Effect of the Titanium: Boron Ratio on the Efficiency of Aluminum Grain-Refining Alloys

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The desirable effects of fine-grain size in aluminum and aluminum alloy DC castings are controlled by proper selection of the grain-refining additive and the casting practice.

SUMMARY

The grain-refining properties of aluminum master alloys containing titanium and combinations of titanium and boron in ratios between 5:1 and 25:1 have been evaluated on a number of commercially produced alloys. The results provide a guide for the selection of the grain-refining route for various applications.

A wide range of grain-refining alloys for use in the aluminum industry are now on the market. The aluminum-based master alloys contain titanium or more usually titanium and boron.

Binary titanium-aluminum alloys (TiAl) usually have Ti contents of 6 or 10% by weight. The most popular ternary alloy has 5% Ti and 1% B (5/1 TiBAI). A number of TiBAI alloys with higher Ti:B ratios are now being used. The most common is 5% Ti, 0.2% B (5/0.2 TiBAI), although alloys containing 0.5% B and 0.1% B are also used (5/0.5 TiBAI and 5/0.1 TiBAI). Thus the Ti:B ratio in the TiBAI alloy range spans 5:1 to 50:1.

Because of the number of different master alloy compositions produced, it is becoming increasingly difficult for the aluminum producer to determine the relative merits of the various grain-refining alloys. The situation is further complicated when one considers that the master alloys are available in waffle plate or rod form, where different properties may be required of the master alloy. In this work, we have attempted to clarify the situation by conducting a research test program aimed at measuring the efficiency of different master alloys on three commercial aluminum alloys. It is hoped that the work will enable the producer to select the master alloy which will best suit his needs on a more scientific basis than hitherto.

GRAIN-REFINING PRINCIPLES

Additions of refining agents to molten aluminum prior to casting can result in increased casting speeds; reduced cracking rates; formation of an equiaxed cast structure, particularly suitable for lithographic and anodizing qualities; and elimination of feather crystals.

Although salt additions based on KBF₃ and K₂TiF₆ mixtures were originally used, they have been largely replaced by metallic master alloys based on virgin aluminum, alloyed with titanium or titanium and boron.

TiAl is used to a limited extent, mainly for critical qualities where pinholes and pencil streaking must be avoided. In the past, TiBAI master alloys which contain TiB₂ particles were not used on such critical applications because of the fear that TiB₂ may be present as large agglomerates rather than discrete particles. Improvements in the production of TiBAI master alloys have largely eliminated this risk, and TiBAI alloys are increasingly employed in this area. 5/0.2 TiBAI was introduced as an alternative to binary TiAl in canstock alloys where freedom from hard particles is of paramount importance. The ternary alloy with a Ti:B ratio 25:1 was found to be more efficient than 6% TiAl and to contain fewer TiB₂ particles than 5/1 TiBAI.

In direct chill (DC) and continuous casting, the master alloys are added to molten aluminum at around 700 °C using two main techniques. Traditionally, the producer has made a waffle plate addition to the holding furnace, the alloy being stirred into the metal by mechanical means or by hand. Casting takes place a minimum of 30 minutes after the grain-refining addition, and under some circumstances the holding time can be up to 6 hours.

In recent years there has been an increasing application of grain-refining alloys in the form of % in (9.5 mm) diameter rod. The rod is fed into the casting trough countercurrent to the metal flow. The time available for solution (contact time) in the aluminum is usually between 30 seconds and 10 minutes. The contact time in DC casting is generally 1-2 minutes, although the use of filters, such as British Aluminium's FILD or Alcoa's Alumina Ball System, prolongs the contact time considerably. In processes where metal flow rates are slow, i.e. Properzi wheel or continuous
sheet casters, the contact time available can be up to 10 minutes.

A recent paper describes the advantages of grain refiners in rod form in some detail. Briefly, the rod addition eliminates furnace contamination due to settlement of TiB₂ and allows more accurate control of the alloying addition. Further, the rod addition gives more-efficient grain refinement compared to waffle additions, thus allowing lower additions with a reduction in the cost of refinement. Excellent refinement can be obtained in casting systems where the contact time available is less than 1 minute.

**GRAIN-REFINING EFFICIENCY**

Jones and Pearson have described a grain-refining test used to measure the efficiency of a grain-refining alloy. A quantity of the refiner is stirred into a bath of aluminum at 720 °C, and conical samples are cast at various time intervals and quenched in water. The solidified samples are sectioned and the surfaces prepared to allow measurement of grain size. It is then possible to construct a grain-refining curve, plotting grain size against the log of time. Figure 1 shows a typical grain-refining curve. It can be seen that the curve has two distinct sections. After the grain refiner has been added, the grain size initially decreases with time (line AO) reaching a minimum at O, referred to as the ultimate grain size. The time to reach this point of maximum efficiency is a measure of the contact-time properties of the master alloy. The portion OB shows a reduction in efficiency, and the corresponding increase in grain size is known as fade.

**EXPERIMENTAL PROGRAM**

The main aims of the program were: 1. to compare the grain-refining efficiency of TiBAI and TiAl master alloys on three commercial aluminum alloys at different addition rates; 2. to show the effect of Ti:B ratio on the efficiency of TiBAI master alloys; and 3. to compare the efficiency of 6% TiAl and 5/1 TiBAI when refining 99.7% Al over the Ti addition range 0.0025%-0.24%.

The master alloys evaluated are shown in Table I. Each master alloy was tested on three commercial aluminum alloys having compositions as shown in Table II. Selected as being representative of pure grades, 99.7% Al is known to be difficult to grain refine. Alloy 3004 is an important canstock alloy. Alloy 7050, a high-strength alloy of increasing importance, was chosen as it is known to be difficult to cast.

The 6% TiAl and 5/1 TiBAI master alloys used in this investigation are typical of those supplied by London & Scandinavian Metallurgical Co Limited. The 5/0.5 and 5/0.2 TiBAI alloys were produced by diluting the 5/1 TiBAI alloy on a pilot scale (40 kg) and adjusting the Ti content. This procedure was adopted to ensure that the TiB₂ in each alloy was initially formed under identical conditions. Differences between the TiBAI master alloys can therefore be attributed to differences in concentration alone.

The alloys to be grain refined were supplied by Alcan (99.7% Al) and British Aluminium (Alloys 3004 and 7050). The test used to measure the efficiency of the grain-refining alloys is similar to the one reported above.

The method of surface preparation used to measure the grain size of the test specimens differed for the various alloys. Details are given in Table III.