Essential Readings in Light Metals: Cast Shop for Aluminum Production.
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7. CASTING DEFECTS AND THEIR CONTROL

This section focuses solely on defect formation during DC casting. Scrap rates are a major determinant of DC casting profitability, hence the focus of the industry on understanding the formation of these defects and their control. These defects include macro-segregation (on the surface and in the bulk of the casting) and hot and cold cracking. Control of sheet ingot shape is also covered in this section.

PRACTICAL PROBLEMS IN CASTING ALUMINUM D.C. INGOT

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Abstract

D.C. casting of aluminum ingots on a production basis must be accomplished without the degrees of freedom used in the laboratory approach. Standard equipment in any given cast house is usually of such rigid design that the options available for establishment of standard casting practices or corrective action in crisis situations is quite limited. The "state of the art" with some emphasis on the use of composition controls as a tool are discussed. Typical defects as related to individual alloys or alloy groups and appropriate controls to minimize problems are covered. The bulk of the information presented will relate to rolling ingot, since D.C. casting is used for the bulk of this type of ingot cast in the industry.

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Introduction

D.C. casting was described by Mr. Ennor some 40 years ago as follows: "The process involves a short mold of a desired shape to form an ingot by mold cooling. The ingot thus formed is lowered at a predetermined rate and solidification is completed by direct application of water below the mold."(1)

As we apply this precept to production facilities, various economic factors and the quantity, cleanliness, hardness and ambient temperature of the available water supply dictate equipment design parameters. Quite often we find plants tied to rather specific design features which tend to perpetuate themselves even though progress means new larger ingot sizes and more difficult alloys must be cast.

When remelted scrap is the major source of molten metal, it is not unusual, as efforts to obtain maximum scrap utilization are made, to get into epidemics of scrap ingot caused by splits or mold cracks (so called since they form in the mold just below the meniscus) and less frequently, tears, bleed outs, and prefrozen or "crusted" metal. The limited flexibility of equipment creates a situation essentially fixed and exploitation of other variables is mandatory to solve casting problems.

Some of the options available will be explored by alloy or alloy groups as the severity of the problems dictates. Unless otherwise indicated, comments relate to rolling ingot.

1XXX Alloys Except for the high purity alloys, above 99.70% minimum aluminum, most problems are mechanical in nature. Uniform water distribution, properly aligned distributors, good metal temperature control, accurate head and speed controls will hold problems to a minimum. Defects observed are hairline surface cracks, crusting, malformed corners, and cold shuts.

In addition to the above, high purity aluminum is affected (more crack prone) by radiation heat losses from the open surface. This can be minimized by providing a floating cover, either as part of, or in addition to, the normal floating distributor. In all cases purity control should be regulated by iron additions to maintain, insofar as possible, maximum spread between iron and silicon contents. From a casting standpoint grain refinement becomes increasingly important as ingot size and purity increase.

2XXX Alloys Ingot cracking, generally a split, is the major defect encountered in this alloy group. Good grain refinement is essential in all 2XXX alloys for successful casting. Beyond this the more common 2XXX alloys differ widely and are discussed on an individual basis.

1. 2014 Alloy This alloy can be poured under a variety of casting conditions with little susceptibility to cracking, provided silicon content is maintained on the high side of the range. If, as a matter of economy, the composition is overlapped with 2017 alloy to

insure a supply of both alloys, very rigid controls of all aspects of the casting practice must be maintained to provide crack-free ingots. Alloy 2014 is very sensitive to turbulence in the transfer system and if ultrasonic soundness is a required feature, practices must be adjusted to provide a quiet transfer from furnace to mold.

2. 2024 Alloy Audible cracking is not unusual and is related to several factors. The alloy is especially sensitive to silicon content with the sensitivity increasing as ingot size increases. For example, small ingot can be poured successfully at a silicon level in excess of 0.18%, whereas large ingot requires a level not exceeding 0.07% for consistently uncracked ingot. It is also recommended that the iron exceed the silicon by a factor of 2 to 3.

Because of 2024 alloy's tendency to split, the severe butt curl commonplace in a sheet ingot creates the need for a starting technique somewhat different than for the softer alloys. To reduce the splitting tendency, it is necessary to approach equilibrium conditions from the outset. This is best accomplished by a "quick start". Prerequisites for this are an ample supply of metal to provide a flow rate several times normal for the first 1-2 minutes of the drop and preferably a double curvature or dish shaped starting block. This permits one to actuate the lowering mechanism before the molten metal contacts the mold sides. In addition it is advantageous to reduce the chill of the starting block in that area of the ingot which remains in contact with the block after the curl. This can be accomplished by use of a pre-sized pad of insulating paper, fiber-frax or asbestos, or by pre-introduction of a small amount of soft alloy, such as 1145, using a hand ladle. The latter method has the advantage of reducing the effect of stress raisers created by any irregularities in the starting block or ingot butt.

3. 2219 Alloy Normally an easy alloy to cast, 2219 alloy is subject to cracking as magnesium content increases even within the published limits for the alloy. If some minor variation of cooling, metal distribution, or the like exists in the casting setup, cracking can occur at a magnesium level of 0.02%.

3XXX Alloys "Familiarity breeds contempt" is especially applicable to the 3XXX group of alloys. The widespread use and apparent ease of casting often leads to serious problems, more frequently in fabrication than in the ingot plant. We refer to the potential in these manganese-bearing alloys for prefreezing or "crusting". Solidification of islands, perhaps better described as icebergs, in the molten pool or on the floating distributor can lead to severe side bursts or surface checking fabrication. Rigid manganese control and pouring temperature control are essential. In addition good metal distribution and careful attention to ambient conditions are needed. A moving stream of air, as from a man fan, directed across the molten surface is an ideal generator of "crusting" during casting.

Alloy 3003, the most widely used, is the most troublesome, not only from crusting, but also from cracking and bleed outs. Iron additions to a minimum of 0.55% accompanied by a silicon addition to provide more than 0.20% promote crack resistance in larger ingots. The short freezing range, about 20°F , promotes a tendency for bleed outs, especially during the start. A skilled operator soon learns to strike a balance. Some hesitation is needed at the start to permit a solid bottom to form, but not so much as to allow the ends to freeze off and permit incoming hot metal to flow over them and out of the mold.

4XXX Alloys By far the bulk of this group are straight silicon alloys used as liner stock for architectural applications and casting practices are similar to those for 1XXX alloys. The piston alloy, 4032, is a problem when the ingot shape being cast has corners, since the corners usually crack off. An octagonal ingot or better yet a round ingot eliminates this problem and the alloy can be cast readily by maintaining good temperature control.

5XXX Alloys Alloys in this group, especially those containing more than 2.0% magnesium are prone to tearing. Oxide patches, minor drag marks, and hot spots often lead to mold cracks. The tendency for cracking and tearing increases with magnesium content. Good mold finish and lubrication are most essential to good casting results. Mold sides must be parallel, or very slightly "toed out". Any tendency for "toe in" will lead to tearing. Clean metal with no entrained oxide and low sodium content (less than 0.0005%) is a must from both a casting and rolling standpoint. A smooth, relatively quick start avoids the formation of butt cracks which can easily propogate.

For those alloys with magnesium as the sole alloying element, 5005 and 5050 for example, a minimum iron content near 0.35% permits maximum casting speeds with minimum cracking. Grain refining additions are also helpful in these alloys. Manganese in alloys such as 5083, 5086, 5454, and 5456 is an aid to casting and with some experimentation a manganese to magnesium ratio can be established to provide maximum freedom from cracking for a particular set of casting conditions. Edge cracking during rolling can be minimized by a distributor design which provides good hot metal flow toward the ingot edges. In other words, as the width of the ingot increases so should the length of the distributor.

6XXX Alloys Best casting results in this alloy group are obtained when a minimum iron control is established. A satisfactory minimum for most cases is 0.30%. Grain refinement must be very good and mold shape and parallelism are as critical as for 5XXX alloys to keep cracking at a minimum. Best results also incorporate the use of a high head and slow casting speed.

7XXX Alloys With the exception of alloys containing zinc only, 7072 for example, which behave like 1100 alloy, the various heat treatable alloys present some of our most difficult casting problems.

7075 Alloy Successful casting of 7075 is a repeat of the 2024 story except that silicon levels must be maintained at lower values for consistent results. When possible, iron control at 2 to 3 times silicon is desired. Good to excellent grain refinement, use of a quick start and some form of chill retardant on the starting block are considered necessary. An added complexity is the presence of chromium in the alloy. A uniformly hot pouring system must be maintained to avoid precipitation and agglomeration of the chromium constituent as a major inclusion. This can cause cracking, mark rolls, and cause rejection in plate products.

This alloy and its stronger sister, 7178 alloy, will serve to test the skill of the people making the equipment installation. Molds, well centered in the spray pattern, sprays completely free from plugged areas and smooth well fitting starting blocks add measurably to successful casting.

7079 Alloy Crack-free ingots are not difficult to cast in 7079 and no particular controls of composition are required to retain such freedom from cracking. Shrinkage voids, however, are frequently a problem. This condition can best be controlled by providing conditions for slow cooling and good feeding to the affected areas. In a rolling ingot these are at or near the quarter points of the ingot width. A high head, slow casting speed, and an elongated distributor reduce the tendency for shrinkage voids.

7039 And Similar Zinc Magnesium Alloys These alloys are not subject to audible or violent cracking but rather to mold cracks in the manner of 6061 or the 5XXX alloys. Practices similar to those for 5XXX alloys are usually adequate.

In conclusion it is apropos to include a list of obvious precautions which are often overlooked or slighted in the maintenance of production.

1. Molds well centered in the spray pattern. Jacketed molds eliminated this concern.
2. Molds free of "toe in" or excessive flare. Suggested tolerances, zero "toe in", 1/32 inch maximum flare.
3. Distributors in good shape and properly centered in mold cavity.
4. Use of lowest practical temperature for the alloy being poured. Avoid wide fluctuations during a pour.
5. Starting or bottom blocks smooth and free of gouges.
6. Adequate metal supply at the start for uniform rapid feeding of all ingots.
7. Proper distributor size for the ingot size being cast.
8. Good regulation of oil flow if continuous lubrication is employed.
9. Good and frequent skimming of magnesium containing alloys to insure freedom from spinel formation. This must be accompanied by good temperature control in the furnace.
10. Elimination of cold areas in the launder system for chromium bearing alloys.

Adherence to the above and proper use of composition guidelines where appropriate can result in a smooth running ingot plant with maximum freedom from crisis situations.

REFERENCES

(1) W. T. Ennor, U.S. Patent 2,301,027, November 3, 1942.