Performance Evaluation of AlB$_{12}$ and AlB$_2$ for the Boron Treatment of Molten Aluminium

A. Khaliq$^1$, M.A. Rhamdhani$^1$, G.A. Brooks$^1$, J. Grandfield$^{1,2}$

$^1$Swinburne University of Technology, Melbourne, Australia
$^2$Grandfield Technology Pty, Ltd, Victoria, Australia

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Aluminium has been used as an alternative to copper for power transmission. However, the presence of impurities especially transition metals deteriorate the electrical conductivity of smelter grade aluminium [1]. Transition metal impurities such as titanium (Ti), zirconium (Zr), vanadium (V) and chromium (Cr) are removed from molten aluminium by the addition of Al-B master alloys, called boron treatment[2-6]. Al-B master alloys contain AlB$_{12}$/AlB$_2$ phases that provide boron to form transition metal borides during the boron treatment process. Transition metal borides formed are heavy that settled at the bottom of the furnace during holding of molten aluminium. Thereafter, relatively pure aluminium is decanted from the top of the holding furnace. The boron treated aluminium is used for the manufacturing of electrical conductors.

Khaliq et al. investigated the thermodynamics and kinetics of transition metal impurities removal from molten aluminium [7-10]. Thermodynamics modelling predicted the formation of stable transition metal diborides (TiB$_2$, ZrB$_2$, VB$_2$ and CrB$_2$) in aluminium melt in the temperature ranging from 650°C to 900°C. It was predicted that excess addition of boron will favour the complete removal of transition metal impurities. The formation of VB$_2$ rings, encapsulating the initially added AlB$_{12}$ were revealed during experimental investigation of Al-V-B alloys. Moreover, the formation VB$_2$ rings in the early stage revealed the reaction was rapid that lead to the increase in electrical conductivity of molten aluminium as reported by previous investigators. It was further reported that the reaction between AlB$_{12}$ and V was incomplete due the formation of VB$_2$ ring [9]. A kinetic plot of V removal and mechanism of VB$_2$ formation in molten Al-1wt%V-0.412wt% B alloy is shown in Figure 1. The rate of reaction is faster in the early stage that becomes slower with time. It has been shown in literature that the rate of reaction in the early stage is controlled by the mass transfer of V in the liquid phase (up to 10 minutes). However, the second stage of reaction (after 10 minutes) is controlled by the diffusion of boron through product layer (VB$_2$) that was formed in the early stage, as shown in Figure 1.

Limited literature is published on the performance of AlB$_{12}$ and AlB$_2$ during the boron treatment of aluminium. This paper describes the performance evaluation of AlB$_{12}$ and AlB$_2$ for the removal of V from molten aluminium. Kinetics experiments on Al-1wt% V alloy were conducted in the resistant pot furnace at 750°C. Samples taken at regular time intervals were analysed using SEM, EDX and ICP-AES techniques. Selected results from this study are presented in this paper.
In this study, pure Al (99.90%), Al-10%V, Al-10%B (AlB\textsubscript{12}) and Al-5%B (AlB\textsubscript{2}) master alloys were used. SEM-SE image of Al-10%B master alloy showed clusters of AlB\textsubscript{12} in the Al matrix having particles in the range of 1µm to 60 µm. AlB\textsubscript{12} particles possess irregular morphology. Contrary to AlB\textsubscript{12}, AlB\textsubscript{2} particles are smaller in size and are elongated. The characterisation detail of Al-B master alloy is given elsewhere [11].
The possible reactions for the formation of VB$_2$ in molten aluminium using AlB$_{12}$ and AlB$_2$ are given in Equations [1] and [2].

$$6[V] + AlB_{12(s)} = 6VB_2(s) + [Al]$$  \[1\]

$$[V] + AlB_{2(s)} = VB_2(s) + [Al]$$  \[2\]

Where “[ ]” indicates that elements are dissolved in solution with molten aluminium and “(s)” represents that compounds are present in solid state.

The formation of VB$_2$ was observed by SEM analysis of boride sludge. Figures 2(a) and 2(b) showed the formation of VB$_2$ in the aluminium matrix. It is evident that the reaction has taken place in the vicinity of AlB$_{12}$ and AlB$_2$ that are added as a source of boron in the molten Al-1wt%V alloy. The dissolution of AlB$_{12}$ provided free boron for reaction with V to form VB$_2$ in the molten alloy. Simultaneously, the mass transfer of V to the interface of AlB$_{12}$ took place and, therefore the formation of VB$_2$ by chemical reaction. The rings of VB$_2$ are formed in the molten alloy treated with AlB$_{12}$ or AlB$_2$ as shown in Figures 2(a) and 2(b). However, rings formed using AlB$_{12}$ are thicker and denser compared to that of AlB$_2$. Moreover, smaller VB$_2$ particles are observed using AlB$_2$ based Al-B master alloys as shown in Figure 2(b). The presence of partially dissolved AlB$_{12}$/AlB$_2$ particles suggested the reaction is incomplete and suppressed by the rings of VB$_2$.

The change in the concentration of V with reaction time is shown in Figure 2(c). Samples collected at regular time intervals were dissolved in HCl and analysed for V in solution using ICP-AES technique. The rate of reaction for VB$_2$ formation is similar for AlB$_{12}$ and AlB$_2$ in the early stage (up to 6 minutes). This is represented by similar mass transfer capacity coefficients as shown in Figure 2(d). However, the kinetics behaviour of AlB$_{12}$ and AlB$_2$ changed with further reaction. The rate of reaction become slower for AlB$_{12}$ compared to AlB$_2$ as shown in Figure 2(c). This is due the depletion of surface area available for further reaction. It was argued that the smaller and elongated particles in AlB$_2$ provided additional surface area for reaction to form VB$_2$ in the molten alloy. Therefore, the rate of reaction was faster using AlB$_2$ based Al-B master alloys.

It was concluded that the rate of transition metals removal from molten aluminium will be faster using AlB$_2$ compared to AlB$_{12}$ based Al-B master alloys. However, the settling of borides will take longer due to smaller VB$_2$ particles formed during reaction. Therefore, it is suggested to use AlB$_2$ based Al-B master alloys for boron treatment in launders. For boron treatment in holding furnaces, AlB$_{12}$ based alloys are more economic due to faster settling rate. However, the consumption of Al-B master alloys based on AlB$_{12}$ will be higher. The chemistry and morphology of phases in Al-B master alloys are important for boron treatment process.

**References:**


