversely affected by the inconsistencies in as-cast surface quality.
- Mold lubricant usage was high.

Figure 1 shows the typical as-cast surface of 6" diameter 6063 and 6061 alloy billet cast at The Dalles with a conventional hot top mold.

Consequently, in 1982, a project was begun to eliminate these problems when casting extrusion billet. The goals of this project were:

- Improve uniformity of as-cast surface quality
- Increase the number of ingots cast per drop
- Improve billet recovery
- Improve internal billet quality.
- Reduce consumption of casting lubricant.

Many of the newer casting methods mentioned previously were felt to offer advantages over existing Dalles' tooling. However, all had at least one or more overriding disadvantages (e.g., high initial cost) which prevented their consideration.

A recent development, the Wagstaff AIR-SLIP™ casting mold was determined to have all of the features necessary to produce the desired billet quality at high production rates. Furthermore, adoption of the Wagstaff AIR-SLIP™ casting mold was determined to entail fewer process and practice changes than for other types of tooling. Hence, casting trials employing this technology were begun at The Dalles in October 1982.

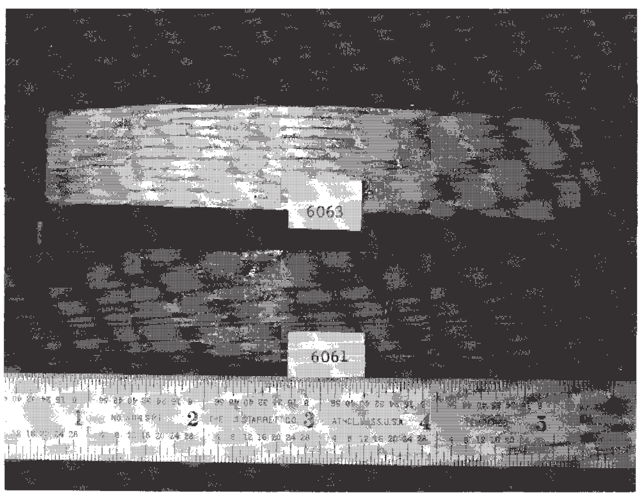


Figure 1 - Typical as-cast surface of 6" diameter 6063 and 6061 alloy cast prior to 1983 using The Dalles' hot top mold.

Description of the AIR-SLIP™ Mold

The Wagstaff AIR-SLIP™ casting mold (hereafter designated as WASM) was developed specifically for high-volume production of extrusion billet of exceptional metallurgical quality. It represents a state-of-the-art development in hot top billet casting and is similar in outward physical appearance to the Wagstaff MAXI-CAST™ mold (12,13).

The WASM, shown in Figure 2, consists of: an aluminum alloy mold body; a graphite insert that mates to the mold body; an aluminum alloy jacket surrounding the mold body to provide both a means of guiding the bottom block or stool cap into the mold, as well as forming part of the chamber for mold cooling water; and a ceramic orifice plate, or transition plate, to connect the mold to the thimble which joins the mold and the pouring pan or distribution trough. This design permits a reduction in the distance between mold centerlines, resulting in a very high mold density for a given casting unit, as illustrated in Figure 3. Table I gives the number of ingots cast with WASM molds for each size of billet produced at The Dalles and compares this to the number cast with conventional molds. It should be noted that the increase in the number of molds for a given size made possible by the WASM technology was achieved with only minor changes to the existing casting unit.

Mold length of the WASM is very short. This, coupled with a high volume of cooling water, provides a rapid solidification rate. In fact, with the WASM, most of the heat transfer during solidification takes place by direct water contact on the ingot shell after it emerges from the mold rather than through the mold wall. This rapid solidification results in a very uniform, fine-grained microstructure.

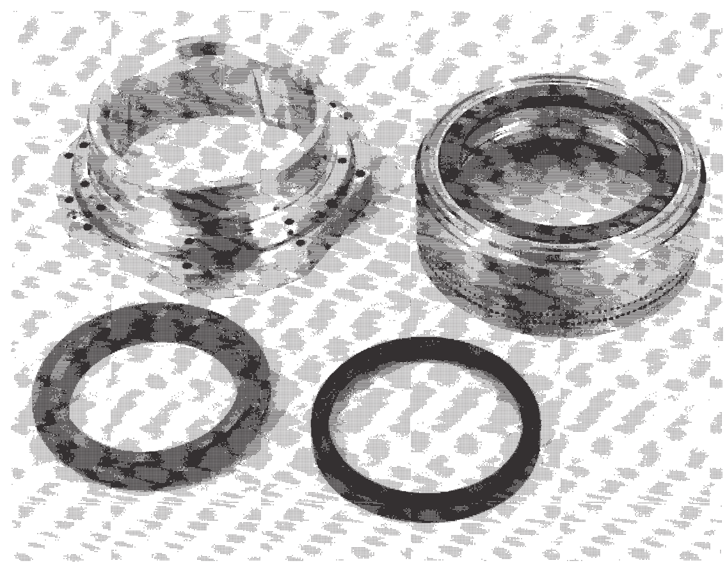


Figure 2 - Overall view of a Wagstaff AIR-SLIP™ casting mold for 6" diameter extrusion billet.

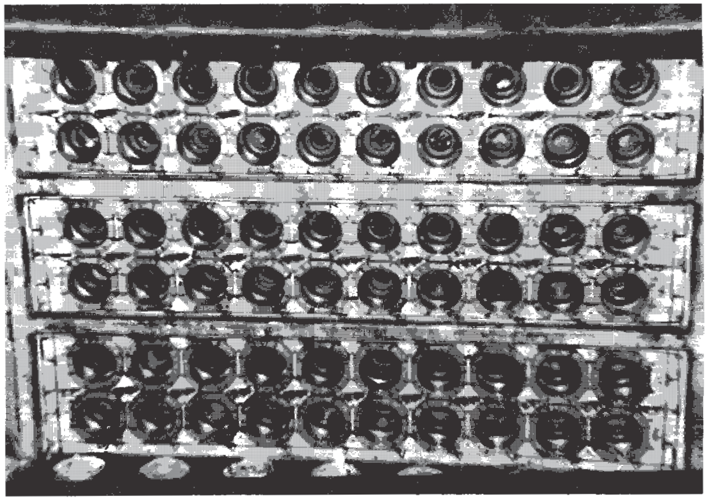


Figure 3 - View of Wagstaff AIR-SLIP™ casting unit for 6" diameter billet showing the high mold density.

TABLE I

Effect of Mold Design on Number of Ingots Cast Per Drop

Ingot Diameter, Inches	Number of Ingots Cast Per Drop with Conventional Mold	Number of Ingots Cast Per Drop with Wagstaff AIR-SLIP™ Mold
5 1/8	48	60
6	28	60
7	28	54
8	28	48
9	18	30

To improve the as-cast surface, the WASM relies on reducing the length and duration of contact between the solidifying ingot shell and the mold wall. This is accomplished by having both a very short mold (as described above) and a proprietary method for applying a mold lubricant and a gas. Precise control of this lubricant/gas mixture not only improves the as-cast surface but significantly reduces lubricant consumption.

A further feature of the WASM mold is a means of self-centering the bottom block or stool cap. This greatly reduces set-up time prior to casting and eliminates damage and wear to the mold bore.

Development of WASM Casting Practices

At the time of writing, not all sizes of WASM had been placed in use at The Dalles. Therefore, this section will deal only with development of practices for the 6" diameter size WASM mold since this was the size first put into production.

The 6" diameter WASM unit -- with 60 ingots/drop -- was installed in May 1983 and subsequently has been used to cast 1235, 6060, 6063, 6061, and 6463 alloys. No changes were made to the casting pit or casting pit controls to accommodate the WASM other than to install a larger diameter inlet pipe for the mold cooling water due to the increased water flow rates (it should be noted that part of this increase was required in going from 28 ingots/drop with the old tooling to 60 ingots/drop with the WASM). Water flow rates up to 2,500 gpm are now obtainable.

There is very little difference in the operation of the WASM compared to The Dalles' hot top unit. In fact, casting with the WASM is actually easier, since the mold/bottom block alignment is simplified by the self-centering bottom block design. Due to the short length of the WASM, the depth of entry into the mold by the bottom block is critical. However, this is controlled by use of a special gage inserted into the thimble. A depth indicator on this gage shows the operator precisely how far into the mold the bottom block has traveled. Other preparation at the start of the drop (e.g., drying bottom blocks, etc.) is the same as with conventional molds.

Each WASM mold has an individual control to adjust mold lubricant and gas flow. Generally, this is done prior to casting and, once set, does not require resetting between drops unless an alloy change occurs. In some instances, lubricant flow rates have to be set slightly higher when a mold is first placed in service, but can be reduced after 2-5 drops have been cast through the mold. Visual inspection of the molds between drops is recommended to ensure that lubricant flow is uniform. Typical flow rates are quite low, for example, a total of approximately 10-32 oz. of lubricant for a 35,000 lb. drop of 6" diameter billet, depending on the alloy being cast.

Experience has shown that the flow rate for mold cooling water should be reduced at the start of the cast to ensure that no water accidentally splashes into the mold prior to the molten metal entering the mold. After the mold is filled with molten metal, the cooling water is ramped up (either manually or automatically) to the desired value.

It is very important when casting with WASM to maintain a constant molten metal level in the distribution trough/pouring pan throughout the entire drop. Additionally, this level should be kept somewhat lower than when casting with conventional molds. It is not necessary to wait until the level in the pouring pan is at the desired depth before starting the platten. In fact, best results have been obtained by starting the platten soon after the thimbles are full and only a shallow layer of molten metal is in the pouring pan.

Actual casting conditions for WASM and conventional molds are quite similar. Typically, it is possible to operate with lower metal temperatures with the WASM, in large part due to the advanced refractories -- that limit heat loss -- used in the pouring pan and mold. Drop rates up to 25% faster than those with an equivalent size conventional mold have been achieved with the WASM with no sacrifice in as-cast surface quality.

However, drop rate is dependent on many factors (e.g., temperature, lubricant flow rate, etc.) and therefore this type of increase is not achieved for every alloy. Additionally, as drop rate increases, the likelihood of ingot cracking increases, particularly for certain alloys. Consequently, for 6" diameter 6063 alloy, drop rates of 6-7 ipm are typically used, even though higher rates may be possible.

At the completion of a drop, the procedures for "plugging off" the WASM are only slightly different than for a conventional hot top type mold. As with a conventional mold, the metal level in the pouring pan is allowed to drop. As this level drops, the drop rate is reduced while, simultaneously, the mold water is reduced to about 50% of the value used for casting. Under these conditions, the ingot will emerge from the mold fully solidified. At no time have there been any problems with the WASM due to accidental draining of the mold before all the metal had solidified.

Since the as-cast ingot surface produced with the WASM is typically much smoother and brighter than those with conventional molds, minor handling marks become very evident. Thus, care should be taken in removing the ingot from the casting pit. The extent to which these handling marks are a concern will vary from one cast shop to another. In our experience, handling marks have not been a cause for scrap at either the casting pit or billet saw, even though The Dalles' handling practices and equipment were not specially modified to accommodate WASM.

Casting Results

The WASM produces extrusion billet superior to The Dalles' previous casting tooling with respect to productivity, quality, and recovery. Table II summarizes productivity comparisons for 6" diameter 6063 alloy cast with the WASM versus conventional hot top molds. As can be seen, use of the WASM resulted in a significant improvement. Additionally, and perhaps even more important, is the fact that the WASM produces a billet of superior metallurgical quality. Figures 4-9 show typical microstructures of 6xxx alloy extrusion billet cast using WASM and conventional molds. Use of the WASM resulted in:

- Elimination of peripheral cold folds or cold shuts, as well as virtually all other types of surface defects (e.g., tears).
- Reduction in the segregated area at the as-cast surface of the billet from $\leq$ 0.250" to $\leq$ 0.005".
- A finer subsurface microstructure with constituents of more uniform size and distribution.

Improvements in quality such as those mentioned above are desirable for improved extrudability since defects remaining from the casting process are known to cause problems during subsequent extrusion (e.g., affect as-extruded surface quality). The improved metallurgical quality imparted by the WASM results from an increased solidification rate, due in large part to the very short mold length combined with several proprietary features.

Additionally, the WASM has improved cast shop productivity. A maximum of 6 drops (i.e., 168 ingots) was possible in an 8-hour shift using conventional 6" diameter tooling. However, 4.5 drops (i.e., 270 ingots) per 8-hour shift are now obtained using the WASM mold. Thus, productivity has increased by 61% through use of the WASM mold. Furthermore, overall recovery has increased due to reduced surface scrap, reduced head and butt

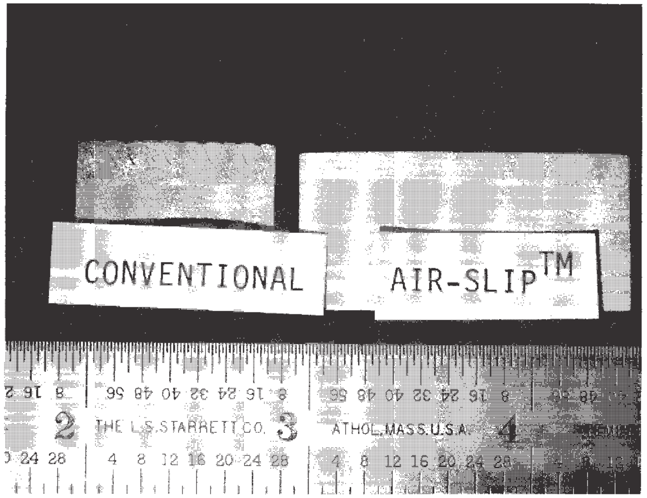


Figure 4 - Macrostructure of 6" diameter 6063 alloy billet cast with a conventional (left) and WASM (right) mold.

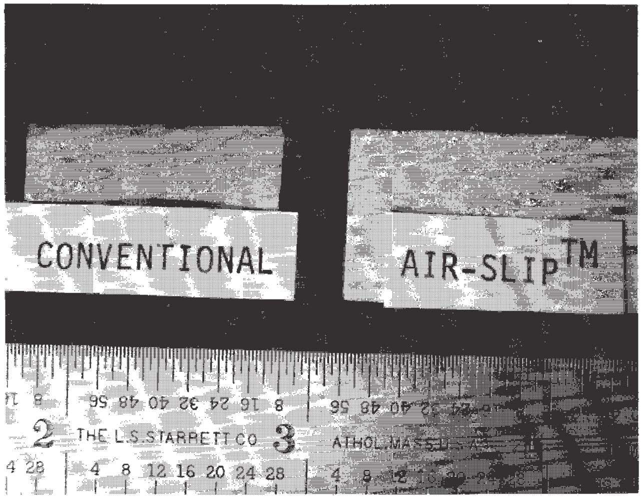
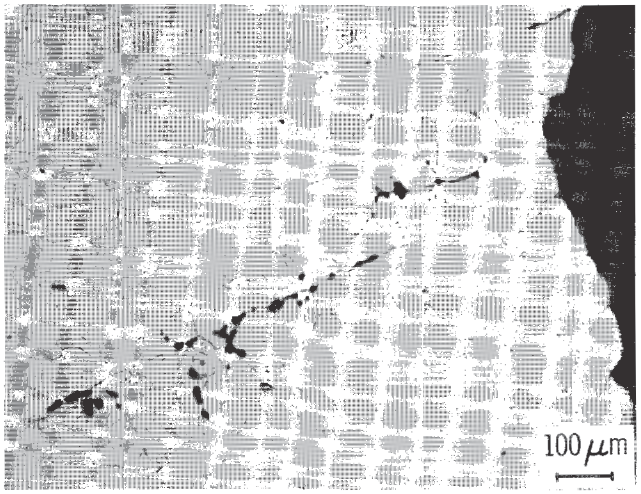
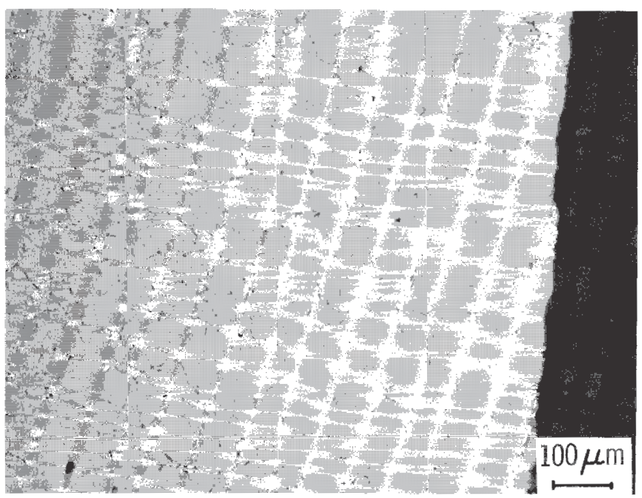


Figure 5 - Macrostructure of 6" diameter 6061 alloy billet cast with a conventional (left) and WASM (right) mold.



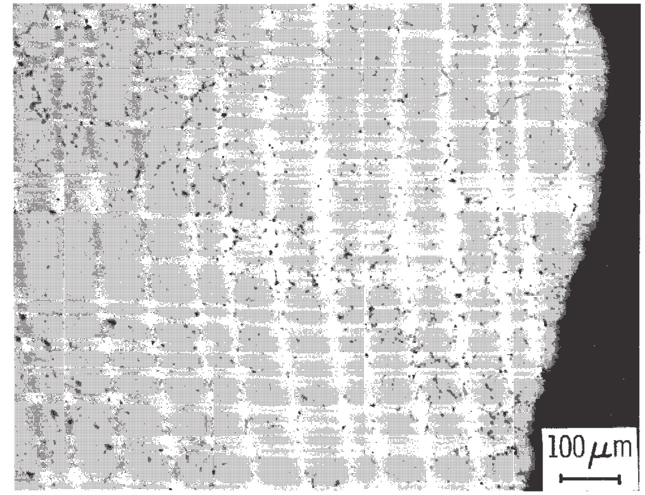
(a)



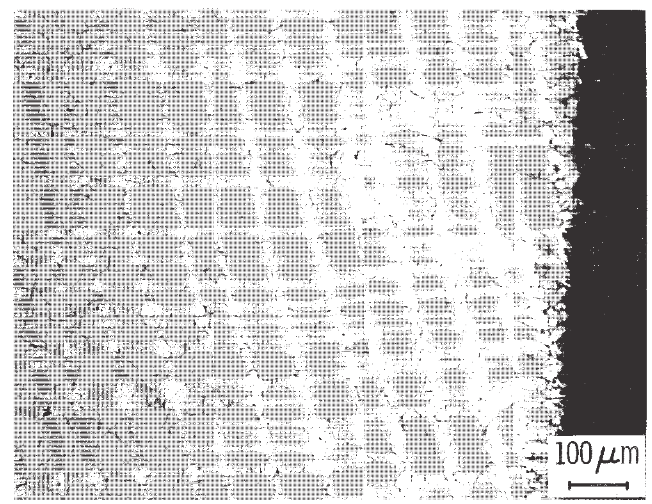
(b)

HF etch

Figure 6 - Typical microstructure at as-cast surface of 6" diameter 6063 alloy cast using: (a) conventional mold; and (b) WASM mold.



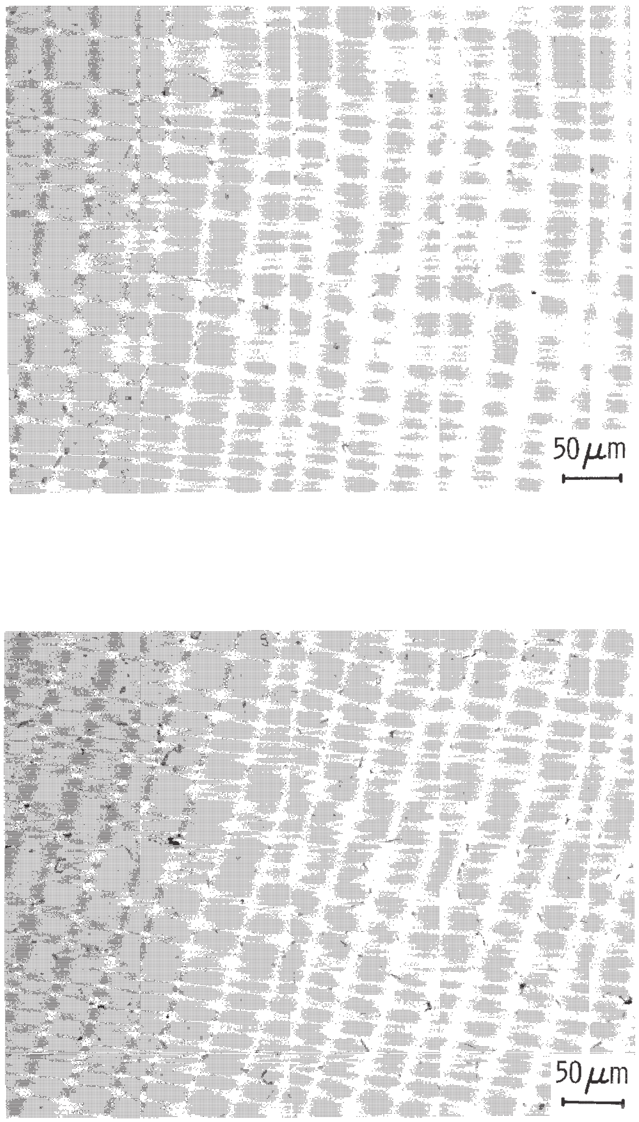
(a)



(b)

HF etch

Figure 7 - Typical microstructure at as-cast surface of 6" diameter 6061 alloy cast using: (a) conventional mold; and (b) WASM mold.

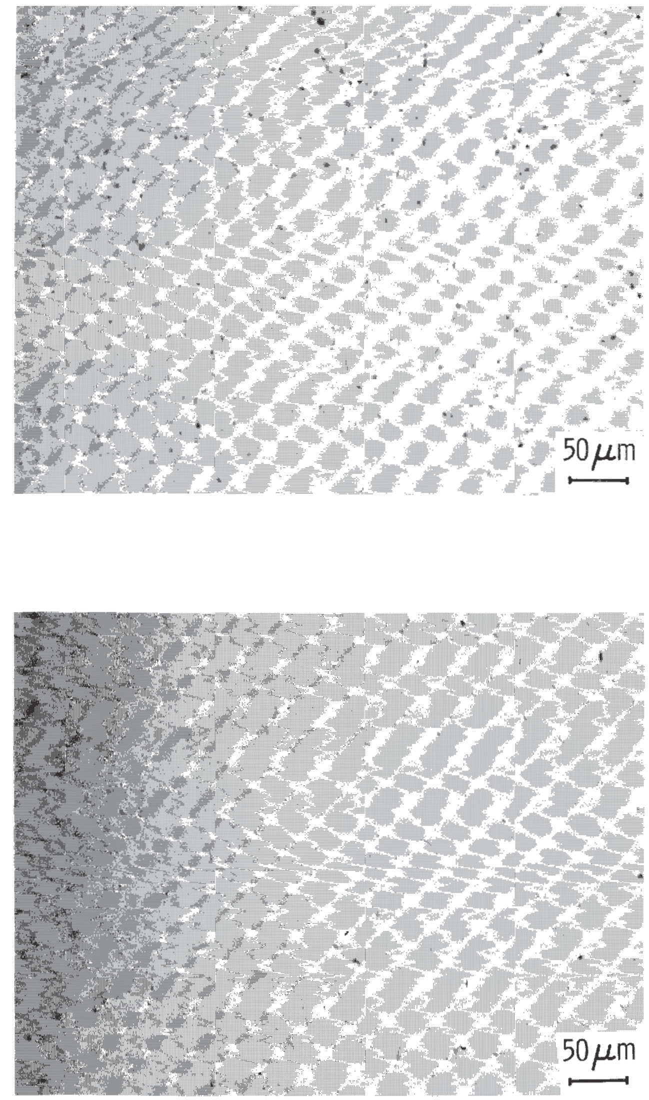


(a)

(b)

HF etch

Figure 8 - Typical microstructure at mid-radius of cross-section of 6" diameter 6063 alloy cast using: (a) conventional mold; and (b) WASM mold.



(a)

(b)

HF etch

Figure 9 - Typical microstructure at mid-radius of cross-section of 6" diameter 6061 alloy cast using: (a) conventional mold; and (b) WASM mold.

crops, and straighter ingots. Actual recent recovery has not been calculated as of this writing since the figure would have been biased by scrap incurred during training of the operating crews and normal "de-bugging" of the equipment. For example, head and butt crops are currently less than those incurred when the WASM molds were first used even though initially these crops were less than those for an equivalent size conventional mold.

Table II

Comparison of Productivity of WASM Versus Conventional Mold(1)

	WASM(2)	Conventional Mold
Production rate (lbs./hr.)	59,935	28,479
Lbs./Man Hr.	19,978	9,493
Crew Size (men/unit)	3	3
Average Lubricant use	18 oz.	192 oz.

Notes:

1) Based on data for 6" diameter 6063 alloy.
2) Approximately 6,000,000 lbs. cast weight

Summary

The Wagstaff AIR-SLIP™ casting mold has been used by Martin Marietta Aluminum for approximately 8 months to cast 6xxx alloy extrusion billet. This process was relatively simple to install and operate by virtue of being compatible with existing processes and practices. The WASM has resulted in a significant improvement in billet quality while simultaneously improving overall cast shop productivity and recovery.

Acknowledgement

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